Why does technology fail to benefit the poorest farmers? A sociotechnical approach to the study of innovation and poverty

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Abstract

This dissertation seeks to understand the barriers preventing the poorest farmers from realizing greater benefits from technology innovation. The goal of the dissertation is to derive policy relevant insights for reorienting the institutions structuring agriculture innovation systems to ensure the poorest farmers reap greater benefits from agricultural technology. The research for the three papers was conducted in India and pairs qualitative interviews of farmers and other actors in the agricultural innovation system, including members of the private sector, government, NGOs, international donor agencies, and researchers, with analysis of survey data collected by the author, and secondary sources, including government documents, NGO and donor reports, newspaper articles, books, and journal articles.

The results demonstrate that the benefits of agricultural technology are frequently skewed toward wealthier farmers. This continues to be the case, even when policy makers and technologists are explicitly concerned with the needs of the poorest. Ensuring benefits of technology are realized by the poorest farmers, requires context specific fit between physical and institutional dimensions of technology that explicitly takes into account the opportunities and barriers facing the poorest farmers. Reorienting agricultural innovation systems to meet the needs of the poorest requires more than just technologies with the appropriate physical dimensions. It also requires efforts across stages of the innovation system to align the physical and the institutional dimensions of technology with local conditions, in ways that meet the needs of the poorest.

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Acknowledgements

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Dedication

The dissertation is dedicated to the many farmers who contributed to my research in India. I am deeply grateful for their time and patience in helping me understand their choices about their agricultural technology investments and practices, as well as the opportunities and constraints they face in accessing technology. I hope that this dissertation will, in some small way, make their lives better. And if (as is decidedly more likely) the results of this research do not in fact make a tangible difference in their lives, that at least they got a good laugh, watching me stumble clumsily through the paddy fields they navigate daily with grace.

Acronyms & Abbreviations

APMIP	Andhra Pradesh Micro Irrigation Project
BMPs	Best Management Practices
BISA	The Borlaug Institute for South Asia
BPCM	Biophysical Causal Mechanism
BREDA	Bihar Rural Energy Development Agency
CGIAR	The Consultative Group on International Agricultural Research
CIIFAD	Cornell International Institute for Food, Agriculture and Development
CIMMYT	The International Maize and Wheat Improvement Center
CIP	The International Potato Center
DSR	Direct Seeded Rice
EMP	Electric Motor Pump
GoB	Government of Bihar
GMO	Genetically Modified Organism
GTZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GGRC	Gujarat Green Revolution Council
HYV	High Yielding Seed Varieties (typically associated with the Green Revolution)
ICIMOD	International Center for Integrated Mountain Development
IWMI	International Water Management Institute
ISV	Improved Seed Varieties (describes all seed varieties improved by modern science including both older high yielding varieties, more recent hybrid seeds and even GM seed where available)
IFAD	International Fund for Agricultural Development
IRRI	The International Rice Research Institute
JEEViKA	Bihar Rural Livelihoods Project (an autonomous body under Dept. Rural Development GoB; jointly funded by World Bank)
LCDI	Low Cost Drip Irrigation
MDGs	Millennium Development Goals
MIS	Micro Irrigation Systems (includes drip and sprinkler irrigation systems)
MLP	Multi-Level Perspective
NABARD	National Bank for Agriculture and Rural Development
NARS	National Agricultural Research Systems
NCPAH	National Committee on Plasticulture Applications in Horticulture
NREGA	Mahatma Gandhi National Rural Employment Guarantee Act
NMMI	National Mission on Micro Irrigation
NGO	Non-Governmental Organization
OBC	Other Backward Caste groups
Pradan	Professional Assistance for Development Action (India-wide rural livelihoods NGO)
PRAN	Preservation and Proliferation of Rural Resources and Nature (NGO in South Bihar)
R&D	Research and Development
SC/ST	Scheduled Caste and Tribal Caste groups

SDGs	Sustainable Development Goals
SIP	Solar Irrigation Pump
SRI	System of Rice Intensification
STCM	Sociotechnical Causal Mechanism
RAU	Rajendra Agricultural University in Bihar
RWP	Large diameter rubber pipe used for transporting water across fields in Bihar
UC	Upper Caste groups
UN	United Nations
US	Unites States of America
USAID	United States Agency for International Development
USD	United States Dollar (conversion rate used between USD and Indian *rupees* is 1:65)
USDA	United States Department of Agriculture
WUE	Water use efficiency

CHAPTER 1. Why does technology fail to benefit the poorest farmers? A sociotechnical approach to the study of innovation and poverty

1.1 Introduction

This dissertation seeks to derive policy relevant insights for reorienting the institutions undergirding agricultural innovation systems to ensure the poorest farmers realize greater benefits from agricultural technology. This dissertation is reported in four chapters. My empirical work is covered in chapters two, three and four. This chapter provides an overview of my theoretical approach, situates my research in the literature, and previews the main findings of the three empirical chapters. The three empirical chapters focus on agricultural technology in India, and the reasons why agricultural technologies contribute (or fail to contribute) to improved well-being for the poorest farmers. The common thread among the three empirical chapters in the dissertation is a focus on understanding the barriers that prevent the poorest farmers from realizing greater benefits from agricultural technology innovation.

Understanding the barriers that prevent the poorest farmers from benefiting from the fruits of technology innovation is important for two reasons. First, agrarian households account for 80% of the world's extreme poor (income of less than 1.90 USD per person per day). These households simultaneously produce food and suffer from food insecurity (Kharas *et al.*, 1994; Castañeda *et al.*, 2016). These households are also the targets of many of the UN's Sustainable Development Goals (SDGs) including Goal 1 "No Poverty", and Goal 2 "Zero Hunger" (United Nations, 2015). Improving the ability of the poorest farmers to benefit from agriculture technology will increase their food security and contribute to achieving at least two of the UN's 17 SDGs. Second, the world's 475 million smallholder farmers are a cornerstone of the global food system, producing up to 80% of the food supply in some regions, including South Asia (Kanayo, 2011).[1] By overcoming barriers to technology access for small and marginal farmers, national and local governments and the development community can boost overall food production in these regions.

It has long been understood that technological innovation is a cornerstone of continued agricultural productivity growth, as well as important for creating solutions to the negative impacts of agricultural production on the environment (Sundig and Zilberman, 1999; Ruttan, 2000; Sayer and Cassman, 2013). Yet, scholars looking at the role of innovation in the pursuit of sustainable development – including myself – have argued that "impoverished, marginalized, and future populations that are a central concern of efforts to improve inclusive well-being too often lack the economic and political power to shape innovation systems to meet their needs" (Anadon *et al.*, 2016, p. 9682). While this is broadly true, why some technologies are more successful than others at benefiting the poorest farmers is not well understood. In this dissertation, I demonstrate that the benefits of agricultural technologies are often skewed towards wealthier farmers. In the three empirical chapters, I analyze the barriers preventing the poorest farmers from realizing greater benefits from technology. My hope is that this project will both contribute policy relevant insights that improve the well-being of the poorest farmers, and sharpen the focus of innovation studies more broadly on the relationship between technological innovation and poverty.

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[1] Internationally, smallholder farmers are defined as having less than two hectares of land (Zimmerer, Lambin and Vanek, 2018). Many farmers in India (and in Bihar in particular) have significantly less land than this. Indeed, two hectares would be considered relatively large in the context of the field settings in this dissertation.

1.2 Theory

This dissertation draws on multiple schools of thought in innovation and technology studies but relies primarily on three theoretical foundations: sociotechnical approaches in science and technology studies; institutional approaches to the study of innovation systems; and multi-level approaches to the study of technological transitions.

1.2.1 Theory: Sociotechnical Approach

The dissertation treats technology not as individual widgets, but as assemblages of artifacts and practices, which are inextricably linked to the institutions and actors that undergird the complex processes tying invention to widespread use. Borrowing from Harvey Brooks who, writing in Daedalus in 1980, critiqued the most common contemporary definition of technology, "novel physical objects created by man to fulfill certain human purposes" (Brooks, 1980, p.65). Rather, he argued that technology is better understood by its function than its physical embodiment in artifacts. He defined technology as the "expansion of the realm of human possibility" (Hannay and McGinn, 1980, p. 35). The critical theoretical distinction Brooks made, was that by defining technology functionally, it was necessary to conceptualize technology differently:

> Technology must be sociotechnical rather than technical, and a technology must include the managerial and social supporting systems necessary to apply it on significant scale. (Brooks, 1980, p. 65)

His point was that to move from initial invention of a new technology to widespread use, required both effective artifacts and practices, as well as effective social systems. This sociotechnical approach to the study of technology coincided with a wealth of empirical research in science and technology studies, looking at the co-evolution of technological and social systems (Bijker *et al.*, 1987; Callon, 1990; Gieryn, 1995; Jasanoff, 2010). The sociotechnical approach captures the idea that processes and patterns of technology adoption and scale, cannot be understood by looking solely at the physical attributes of technology. Rather, the institutional structures, such as public policies, market logics, culture and beliefs are critical to understanding why some technologies are adopted and others are not (Jasanoff and Kim, 2009).

A sociotechnical approach widens the lens of technology adoption research to include the managerial and social supporting systems fundamental to widespread technology adoption. This allows for identification of barriers to technology adoption that go beyond the attributes of the technologies themselves, to the roles of actors and institutions in both creating and overcoming barriers (Anadon *et al.*, 2016). By using a sociotechnical approach to conceptualizing technology, the papers in this dissertation are better positioned to elucidate the intertwined physical and institutional reasons why some technologies benefit the poorest farmers more than others.

In the dissertation, I use the sociotechnical approach to technology studies to look at the factors that influence the benefits the poorest farmers realize from technology. In order to use this approach, precise language to differentiate between the physical and institutional aspects of technology is needed. To refer to the aspects of technology imbedded in the physical artifacts or practices, I use the term "physical dimensions" of technology or sometimes simply "the physical technology." The physical dimensions of technology may include technical aspects of design, such as the specifications of an electric pump or irrigation system. Physical dimensions of a technology also include the agronomic practices associated with the System of Rice Intensification (SRI).

To refer to the social and managerial aspects of technology, I use the term "institutional dimensions" of technology. Institutions are the rules and norms, as well as culture and beliefs that together make up the "social supporting systems necessary" (Brooks, 1980) to apply the physical dimensions of technology at scale (North, 1990; March and Olsen, 2009). Institutional dimensions include things like government subsidy programs, that might change the price a farmer pays for a physical technology. However, a given subsidy institution may have specific rules that dictate who is eligible for the subsidy, including requirements like socioeconomic status, the availability of land-title documents, or other requirements that limit the benefits of the technology to certain groups of farmers. There may also be norms associated with the subsidy institution. For example, extension officers responsible for the program may expect farmers to approach them in their offices to receive the subsidy with some kind of bribe or kick-back. In contrast, an alternate set of norms may send extension officers to villages to advertise the availability of the subsidy program and target their outreach at the poorest communities. The institutional dimensions of technology also include cultural norms, such as the relationships between different social castes in a village, that mediate how information about physical technologies flows between farmers, or how and when farmers engage in collective action behavior to demand better access to a physical technology.

Of course, the physical and institutional dimensions of technology interact in complex ways. Two physical technologies that achieve similar goals (e.g. irrigation for a crop) may use different quantities of water (e.g. drip irrigation vs. flood irrigation). In this context, the institutions effecting the market price of water will impact the benefits farmers realize from using each of the two physical technologies and may influence their ultimate choice about technology adoption and use. If an institutional change, such as electricity subsidies, impacts the price of the water that farmers face, the institutional dimensions of both drip and flood irrigation will change. Likewise, the interaction between the institutional and physical dimensions of each technology will also change the relative benefits a farmer realizes from each technology.

From a policy perspective, it is possible for actors to intervene and change both the physical and institutional dimensions of a technology. For example, by recruiting an engineer or an agronomist to improve specific physical design elements of an existing technology or to design an entirely new physical technology. Alternatively, actors can change the institutional dimensions necessary for technology innovation and widespread use. Government actors, for example, can channel more funding into R&D,

NGOs can change the methods through which they support farmers in adopting technology in the field, private sector companies can change the processes by which they select technology, or identify new business opportunities that engage different groups of farmers.

In this dissertation, I evaluate both the physical and institutional dimensions of technology to understand the barriers preventing the poorest farmers from realizing greater benefits from agricultural technology. Using this logic, a technology may not benefit the poorest farmers because the design of the physical dimensions of the technology does not meet their needs. This could be because the technology is not useable on smaller landholdings. Alternatively, a technology may not benefit the poorest farmers because the institutional dimensions of the technology skew benefits to wealthier farmers and away from the poorest. This could be because the technology requires complex knowledge inputs that the poorest farmers are more likely to have difficulty mastering, given their limited educational access. Or because the initial capital investment is too high for the poorest farmers, and credit is unavailable for farmers without sufficient collateral.

1.2.2 Theory: Innovation Systems

The sociotechnical approach to the study of technology is closely linked to a related approach focused on innovation systems. In the same essay where Brooks laid out the sociotechnical nature of technology, he defined innovation as the "process by which technology is conceived, developed, codified and deployed" (Brooks, 1980, p. 67). Scholars have further articulated this approach, demonstrating that innovation takes place within a complex "innovation system," which includes the actors and institutions that shape innovation processes across different sectors and scales (Lundvall, 1992; Nelson, 1993). The dissertation situates the study of agricultural technology within the literature on the innovation systems responsible for their production and scale. Specifically, the dissertation treats technological innovation as a complex system with overlaps and feedback loops between different stages of the system, including *invention*, *selection*, *production*, *adoption*, *widespread use*, *adaptation* and *retirement* (see Figure 1.1) (Anadon *et al.*, 2014).

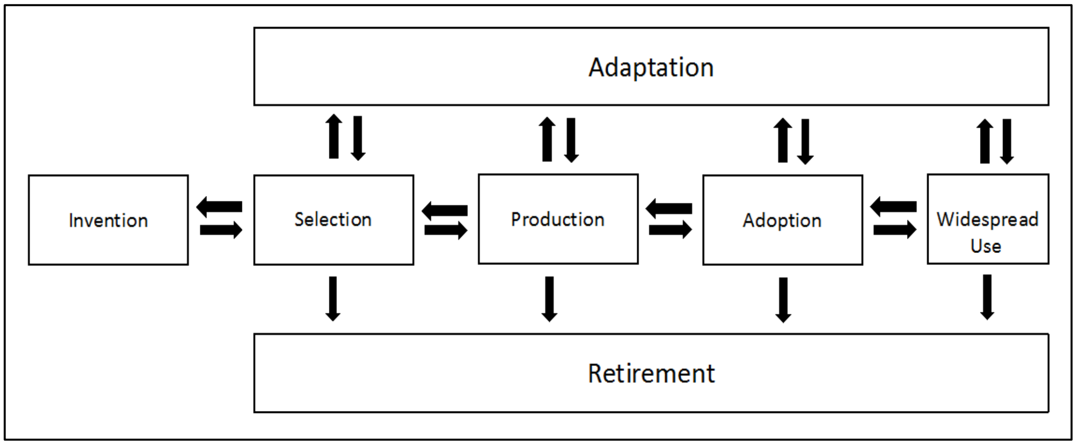

Figure 1.1: Simplified heuristic model of an innovation system.
Source: (Adapted from Anadon et al., 2014)

Note that while the dissertation is particularly concerned with the adoption and widespread use stages of the innovation system (and especially the causal mechanisms that enable or disenable the poorest farmers from adopting technology at scale) because the adoption and widespread stages are interconnected across the innovation system, often mechanisms at other stages of the innovation system, such as those that drive technology selection are meaningful to understanding the barriers that prevent the poorest farmers from realizing greater benefits from technology.

It is important to note that (despite the limits of two-dimensional paper) the model of the innovation presented here should not be conceptualized as a linear process where the *invention* stage necessarily precedes the *selection* stage which precedes the *production* stage. Rather, the system is non-linear where, for example, it is possible for *selection* decisions to drive *invention* activities. Or where *invention* happens not in formal research settings, but by end-users. *Adaptation* is a particularly important stage which can occur simultaneously with any other stage in the innovation system. And indeed, much innovation systems scholarship points to the need for frequent and iterative learning and adaptation in order for technology to successfully reach *widespread use* (Henderson and Clark, 1990; Pavitt, 1995; Lundvall, 2007; Anadon *et al.*, 2016).

While the three papers in this dissertation are not concerned with detailing each stage of the innovation system for every technology (and in particular, the dissertation does not focus on incentives for invention), diagnosing barriers to technology adoption by end-users requires a broader systems perspective of innovation, including feedback loops between stages (e.g. weak demand in the adoption of a technology sends engineers back to the drawing board to redesign the physical attributes of the technology in the invention stage, or forces policy makers to re-think the institutional structures supporting technology adoption through the design of extension services, subsidy programs, or risk mitigation programs). By incorporating innovation systems thinking, the papers are better positioned to understand the causal mechanisms determining the degree to which the poorest farmers benefit (or fail to benefit) from technology, whether those mechanisms are directly linked to the *adoption* and *widespread use* stages of the innovation system, or have their roots in the *invention*, *selection, production, adaptation,* or *retirement* stages.

1.2.3 Theory: Sociotechnical Regimes and the Multi-Level Perspective (MLP)

Finally, the dissertation borrows specific theoretical language from the multi-level perspective (MLP) on innovation systems from the sociotechnical transitions literature (Geels, 2002, 2004). This literature is concerned with long-term transformative change in industries and sectors. To explain the stickiness, inertia, and path dependence of technological change, this literature has developed the concept of the "sociotechnical regime" which "forms the 'deep structure' that accounts for the stability of an existing socio-technical system" (Geels, 2011, p. 27). This deep structure is made up of the "semi-coherent set of rules that guide, orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems" (Geels, 2011). This understanding of sociotechnical regimes relies heavily on institutional theory and especially, on the deep concepts of structure articulated by Giddens in his theory of structuration (Giddens, 1986). Building off Giddens's concept of deep structure, Fuenfschilling and Truffer usefully define sociotechnical regimes as "highly institutionalized, yet not necessarily coherent formal and informal rules (e.g. shared beliefs and values, routines, regulation, institutionalized practices, capabilities, etc.) that mutually construct and are constructed by actors in a system" (Fuenfschilling and Truffer, 2014, p. 773).

The concept of the sociotechnical regime is a key piece in linking the sociotechnical nature of technology (Brooks, 1980; Bijker *et al*., 1987) with the technological innovation systems literature (Lundvall, 1992; Nelson, 1993). All stages of an innovation system, from *invention* through widespread *adoption* and *retirement,* take place within sociotechnical regimes, which are made up of the institutions (rules, norms, culture, and beliefs) that coordinate the behavior of actors in the regime. In other words, institutional structures shape innovation pathways and coordinate the activities of actors in a given innovation system. While the MLP literature goes far deeper into the driving forces of innovation in the *regime*, *landscape* (social trends and large special patterns such as wars, natural disasters, changes in political coalitions) and local *niche* levels (alternate sociotechnical systems often pushed for by alternative actor networks), their clarification of the sociotechnical regime that forms the institutional 'grammar' undergirding innovation offers an important theoretical grounding, that was absent from Brooks' work on the sociotechnical nature of technology and innovation. By exposing the institutional backbone of innovation systems, the MLP literature underscores the importance of institutional theory in the study of technology and innovation in social systems.

The contribution of the sociotechnical regime approach underscores the centrality of institutions in stabilizing specific sociotechnical configurations and highlights an important dimension of the dissertation. While I discussed the sociotechnical approach in Section 1.2.1, where both the physical and institutional dimensions of technology are important factors in determining whether the poorest farmers benefit from technology, the sociotechnical regime approach highlights the centrality of institutions in structuring technological innovation systems. This insight is at the core of the approach behind the researching and writing of this dissertation. In field settings, I looked at both physical and institutional reasons why a particular technology benefited, or failed to benefit, the poorest farmers. But, my conclusions have much more to say about institutional design than they do about the design of the physical technologies themselves. This is largely a methodological preference (after all, I am not an engineer), but I also argue that deep structural norms around technology *invention* and *selection* are responsible for the types of physical technologies actors operating at the *invention* stage chose to *invent*, and the kinds of physical technologies that actors operating at the *selection* stage chose to *select* for *production*. Thus, if there is a chicken or egg debate around the primacy of technology or institutions in undergirding change in innovation systems, unlike some coproductionist accounts, I come down at least modestly on the side of institutions, which structure the behavior of actors across stages of the innovation system.

Whether or not the institutions undergirding sociotechnical regimes incorporate the needs of the poorest farmers systematically into the innovation process, is likely to have significant impact on the benefits the poorest farmers realize from technology. Likewise, from a policy perspective, institutional design can help reorient innovation systems across all stages (from invention to widespread use) towards the needs of the poorest farmers. Reiterating the goal of this dissertation in the theoretical language developed in this section: The three empirical chapters seek to understand both the physical and institutional casual mechanism preventing the poorest farmers from realizing greater benefits from technology, in order to derive policy relevant insights for reorienting the institutions structuring agricultural innovation systems towards the needs of the poorest farmers.

1.3 Literature

1.3.1 Literature: Situating the Research in the Broader Discourse on Poverty and Inequality

During the (too) many years that went into the design, fieldwork, and writing of this dissertation, concerns over rising global inequality grew in the popular consciousness and led a number of public intellectuals to sound the alarm bells about the detrimental effects of inequality on our polity (Jensen, 1975; Piketty, 2015). As I struggled with synthesizing the findings from my research in January 2017, Oxfam drew global headlines for their report that just eight men own the same amount of wealth as the poorest half of the world's population (Hardoon, 2017).

There are many ways to understand and measure inequality, including inequality in wages and assets, inequality in access to resources, inequality in opportunities, and inequality in freedoms and capabilities (Sen, 1999; Neckerman and Torche, 2007; Milanovic, 2013). The reasons to be concerned about inequality are also multifaceted – scholars have identified multiple detrimental impacts of inequality, both on the poorest people and on larger social systems, including impacts on health and mortality, educational outcomes, crime, and political stability, among others (Neckerman and Torche, 2007).

In response to these concerns, the United Nation's broadened their focus from poverty and hunger in the Millennium Development Goals (MDGs), which launched in 2000, to include a specific focus on inequality in the 2015 Sustainable Development Goals (SDGs). In including reduced inequality as goal 10 of the SDGs, the United Nations noted that "while income inequality between countries may have been reduced, inequality within countries has risen" (Goesling, 2001; United Nations, 2016). This empirical finding challenges theories of trickle-down economics. The UN argues that at the scale of the nation, "economic growth is not sufficient to reduce inequality if it is not inclusive" and to be inclusive, policies promoting economic growth must pay more "attention to the needs of disadvantaged and marginalized populations" (United Nations, 2016).

This dissertation was written in the context of these larger concerns about trends in global poverty and inequality, and is an attempt to place the lens of innovation and technology studies more squarely on the challenges and opportunities facing the poorest. At the macro scale, research has uncovered links between surges in technological innovation and increased inequality (Milanovic, 2016). Of course, this in and of itself is not entirely concerning. Along the lines of Jagdish Bhagwati's argument and empirical findings that while economic growth benefits wealthier segments of society, it also tends to benefit the poorest (Bhagwati, 1988), many technologies similarly may benefit the wealthy while also benefiting the poor. My argument is not that all technologies should benefit all farmers equally. Rather, that embedded in the SDGs there is a social goal of developing and deploying technologies that will help the poorest. With this goal in mind, innovation scholars ought to worry about why so many efforts to mobilize technology to help the poorest seem to fail. Yet we have a dearth of conceptual tools with which to discuss the differentiated impact of technological innovation on poverty and inequality.

More generally, the literature on poverty and inequality lacks precision when it comes to the distinction between interventions that target poverty (focus on the bottom quintile) and interventions that target inequality (reduce differences between the poor and the wealthy). Conceptually, a technology can be judged both on its potential to reduce poverty as well as its potential to reduce inequality. What is important to understand is that these two metrics are not the same. Technologies that benefit the poor may also benefit the rich, and perhaps benefit the rich relatively more than the poor, thereby increasing inequality while still decreasing poverty. On the other hand, technologies may benefit the poor while having no benefits for wealthier social groups. In this case, the technology would both reduce poverty and inequality. It is possible to think about a two-by-two matrix of technology types with respect to their benefits to the poorest farmers (see Figure 1.2).

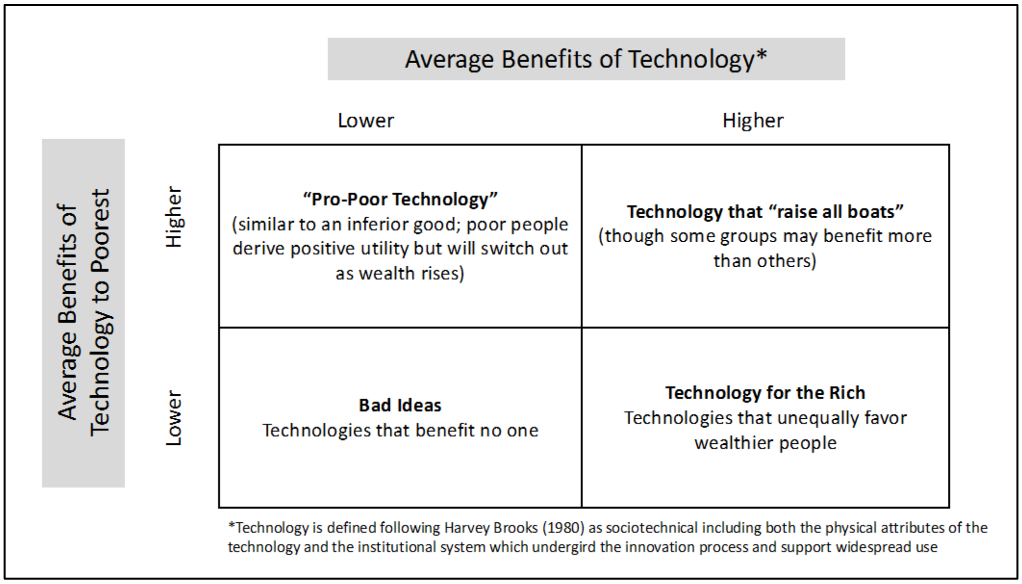

Figure 1.2: Stylized conceptualization of the impact of technology on poverty and inequality.

1). "Pro-Poor" Technologies: Technologies that benefit the poorest in particular. These technologies have low benefits or are otherwise unattractive to other social groups. These technologies are similar to a consumer theory definition of inferior goods, in that they have high utility under low levels of wealth, but as wealth rises, people will tend to switch away from these technologies. These technologies could be said to be inequality reducing, in that the poor benefit from them relatively more than wealthier groups. Examples of these technologies include some types of public transportation, especially intra-city bus services in the US, which are significantly cheaper than rail and air transit options, household fans and water coolers when air conditioning is unaffordable, and low cost water filters, such as ceramic pots where the poor cannot afford access to higher quality water supplies (Murthy *et al.*, 2013).

2). Technologies that "raise all boats": These technologies benefit all groups, though they may benefit some groups more than others. If the wealthy benefit more from these technologies than the poor then the technology would increase inequality, while at the same time reducing poverty. An example of this type of technology includes much of modern medicine, such as x-rays and vaccines, which likely benefit the wealthy more because of better access to healthcare, but certainly also benefit the poorest. Other examples likely include paved roads and airplanes.

A salient example of technologies that "raise all boats" from the perspective of this dissertation, which has recently been the subject of a great deal of empirical research and popular writing, is the role of cellular phones in helping developing countries technologically leapfrog developed countries (James, 2009; Aker and Mbiti, 2010). Cellular technology has certainly benefited all social groups but perhaps especially benefited the poorest communities in developing countries, by providing access to other services, such as mobile banking. In Kenya, one channel through which mobile banking has benefited the poorest farmers is through the ability of relatives and friends who have migrated to urban centers to easily transfer cash back to rural areas. More generally, in cash-based economies where the percentage of the population with access to traditional banking services is low and largely confined to the wealthy, mobile banking specifically benefits poor farmers. This in turn has been found to improve resilience among small farmers, decrease farmers' perceived risk, and promote more investment in technological inputs (Kikulwe, Fischer and Qaim, 2014).

A second example of a technological innovation system that "raised all boats" can be found in the history of efforts to develop malaria treatments. Early efforts to development treatments for malaria were driven by the desire of European colonial powers to protect their own militaries and economic interests in their colonies (Keusch *et al.*, 2010). These early efforts to create technologies "for the rich" later evolved into a much more inclusive innovation system with significant benefits for the poorest communities, as transnational actors, including the Bill & Melinda Gates foundation, build on earlier research in an effort to eradicate malaria (Gates, 2007).

3). Technologies for the rich: These technologies benefit the wealthiest people or groups while having limited to no benefits for the poor. These technologies increase inequality and have no impact on poverty reduction. Examples of this technology include high end smart phones, expensive cars, expensive cheeses and wines, and potentially even powerful personal computers, which are too expensive for the poorest to buy. Going beyond this even if the poorest had access to these computers, they likely would not have the necessary training or skills to make full use of the physical technology.

4). Bad idea technologies: These technologies have little benefits for the rich or the poor. In theory, these technologies will not achieve any kind of scale as they have limited benefits to any social group. Such a technology would not increase inequality, but it also would not reduce poverty. Examples of such bad idea technologies include Google's failed Google Glass wearable technology, which was discontinued less than two years after the product's launch, Samsung's Galaxy Note 7, which had a tendency to catch fire, and cassette tapes in the context of 2017, where CDs and digital audio files offer the same capabilities with greater convenience and at lower costs.

The two by two matrix presented above is a highly-stylized heuristic for thinking about technology types based on their impacts on poverty and inequality. The examples given for each cell of the two-by-two matrix, demonstrate that the categories a technology fall into are not fixed and may differ, based on both geography and historical context. Most technologies are likely to fall somewhere on a continuum between these stylized types. In addition, over longer time periods, technologies may switch from one type to another as one technology becomes obsolete. Cassette tapes were once useful technologies, that likely benefited both the wealthy and the poor in America in the 1980s (category 2), while benefiting only wealthier people in many developing countries, where they were too expensive for the poorest (category 3). Today, cassettes have become obsolete and increasingly benefit no groups (category 4). Despite the contingencies of categorizing technologies into this typology across region and historical period, the generalizable conceptual categories are useful for theorizing the potential relationships between technology, poverty and inequality.

This dissertation is concerned with the impact of technology on poverty. This group has been alternatively defined as the "bottom billion" (Collier, 2007) or more commonly, as the poorest quintile of the population (Baulch and Hoddinott, 2000; Coady, Grosh and Hoddinott, 2004). Technologies that benefit the bottom quintile can either be category 1 technologies (those that are specifically "pro-poor") or category 2 technologies (those that "raise all boats" by benefiting multiple socioeconomic groups including the poorest).

The impact of technology on inequality, rather than poverty, is largely outside the scope of this dissertation. However, the distinction is still conceptually important. Indeed, understanding which technologies are specifically "pro-poor" versus technologies that "raise all boats," has important implications for political strategies across all stages of the innovation system. For example, "pro-poor" technologies may require greater public sector and donor investments at the *invention* stage. In contrast, technologies that "raise all boats" may have more private sector actors participating across stages of the innovation system but may still require public sector intervention at the *adoption* and *widespread* use stages, to ensure the poorest also benefit. Finally, it may be wise for governments to limit their investment and support for technologies that would primarily benefit wealthier groups.

By conceptualizing the impact of technology on poverty (and inequality), the approach presented in this section opens the door for researchers and policy makers to evaluate innovation systems, not only for their contributions to efficiency and productivity in agricultural systems, nor for their ability to reduce labor requirements, or even for their environmental externalities, but also for the way different sociotechnical configurations impact fundamental social relationships in agriculture systems. While this study focuses only on technologies that benefit the poorest (irrespective of their impact on inequality) there is scope for further research that disentangles these relationships in order to marshal technology, not only to reduce poverty, but also inequality.[2]

1.3.2 Literature: Innovation and Poverty in the Literature

While the development community switched their focus from economic growth to poverty reduction in the late 1980s and 1990s (World Bank, 1990, 2001; IFAD, 2016), the literature on innovation has been slow to engage with this challenge. At the same time, the SDGs include specific goals on both poverty reduction (goal 1), and innovation (goal 9). Clearly, innovation has a role to play in meeting the SDGs. However, there is a need in the innovation literature for greater focus on the issue of poverty, and the ways in which the extensive literature on innovation can contribute to our understanding of how to make technology work for sustainable development.

This section reviews several disparate literatures on innovation and poverty and situates this dissertation within these literatures. What will be clear by the end of this brief literature review is that the union of these two literatures is relatively sparse and undertheorized. This dissertation brings these two literatures together to provide policy relevant guidance for reorienting innovation systems to better meet the needs of the poor.

There is a rich and varied set of literatures addressing the complexities of technological innovation. While interest in the dynamics of innovation date back to at least the nineteenth century and the work of Karl Mark in *Das Kapital* (1867), modern innovation studies began with the work of Joseph Schumpeter, in his explanation of business cycles as innovation-driven processes of change in which

[2] This is not to say that reduced inequality is always the social or political goal that should be pursued. Indeed, some level of inequality is an emergent property of social environmental systems. At the same time, the evidence that the world today has become too unequal is mounting and the causal role of technology as a driver of increased inequality is frequently discussed in the issue rhetoric. A better analytic approach and more empirical data is needed to offer policy relevant advice for how technology can be marshalled for the dual goals of poverty reduction and inequality reduction. This conceptual framework is a first stab in this direction and should be developed further.

societies respond creatively to changes in the factors of production (Schumpeter, 1947, 1982). Later work by Robert Solow demonstrated that increases in labor and capital alone are not sufficient to explain economic growth. Instead, he argued that "technological change" is central to explaining economic growth (Solow, 1957). By demonstrating the link between technological improvements and economic growth, Solow showed the importance of investment in basic research and R&D – an insight which spurred many countries, including the United States, to invest heavily in their national research capacity. Since Solow's seminal work, a large body of empirical literature has arisen which seeks to quantify the value of investing in research and development (R&D) (e.g. Griliches, 1981; Jones & Williams, 1998). Investments in R&D in the agricultural sector, for example, are estimated to yield a rate of return somewhere between 40 and 60% (Alston *et al.*, 2000).

Since the iconic studies of Schumpeter and Solow, a wide-ranging literature in economics, science and technology studies, management studies, and other disciplines has expanded our understanding of the relationship between innovation, economic growth, and development. Major contributions to the economics of innovation were made by agricultural economists Yujiro Hayami and Vernon Ruttan, who showed that the causes of agricultural productivity growth (or stagnation) required understanding not only changes in factors of production (e.g. labor, inputs, water), but also the larger institutional conditions under which agricultural growth takes place. They developed a model that included "technological and institutional change as factors endogenous to the economic system" (Hayami and Ruttan, 1971, p. 1). The importance of technological and institutional change in driving change in agricultural productivity meant that a wide range of actors, including governments, researchers, and the private sector, all played important roles in the functioning of agricultural systems. In their model of agricultural innovation, which they called the "induced development model," Hayami and Ruttan argue that processes of change in any agricultural system are "induced by farmers, agribusiness and administrators" responding to changes in factors of production and market prices by demanding new technologies that either save land or labor, depending on their relative scarcity. Perhaps the most critical insight to come out of Hayami and Ruttan's work was that there is variation between different contexts, not only in terms of their relative allocations of land and labor, but also in terms of their institutions. Their approach to understanding agricultural systems was particularly nuanced in identifying the barriers to agricultural productivity across contexts (e.g. the United States and Japan (Hayami and Ruttan, 1971), and India and East Asia (Hayami, 1981). In addition, their identification of the "non-agricultural sector" as a vital source of knowledge and technical input into agricultural systems, was a novel insight – without effective coordination between disparate parts of the larger system in which agriculture operates, they argued, the necessary technological change for agricultural development will not take place.

In summary, Hayami and Ruttan argued for a view of technology innovation that includes actors and institutions, across a wide range of activities, relevant to agricultural production. They also argued that effective alignment between these different parts of the system is critical to the performance of the system as a whole. Despite their significant contributions to the field of innovation studies, their work was not particularly concerned with the impacts of innovation across socioeconomic groups. This failure to contemplate how the needs of the poorest farmers fit into induced innovation models was perhaps their largest oversight, and would require more input from sociologists and organizational theorists to solve. Their oversight was that in order for the induced innovation model to work, famers facing different allocations of land and labor, as well as variated agroecological and sociotechnical constraints, would need to be able to communicate their demands to other actors in the system – specifically, actors operating in the *invention* and *selection* stages of the innovation system. There are multiple ways to view these pathways of communication. Many economists assume they happen through price signals, where private sector companies develop technologies for which they see a profitable market. In contrast, the premise of the Land Grant University System in the United States is that that these universities conduct research based on close collaboration with and understanding of farmers' needs. This model relies on social and organizational ties rather than economic incentives, to "induce" the right kinds of innovation that farmers need. However, for the poorest farmers, the pathways by which they can communicate their needs into the larger agricultural innovation system are not as clear. Like concerns over neglected diseases (Trouiller *et al.*, 2002; Moon, Bermudez and 't Hoen, 2012) and orphan crops (Naylor *et al.*, 2004), in theory, it is quite easy to imagine that there are many neglected technological needs, where the induced innovation model has failed because the poorest farmers lacked the purchasing power or voice to communicate their needs into the agricultural innovation system.

In many ways, the work of Hayami and Ruttan presaged a particularly productive approach to studying innovation that emerged in the 1980s – namely, the study of innovation as a complex adaptive system. Innovation systems scholars focus on how societies generate, exchange and use knowledge and technology, as well as the benefits (and costs) of these processes. Within this perspective, an innovation system is broadly defined as the set of agents involved in the innovation process, their actions and interactions, and the institutions (rules and norms) that guide and constrain the agents in the system (Edquist, 1997). The systems approach to innovation was first explicitly introduced in the literature by Freeman (1987), who like Hayami, drew a great deal of his empirical experience from Japan. In the innovation systems literature, innovation emerges out of the interaction between organizations and institutions. Much of this literature focuses on understanding the determinants of innovation, including political and economic factors, and the impact of innovation processes, from *invention* through *widespread use,* of new knowledge and technology. While there is now a wealth of literature on innovation systems (e.g. Lundvall, 1992; Nelson and Nelson, 2002; Hekkert *et al.*, 2007) little of this literature focuses specifically on the links between technological innovation and its impacts on the poor, and none of this literature (that I could find) looks at the relative impacts of technology across socioeconomic groups.

A related literature discussed in Section 2.3 of this chapter, the multi-level perspective (MLP), is a theoretically rich and empirically grounded analysis of the sociotechnical nature of innovation. It draws on both the innovation systems literature, as well as literature in science and technology studies, to build a historically embedded understanding of the intertwined processes of technological and social change. The field originated with the study of the dynamics of technological change, focusing almost exclusively on historical examples, including the transition from sailing ships to steamships, and from horse drawn carriages to automobiles (Geels, 2005, 2002). In more recent years, the field has increasingly begun to grapple with the nature of sociotechnical change in the context of sustainable development (Kemp and Loorbach, 2007; Markard, Raven and Truffer, 2012), particularly transitions toward low-carbon economies (Hake *et al.*, 2015; Geels *et al.*, 2016). However, the MLP field has largely failed to focus on empirical cases that address the dynamics of innovation in developing countries, or to focus on the specific challenges facing the poorest populations, whether in the developed or developing world (Loorbach, Frantzeskaki and Avelino, 2017) – with a few exceptions, including an analysis of transition dynamics in energy systems in Asia (Berkhout, Angel and Wieczorek, 2009) and a study of the emergence of the Chinese solar PV sector (Binz and Anadon, 2016). Neither of these papers, however, address the issue of differentiated impacts of technology across socioeconomic groups.

One of the few fields to directly address the relationship between innovation and poverty reduction is business and management studies. In a 2012 special issue in the *Journal of Management Studies*, the authors explored emerging research on "inclusive innovation." In the introduction to the special issue George et al. (2012) define inclusive innovation as "innovation that benefits the disenfranchised" and sees inclusive growth as the "*desired outcome* of innovation initiatives that target individuals in disenfranchised sectors of society, as well as, at the same time, a characteristic of the *process* by which such innovative initiatives occur" (p. 661). This nascent literature is one of the few literatures to focus explicitly on the potential link between innovation and its impacts on poverty.

Coming out of business and management literature, much of the inclusive innovation literature is concerned with Bottom of the Pyramid (BoP) business models that see the poor as an untapped market for growth and largely focuses on product and business model innovation that more effectively turns the poor into consumers (Nestlé, 2011). Other authors in this literature offer a more critical lens, arguing that much of what is published under the heading of inclusive innovation is less about improving the well-being of the poorest than it is about market creation for private sector companies (Ansari, Munir and Gregg, 2012). In a compelling moral argument, Ansari et al. call for future research in the field to measure inclusive growth not only in terms of impact on market engagement, but in terms of impact on the capabilities of the poorest. This call to reframe the goals of the BoP and inclusive growth literature is in line with Amartya Sen's capabilities approach to conceptualizing the ends of development (Sen, 1999). However, despite Ansari *et al*.'s appeal to focus more explicitly on the well-being of the poorest, no subsequent studies have clearly taken on this challenge.

Over optimistic assumptions about inclusive innovation have also been highlighted by the World Bank in their 2016 report "Digital Dividends," which argues that while digital technologies have enormous potential to improve the lives of the poorest, to achieve these goals, greater digital adoption must be combined with "analog complements," including "strengthening regulations that ensure competition among businesses, by adapting workers' skills to the demands of the new economy" (World Bank, 2016). Without changes in the institutional dimensions of new digital technologies, the World Bank worries that the benefits of new technologies will be disproportionately accrued by wealthier and better educated populations in developing countries.[3]

With its roots in Hayami and Ruttan's work on the drivers of innovation in the agricultural sector (Hayami and Ruttan, 1971, 1984), and drawing on later scholarship on innovation systems across sectors

[3] This is one of the few studies I have come across that explicitly looks at the heterogeneous benefits of technology across socioeconomic groups.

(Lundvall, 1992; Edquist, 1997; Nelson and Nelson, 2002; Charles Edquist, 2005), a sub-literature on agricultural innovation systems has emerged over the past thirty years. One of the earliest papers applying innovation systems thinking to agriculture looked at the relationship between formal R&D and informal or farmer-led R&D (Biggs and Clay, 1981). In their paper, Biggs and Clay argue that despite the "comparative static analysis" of the impact of technologies, such as irrigation systems and high yielding seed varieties (HYVs) on farmer well-being coming out of the agricultural economics literature, the relationship between technology and socioeconomic outcomes has not been studied in the context of the larger "innovation systems" which produces these technologies (p. 323). To better optimize the allocation of research funding in the R&D system, the authors argue that it is necessary to understand the role of both informal and formal R&D, within the context of the specific sociotechnological systems facing farmers in developing countries. Their study, while not explicitly teasing out the sociotechnical mechanisms undergirding variation in benefits of technology across socioeconomic groups, goes a long way towards articulating the need for such an approach in the future.

Following on Biggs and Clay (1981), later work in agricultural innovation systems, while contributing important insights to the drivers of innovation in the agriculture sector, lacked the focus on the impact of technology across socioeconomic groups that Biggs and Clay called for in their article. Moreover, too much of the agricultural innovation systems literature continues to focus on the developed world (e.g. Klerkx and Leeuwis, 2009), and the research that does expand its focus to the developing world largely overlooks differences between socioeconomic groups of farmers, unconsciously assuming that technologies and changes in innovation systems will impact all farmers equally in a given context (Clark, 2002; Kilelu, Klerkx and Leeuwis, 2013; Schut *et al.*, 2015). For example, in an analysis of agricultural innovation systems in India, the authors demonstrate the importance of "research partnerships" between public agricultural research centers and the private sector for improving the overall functioning of innovation systems (Hall *et al.*, 2001). However, the authors do not address the issue of heterogeneous impacts of technology across socioeconomic groups of farmers, despite the fact that Indian farmers are highly diverse both across geographies and socioeconomic groups, and that agricultural innovation policy has almost certainly already created winners and losers (Prahladachar, 1983; Prakash, 2005).

In a second example, Lamers *et al*. (2017) usefully apply the functions of the innovation systems approach developed by Hekkert *et al*. (2007), to three countries in sub-Saharan Africa. They evaluate the performance of innovation platforms, and make a useful contribution to the literature, by identifying obstacles in transitioning innovation platforms set up with a research mission into innovation platforms that can foster innovation through private sector channels with the potential to outlive the life of the original research project. However, their analytical approach fails to differentiate farmers across socioeconomic groups, rather assuming all farmers in their case studies have the same interests and face the same opportunities and constraints. A review of the few other studies applying agricultural innovation systems frameworks to the developing world, shows that the black-boxing of farmers into a single homogenous interest group is endemic to this literature.

An exception to the absence of research into the relationship between technology innovation and poverty is a working paper from 2002 by Berdegué and Escobar, which was, unfortunately, never published as a more formal journal article. Their paper integrates extensive research by the authors on the complex "multi-dimensional" nature of rural poverty with innovation studies to "argue for a differentiated approach to targeting agricultural innovations, based on an analysis of rural assets" (2002, p. i). This useful contribution points to the differential benefits that technology can have across different categories of rural poor households. While their insight that technological innovation is likely to impact different categories of rural households differently is novel, the working paper is largely a theoretical identification of the problem, and does not offer an empirical investigation of the relationship between innovation and poverty.

Like Berdegué and Escobar, Spielman *et al*. (2009) writes about the important role that innovation studies can play in helping to better understand and intervene in agricultural systems in the developing world. They also note the scarcity of studies in the innovation systems literature that "examine the poverty-related effects of innovation processes" (p. 5). Moreover, they usefully note that "few studies make the leap from descriptive *ex post* analysis of an innovation system to *ex ante* analysis of how an innovation system promotes institutional and technological changes that are explicitly pro-poor" or that focus on "sustainability and equity" (p. 5). While Spielman *et al*. (2009) do not include an empirical case that addresses these issues, they do offer several methodological approaches, including social network analysis, innovation histories, and comparisons across countries, which they think will help scholars better investigate the links between agricultural innovation and poverty.

Berdegué and Escobar (2002) and Spielman *et al*. (2009) notwithstanding, this brief overview of the agricultural innovation literature underscores the underdevelopment of this literature with respect to the needs of the poorest.

A final strand of literature on innovation deals more directly with issues of poverty. This is the grassroots innovation led by Anil Gupta (among others) at the Indian Institute of Management Ahmedabad (IIMA) in the state of Gujarat. This literature grapples with the important point that the poor often create novel solutions to their own problems, and looks at ways to scale these solutions so that individual innovations that solve problems in one location are transportable to other locations (Gupta, 2016). Gupta and colleagues have built a community of scholars and activists, called the Honey Bee Network, to catalog a database of local knowledge and innovations. The Honey Bee Network has thus far cataloged over 100,000 "ideas, innovations and traditional knowledge practices" of the poor (Honey Bee Network, no date). The poor, they assert, may not be monetarily wealthy, but they nonetheless have enormous capabilities to frugally and creatively solve their own problems. By fostering local innovations, the grassroots innovation community argues that they are both promoting appropriate innovation for the realities of the rural poor, and empowering the creativity and valuable traditional knowledge of these communities.

The grassroots innovation literature shares a great deal epistemologically with literature in science and technology studies, which posits that technologies must be understood in relation to social systems and that technological change and social change are firmly intertwined. As such, we cannot understand a complete picture of either social or technological systems without reference to the other (Callon, 1998; Jasanoff, 2010). Building on this understanding of technology as inextricably intertwined with social systems, the grassroots innovation literature sees innovations systems as systems that can be studied and judged, not only for their contributions to efficiency and productivity, or even for their ability to reduce labor requirements or environmental externalities, but also for the way different technologies embody and reproduce specific forms of power and authority within social systems (Winner, 1980). By promoting local and frugal innovations, scholars of grassroots innovation argue that they are promoting technologies that bring positive benefits to the poorest. At the same time, they are acknowledging and countering the biases of so much technology and innovation research, which despite increased attention to the non-linear nature of innovation, continues to ignore the contributions of the poorest to innovation processes.

Finally, my own work with colleagues has grappled with the issue of how to ensure innovation systems meet the needs of vulnerable populations, now and in the future. In an invited Perspectives article for the '*Proceedings of the National Academies of Science'* (PNAS) we argue that "the current institutions (rules, norms, and incentives) shaping technological innovation are often not aligned toward the goals of sustainable development because impoverished, marginalized, and unborn populations too often lack the economic and political power to shape innovation systems to meet their needs" (Anadon *et al.*, 2016, p. 9682). The paper concludes that measures to systematically take into account the interests of underserved populations are urgently required in innovation and technology studies, and that institutions need to be reoriented toward sustainable development across stages and scales. This dissertation takes up this charge, looking specifically at how to make the institutions structuring agricultural innovation systems work for the poorest.

1.4 Fieldwork Setting

An observation made in 1981 by renowned Japanese agricultural economist Yujiro Hayami, highlights some of the reasons why India is a particularly rich field setting for a project focused on the relationship between agricultural technology and poverty. On Hayami's first visit to the subcontinent, he made field visits over the course of three months to Haryana, Karnataka, Kerala, and Uttar Pradesh. Despite the brevity of his visit, his comparative view of India's agricultural system, with respect to that of East and Southeast Asia, was insightful. He observed that the "basic root of poverty and inequality" was the same in both India and East/Southeast Asia (Hayami, 1981, p. 708). Both regions, he argued, had low rates of return on labor due to low levels of technology adoption, caused by limited endowments of land and capital relative to labor. In addition, both regions faced extreme inequality in endowments of capital assets across socioeconomic groups. However, Hayami thought India's challenges were greater because of sharp class conflicts between landowners and laborers. In East/Southeast Asia, a technocratic approach, which focused on intensification of agriculture through investments in irrigation and land-saving and labor-using technologies, had led to growth in employment and wage earnings. In contrast, in India he worried that the same technocratic approach "may induce mechanization under the condition of high labour transaction costs" thereby aggravating, rather than ameliorating, the challenges of poverty and inequality in the country (p. 707). At the same time, a "reformist" approach aimed at redistributing land to the poorest also seemed infeasible in India, because the majority of land was not in the hands of large absentee landowners, but rather small and medium cultivators, making redistribution technically and politically infeasible. Hayami concluded that India would have to carefully balance a technocratic and reformist agricultural agenda if the country were to make progress in decreasing rural poverty and inequality (Hayami, 1981).

Almost 40 years after Hayami made these observations and more than 75 years since the start of the Green Revolution, India still struggles with the challenges of balancing technocratic and reformist approaches to agricultural development (Witsoe, 2006). And in some places like Bihar, the challenge of balancing technocratic and reformist approaches has proven especially difficult. Between the late 1960s and early 1980s, the Green Revolution came to some parts of India, but the revolution was by no means a nationwide phenomenon. In the years immediately after the start of the Green Revolution, the North-West region of India, including Punjab and Haryana, saw an average annual compound growth rate of 3.39%. In contrast, the eastern region of the country, including Bihar, Orissa, and West Bengal, lagged far behind with an average annual compound growth rate of 1.3% between 1965 and 1983 (Singh, 2010). Research into the causal mechanisms undergirding these stark differences in growth rates, identified strong inter-regional variation in the adoption of modern seed varieties as the primary driver of the yield gap (Prahladachar, 1983).

The inter-regional yield gaps caused increasing inter-regional income differences over this same period, indicating that regions that benefited from the Green Revolution technologies saw corresponding benefits to the well-being of their populations (measured in terms of income). What is perhaps even more interesting is that while inter-regional differences in technology adoption were high, intra-regional differences between small and large farmers were relatively low, indicating that farmers across socioeconomic spectrums benefited from the introduction of improved seed varieties within a given region (Prahladachar, 1983). The characteristics that distinguished the regions that benefited from the Green Revolution from those that did not were differences in the development of infrastructure, as well as differences in the extent of administrative and institutional support for the agricultural sector

(Prahladachar, 1983; Chopra, 1985). In other words, inter-regional variation in sociotechnical regimes strongly impacted the benefits accrued by regions from the new Green Revolution technologies.

While the stark inter-regional differences in agricultural output and adoption of improved seed varieties leveled off to some extent in the 1990s, there are still significant differences in the sociotechnical regimes undergirding the agricultural systems across states in India. This variation in sociotechnical regimes is one reason India is a particularly interesting field site for the study of agricultural technology. I make use of this inter-regional variance in Chapter 4 of the dissertation.

The second and third chapters focus on a single state in India – Bihar. I selected Bihar because the state underwent a profound shift in the governance regime in the early 2000s (Singh and Stern, 2013; Witsoe, 2013)The shift in governance had implications for the agricultural sector, which I leverage in my fieldwork in Chapter 2 to understand the sociotechnical causal mechanism (STCMs) undergirding the distribution of benefits from agriculture technologies across socioeconomic groups.

Bihar is one of the poorest states in India, as well as one of the states with the lowest rates of agricultural productivity. The poor performance of the agriculture sector in Bihar is not due to Bihar's lack of agricultural potential. Indeed, when the British first colonized India, they identified Bihar as having exceedingly favorable conditions for agricultural production and built the first agricultural research institute in the State. Despite this potential, agricultural productivity stagnated, and Bihar showed the slowest rate of growth out of all of India's states, over the past five decades (Kishore, Sharma and Joshi, 2014).

While the reasons for Bihar's agricultural stagnation are complex (and discussed in Chapter 2), one important explanatory factor is a period of poor governance during the era of Chief Minister Lalu Yadav, who was elected in 1990, and for all intents and purposes, served through 2005.[4] Lalu's era was

[4] For some of this time, Lalu Prasad was in prison after being convicted on corruption charges, but continued to govern through his wife, Rabri Devi Yadav, who was appointed Chief Minister by the party.

characterized by caste-based politics, lower caste empowerment, and the deterioration of government services (Witsoe, 2013). The abrupt shift in Bihar's sociotechnical regime took place in 2005 when a new Chief Minister, Nitish Kumar, came to power. Nitish Kumar was elected with a strong technocratic mandate and the goal of revamping Bihar's deteriorated bureaucracy including developing a new rural development strategy. Bihar became the first state in India to develop an Agricultural Road Map in 2008, and significant institutional support was directed to rural development and agricultural production in the state (Government of Bihar, 2008).

It is this abrupt shift in the sociotechnical regime surrounding Bihar's agricultural sector that made the state an interesting field setting for this project, for a number of reasons. First, the abrupt change in sociotechnical regimes between the old and new Chief Ministers was a particularly good inroad for discussions with farmers, about the sociotechnical mechanisms related to different agricultural technologies in the state. Asking about the changes before and after Nitish Kumar, led to more thoughtful answers, that more deeply engaged with the institutional dimensions of the technology under discussion. Second, my hypothesis, which was later confirmed by survey data, was that many technologies that had reached widespread use in states like Gujarat and Haryana decades earlier, in the 1970s and 1980s, had only reached widespread use in Bihar over the past 10 to 15 years. This more recent "Green Revolution" offered a laboratory for observing, in real time, the differential benefits of newly introduced technologies across socioeconomic groups of farmers. Finally, significant new resources had been directed to Bihar's agricultural economy since 2006. The degree of financial and institutional support is reminiscent of the support received by other states during the Green Revolution, but rather than being a distant historical memory, the changes are fresh in the minds of Bihari farmers. This provides a modern opportunity to research the dynamics of a changing sociotechnical regime in the agricultural sector and in particular, the impact of the changing regime on the poorest farmers.

1.5 Challenges of Measuring Poverty

A project that focuses on the poorest farmers must, of course, grapple with defining and measuring the well-being of this group. There is tension between the use of *absolute* and *relative* measures of wealth, with tradeoffs between the power of *absolute* measures for cross-national and global comparisons, and the utility of *relative* measures, which are more sensitive to the particular dynamics of a community and what constitutes poverty locally (Kates and Haarmann, 1992). In the context of this study, a relative approach is more useful as it lends itself to qualitative approaches where poverty is seen within the context of the local circumstances facing each farming household. In the three papers in this dissertation, poverty is defined with respect to other households in each study and not with respect to national or global poverty levels.[5]

Beyond the decision about whether to define poverty in absolute or relative terms, the issue of measuring poverty can prove to be even more complex. In many countries, poverty thresholds are set based on income, but in India, robust data on household income is often unavailable. Instead, most scholars rely on measures of expenditure, which tend to provide inferior estimates of poverty (Sen and Drèze, 2013). However, both income and expenditure data are at best an approximate measure of a household's overall well-being. Neither income nor expenditure data captures assets, such as landholdings, health, education, or social networks, all of which contribute to a household's overall well-being, and circumscribe the set of capabilities and opportunities households face (Narayan, 1997; Sen, 1999; Dasgupta, 2000; Arrow *et al.*, 2012). Still, obtaining the necessary data, let alone overcoming the methodological challenges of creating equivalences across categories, makes using a single metric for

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[5] It is worth noting that in this dissertation, poverty is measured at the household level. This approach is appropriate for a study on agricultural systems, as the household is usually the unit of decision-making in smallholder agricultural systems. However, this approach to measuring poverty is certainly an incomplete picture of intra-household differences in access to resources which can be quite acute, especially in a South Asian context, where there is high intra-household inequality, especially for women and younger siblings (Jayachandran and Pande, 2015).

household well-being difficult. Instead, scholars are left to select appropriate proxies for household well-being, for the context of their studies.

In this paper, I use proxies for farmer well-being, and generally define the poorest farmers as the bottom quintile of the distribution in terms of the proxies I use. There are a number of proxies available for categorizing households by well-being indicators. One of the most common approaches used in the study of agriculture and technology is landholding size. A second and more comprehensive approach is to calculate the value of all household assets, as well as on-farm income and income from other sources (e.g. daily construction labor or remittances from household members who have migrated to other areas). Finally, in India, a frequent method for categorizing people into socioeconomic groups is based on their social caste.

While I attempted to measure all three proxy variables in the data collection process, I found that the data quality when comparing the qualitative findings from the primary village where I worked, with answers to survey questions collected by a survey team in the same village, was very poor. Respondents often tried to minimize their assets in the more formal survey, perhaps believing that their answers to the survey might give them access to government or NGO support if they appeared poor.[6] I suspect that the poor quality of responses to survey questions about assets and income plagued the entire data collection process in the 11 additional villages.[7] Ultimately, I decided that building a measure of well-being based on the asset stocks would not have been productive, because the quality of the data was too poor. Instead, I used both landholding and caste based proxies for classifying farmers by their relative wealth and

[6] One of the members of my survey team in Bihar reported a humorous anecdote: He was sitting outside a farmer's house while asking him about his household income and assets. As they talked, the farmer leaned on a tractor. When the surveyor came to the question of whether the farmer owned a tractor he replied that he did not. While the surveyor took the farmer at his word, after finishing the survey, he learned from multiple other households that the tractor indeed belonged to the farmer in question. Moreover, he earned substantial income by renting the tractor to other households.

[7] My belief is that the challenge of measuring household assets plagues almost all datasets and one should be extremely careful using aggregate household assets collected through surveys.

poverty, for the very practical reason that I trust the data. But there are also sound theoretical reasons for using caste and landholding size as proxies for well-being in this study.

In terms of landholding metrics, while farmers may possibly hide their landholdings, I found that in general, responses to this question were relatively accurate. Moreover, the size of a farmer's landholding has important implications for their decisions about technology adoption, that may not be captured by overall assets. For example, a household with relatively high assets but a small landholding (e.g. primary income from non-agricultural sources) is unlikely to be particularly concerned with maximizing the benefits from their agricultural production, and decisions about technology adoption may not be particularly insightful with respect to the question of access and benefits. Within the landholding approach, I am also able to include households that do not own their own land, but lease or sharecrop on other farmer's land. This can be particularly useful, especially for understanding the impacts of land tenure regimes on technology benefits.

In terms of caste metrics, farmers are not likely to disguise their caste in surveys. Indeed, I have never had an experience where a respondent was reticent to reveal their caste in rural India. Caste also continues to be an extremely important social marker in modern India. As Jean Drèze and Amartya Sen note, "India seems to be quite unique both in terms of the centrality of caste hierarchies and in terms of their continuing hold on modern society." Moreover, "caste stratification often reinforces class inequality, giving it a resilience that is harder to conquer" (Sen and Drèze, 2013). In the context of Bihar, and the lower caste mobilization of the 1990s under Lalu Prasad, caste turned out to be an even more salient marker of identity. Furthermore, caste continues to be highly correlated with other metrics of poverty (Borooah, 2005). More information on how I treat caste in this dissertation can be found in Appendix 1, where I also discuss monetary conversions to US dollars and Hindi-English translations used in the dissertation.

1.6 Chapter Overview

The three empirical studies included in this dissertation grapple with the overarching research question – why does technology fail to benefit the poorest farmers – from three different angles. Chapter 2 compares multiple technologies within a single geography, focusing on the barriers preventing the poorest farmers from realizing greater benefits from these technologies. Chapters 3 and 4 take deeper dives into two specific technologies touched on in the first paper. The third chapter focuses on a technology that has been labeled *a priori* a "pro-poor" technology – SRI. The fourth chapter looks at a single technology, drip irrigation, comparatively, across four Indian states. In this section, I summarize the questions asked, methods used and conclusions for each of the individual empirical chapters.

Chapter 2, '*What keeps the poorest farmers from benefiting from technology? A study of agricultural technology and poverty in Bihar, India*,' looks at the extent to which a range of technologies benefits the poorest farmers in a single state – Bihar, India. The chapter engages with a broad range of hypotheses explaining low agricultural productivity from a wide variety of literatures. The chapter examines these hypotheses, or sociotechnical causal mechanisms (STCM), not for their value in explaining low yields in general, but rather for their value in explaining barriers preventing the poorest farmers from realizing greater benefits from technology. This empirical chapter is included first in the dissertation because it most explicitly develops new methodological territory. Using both ethnographic research and survey data, I analyze the extent to which 11 sociotechnical causal mechanisms function as barriers causing the poorest farmers to (disproportionately) lose out on the benefits from technology. I find that that *missing infrastructure* and *misaligned incentives* are the primary sociotechnical causal mechanisms preventing the poorest farmers from realizing greater benefits from agricultural technology in Bihar.

Chapter 3, '*The System of Rice Intensification: The Challenges of Technology Selection for Meeting the Needs of the Poorest Farmers*,' focuses on a single technology, the System of Rice

Intensification (SRI), that emerged onto the global stage in the early 2000s, and whose proponents hoped would benefit poorest farmers in particular. The first part of the chapter looks at a dispute over the benefits of SRI, between different actors at the selection stage of the innovation system. This section of the paper demonstrates the challenges at the *selection* stage in prioritizing the needs of the poorest farmers over sociotechnical path dependence. These challenges include 1) propensity for silver bullet thinking; 2) failure to take into account variance and uncertainty in local conditions; 3) selection of technology based on institutional incentives not aligned with the needs of the poorest farmers (e.g. political and professional incentives). The second part of the chapter grounds the discussion of SRI in Bihar through ethnographic fieldwork and survey data, in order to bring greater clarity and nuance to the debate around SRI, and most importantly, to analyze *if*, *how,* and *under what conditions* SRI is a "pro-poor" technology, as many of its proponents claim. The chapter finds, that while the physical dimensions of SRI have the potential to benefit the poorest farmers, in the context of Bihar, relatively wealthier farmers are benefiting more from SRI than their poorest neighbors. The benefits of SRI are failing to reach the poorest farmers because of limited and expensive irrigation infrastructure, but also because the institutional design of the government support policy is not targeted at the poorest farmers. These findings demonstrate that even when the physical dimensions of technology are "pro-poor," realizing these benefits still requires reorienting the larger sociotechnical regime towards the needs of the poorest.

Chapter 4, '*Subsidies for Whom? Comparative Evaluation of India's Drip Irrigation Subsidy Program*,' looks across four states in India at programs that promote widespread use of a single technology: drip irrigation. These programs, together represent a modern and sustained effort by a wide range of actors to bring a new technology into widespread use. The effort to scale drip irrigation in India required the establishment of a broad institutional infrastructure, which included specific mechanisms to target the poorest farmers. Both the size of India's drip irrigation programs, as well as the explicit effort to ensure benefits to the poorest farmers, make drip irrigation in India a good case study for evaluating goal-oriented efforts to ensure the poorest farmers benefit from technology. The paper demonstrates that India's drip irrigation subsidy program was able to leverage both public and private sector strengths to achieve widespread use of drip irrigation across multiple states in India. But, despite inbuilt institutional mechanisms to target the poorest, the program largely failed to benefit this group. The failure of the drip irrigation subsidy program to benefit the poorest farmers was due to both institutional and technical dimensions of the technology. On the institutional side, the design of the subsidy program attempted to generate demand from the poorest farmers by offering larger subsidies to this group, but the program failed to offer the private sector equipment dealers, responsible for marketing and sales, their own incentives to engage with the poorest farmers. Rather, the private sector dealers incurred greater overall costs in terms of their time and earnings when working with the poorest farmers. As a result, the poorest farmers failed to learn about the technology or the availability of a substantial subsidy to help them afford it. On the technical side, the subsidy program excluded low-cost irrigation systems in the standards set by the guidelines of the program. While low cost drip irrigation systems had gained traction in some parts of the country prior to the introduction of the subsidy program, the subsidy program pushed these technologies out of the available technology space, in favor of more expensive designs. The failure of the subsidy program to include low-cost drip irrigation kits negatively impacted the poorest farmers, by driving this type of technology out of the innovation system of the major drip irrigation companies. The paper demonstrates the strengths of leveraging the private sector in last-mile technology delivery, but also the difficulty of ensuring that the needs of the poorest farmers are met in public-private programs in the agricultural sector. I ground the policy conclusions of this chapter in emerging innovation systems literature on the role of government in market-creation, arguing that the government's drip irrigation subsidy program can be scrutinized as a large-scale effort to support the emergence of a new market and industry. From a policy perspective, given the large publicly funded investment in market-creation, I argue that the government should demand more from the private sector in return for its investment. In particular, the subsidy program should be re-written so that the incentive structures created by the program ensure that the poorest farmers realize greater benefits from the technology. The government can do this by offering specific financial incentives to the private sector equipment dealers for working with the poorest farmers, and by limiting the availability of the subsidy for medium and larger farmers.

1.7 Overall Findings: Relevance for Policy and Scholarship

All three chapters in this dissertation diagnose a common problem: The benefits of technology under current sociotechnical regimes in Bihar (and in the case of drip in India more broadly) are often not being realized by the poorest farmers. Failure of technology to benefit the poorest farmers is neither exclusively a consequence of the physical nor the institutional dimensions of technology. Ensuring technological innovation meets the needs of the poorest is not *just* about getting the physical dimensions of technologies right, nor is it *just* about getting the institutional dimensions right. Rather, an alignment between the physical and institutional dimensions of technology and local context is required—an alignment that is goal-oriented towards the needs of the poorest.

I find that this kind of goal-oriented alignment, towards the needs of the poorest, is difficult to achieve even when it is an explicit goal of powerful actors in the innovation system (which it often is not). For example, in my drip irrigation study, despite the government's concern for the poorest farmers, as demonstrated by the higher subsidies for this group, the criteria embedded in the subsidy policy selected for high cost drip irrigation technologies, at the expense of low-cost versions of the technology that were more appropriate for the poorest farmers. In a second example, in my study of the System of Rice Intensification in Bihar, the government selected the technology specifically because of its "pro-poor" physical dimensions and put substantial financial and institutional resources behind promotion of the technology. Yet, while the physical dimensions of the technology were aligned to benefit the poorest farmers, the high cost of irrigation in Bihar, poorly run extension services, and the ineffective design of the subsidy policy, led to the benefits of SRI being skewed towards wealthier farmers. Finally, in a third example of solar irrigation pumps (SIP) (one of the technologies studied in detail in the Chapter 2), my work shows that both the physical and institutional dimensions of the technology were not aligned to benefit the poorest farmers. On the physical side, the design of the SIPs offered no flexibility for switching to diesel power when solar radiation was limited (at night or during fog). On the institutional side, multiple factors, including poor promotion of the subsidy scheme to the poorest farmers, combined with bureaucratic corruption, restricted the benefits of the technology to wealthier farmers. This outcome of the SIP case in Bihar was particularly unfortunate, because the physical dimensions of the technology have the potential to bring relatively more benefits to the poorest farmers, who tend to live farthest from electrical grids. In other words, SIP could be a specifically "pro-poor" technology, under the right circumstances. In Bangladesh, for example, careful design of both the physical and institutional dimensions of SIP led to substantial benefits for the poorest (ICIMOD, 2015).

The implications of my core finding – that to benefit the poorest farmers an alignment is required between the sociotechnical dimensions of technology and the needs of the poorest farmers – is that the vast majority of remedial measures that focus exclusively on one or the other dimension of technology are unlikely to work. Thus, ensuring the poorest farmers benefit from agricultural technologies requires shifts in the entire sociotechnical regime. My conclusion contradicts both the appropriate technology literature and the institutional development literature in important ways. The appropriate technology literature highlights the importance of the physical dimensions of technology for increasing benefits to the poorest farmers (e.g. Timu *et al.*, 2014; Chekene and Chancellor, 2015). The institutional development literature focuses on removing barriers the poorest farmers face by improving market linkages, fixing land tenure regimes, and improving access to rural credit (e.g. Place and Otsuka, 2002; Jayne, Mather and Mghenyi, 2010; Ololade and Olagunju, 2013). My findings do not reject the importance of the specific findings in each of these literatures. Instead, I argue that the challenge is that under most circumstances focusing on any one of these issues in isolation is not effective. Rather, I conclude that a systems approach that takes into account a wide-range of sociotechnical dimensions of technology and their fit to local context, is essential to ensuring that the poorest farmers benefit from technological innovation.[8]

My findings both confirm and extend previous work in sociotechnical transitions literature, as discussed in Section 1.2.3 (Geels, 2002, 2004). The sociotechnical transitions literature argues that in order for new technological innovations to achieve scale, they need to overcome barriers in path dependency created by both incumbent physical technologies, and social and institutional systems that have developed alongside them. Sociotechnical transitions are thus seen as systems innovations which involve several different physical technologies, in conjunction with institutional change by a diversity of actors (Steward, 2012). In other words, the sociotechnical transitions literature argues that for any new technology to reach *widespread use*, an alignment between the physical dimensions and the institutional dimensions of technology(ies) is required. Likewise, a "transition" toward innovation systems that benefit the poorest requires changes in the evolutionary pathway of agricultural technologies, that ensure both the physical and institutional dimensions of technologies are designed in ways that the poorest can extract more well-being from their *widespread use.*

By identifying the importance of the alignment between physical and institutional dimensions of technology and their fit to local context, my work confirms the findings of the sociotechnical transitions literature. At the same time, my work extends the sociotechnical transitions literature in two ways. First, I apply sociotechnical transitions concepts to cases in the developing world where empirical work in this

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[8] A question this finding raises is whether the need for "fit" between the sociotechnical dimensions of technology and local context is specific to the challenge of ensuring the poorest farmers benefit from technology, or rather generalizable as a criterion for success for widespread use of technology more broadly? My instinct is that the answer is both. While the broader MLP literature has already pointed to the importance of "fit" in innovation systems, there is likely an added challenge to this problem when addressing the needs of the poorest farmers who have fewer capabilities and resources to create this alignment for themselves.

literature is sparse. Second, I extend this literature to look at the impacts of technological innovation across socioeconomic groups, something that to the best of my knowledge has not been done before.

Several more specific findings from this dissertation offer insights into particular strategies for orienting agricultural innovation systems towards the needs of the poorest.

First, making improvements to current sociotechnical regimes that will more effectively benefit the poorest requires context specific understanding of the sociotechnical and agroecological opportunities and constraints facing this sub-group of farmers. Chapter 2 looks at the most important barriers preventing the poorest farmers from realizing greater benefits from technology in Bihar. The study finds that many institutional solutions to improving farmer well-being identified in the literature, fail to address the biggest barriers preventing the poorest farmers from accruing greater benefits from technology in Bihar. For example, in the context of Bathani village, market access was not a significant barrier preventing the poorest farmers from benefiting from technology. For this reason, focusing on policies that improve market access in Bihar may have the effect of incentivizing technology investments by wealthier farmers, raising overall yields, but increasing intra-village or intra-regional inequality. To help the poorest farmers in Bathani, government resources would be better spent improving access to infrastructure, such as electricity and water for irrigation.[9] This example demonstrates how making an effective improvement to a sociotechnical regime that benefits the poorest, requires context-specific understanding of barriers and opportunities the poorest farmers face. Generalized solutions (e.g. market access) that do not take

[9] Infrastructure is usually considered a public good (one that is both non-excludable and non-rivalrous). In this sense, I argue that pro-poor investments by the government share much in common with investments in public goods. At the same time, my research problematizes the notion of public goods by demonstrating that not all goods are usually categorized as 'public' are truly public goods. For example, while roads in Bihar function as truly public goods that are both non-excludable and non-rivalrous, both electricity and irrigation infrastructure often do not live up to the definition of pure public goods. This raises a question for the public goods literature to look more carefully at the extent to which goods we assume are public goods actually exhibit the key characteristic of public goods, especially with respect to the needs of the poorest. There is a large literature that more critically reflects on the notion of public goods especially at the global scale (Kaul *et al.*, 2003). The challenge of ensuring public goods benefit the poorest can be fruitfully put into conversation with this literature.

account of local conditions not only will not work, but may even create bigger gaps between the poorest farmers and their wealthier neighbors.

Second, institutions structuring the incentives of actors in the innovation system need to be designed to ensure the poorest farmers benefit from agriculture technology. For example, in my three case studies, we see that government actors had limited success in last-mile technology delivery. Institutional structures, which pair government support with private sector and NGO actors acting as "last mile" intermediaries, were significantly more successful at connecting the farmers with physical technologies. Whether or not these partnerships benefit the poorest farmers, depends on how the incentive structures for the different actors in the innovation system are arranged. In the case of drip irrigation, the institutional design of the subsidy program incentivized the private sector to take over the responsibilities for technology promotion but offered little incentive for the private sector to promote the technology to the poorest farmers. In contrast, NGOs, whose mission is explicitly targeted at the poorest farmers, have had far greater success promoting SRI amongst the poorest farmers in Bihar.

Third, when powerful actors in the innovation system fail to specifically take the circumstances and objective functions of the poorest farmers into account, the poorest farmers are almost always excluded from the benefits of technological innovation. In the case of SRI, the failure of the transnational innovation system to respond with more humility to a technology that claimed to benefit the poorest, demonstrates the failure of the agricultural innovation system to systematically prioritize the needs of the poorest farmers. Changes in the goals of agricultural research will require a systematic shift in the institutional culture of many research organizations, to include a greater sensitivity towards the distributional impacts of their research.

My findings demonstrate that there is significant scope to reorient innovation systems to bring greater benefits to the poorest. Through the chapters in the dissertation I demonstrate the importance of alignment between the institutional and physical dimensions of technology with local context, but also the roles that actors in the innovation system play in either fostering or blocking such alignment. Mobilizing technology to meet the SDGs and reducing global poverty, will require sustained efforts by actors in the innovation system, to change the institutions structuring incentives across stages of the system. This will require embedding distributional concerns as a topic for research and action across sectors and levels of agricultural innovation systems.

CHAPTER 2: What keeps the poorest farmers from benefiting from technology? A study of agricultural technology and poverty in Bihar, India

2.0 Abstract

While poorest farmers almost certainly enjoy the fruits of the plough and the hoe, whether and under what conditions modern agricultural technologies such as high yielding seed varieties, drip irrigation, or new cultivation practices benefit the poorest farmers, is an important empirical question. This chapter focuses on the barriers preventing the poorest farmers from realizing greater benefits from agricultural technologies. Using a sociotechnical approach which conceptualizes technology as inextricably linked to the institutional systems necessary for scale (Brooks, 1980), this chapter uses a mix of ethnographic research and survey data to study the sociotechnical causal mechanisms (STCMs) preventing the poorest farmers from realizing greater benefits from technology in Bihar, India. The chapter finds that in the context of Bihar, the primary STCMs preventing the poorest farmers from benefiting from agricultural technology are missing infrastructure and misaligned incentives. The STCMs that play a lesser role in preventing the poorest farmers from benefiting from agricultural technology include lack of individual farmer capacity, weak capacity for collective action, and missing market linkages. While these findings are specific to the context of Bihar, the paper offers a novel framework for studying the impact of technology on poverty that can be used across contexts. Methodological approaches such as the one used in this paper are important for ensuring that the poorest and most vulnerable groups are served by the global innovation systems across sectors from agriculture to energy to healthcare.

2.1 Introduction: Rural Poverty and Agricultural Technology Innovation

The importance of technological innovation to agricultural productivity is well established (Ruttan, 1977; Hamilton and Sunding, 1998; Sunding and Zilberman, 1999). Yet the poorest farmers, especially in the developing world, often miss out on the benefits of technological innovation. Indeed, concerns about the relationship between agricultural technology and poverty are not new. A study of the introduction of groundwater irrigation during the Green Revolution in a village in Gujarat, India, demonstrated that the new borewells benefited wealthier farmers, while failing to benefit the poorest. Moreover, the introduction of borewells had multi-generational social and economic implications for both the farmers who adopted borewells, and those who did not (Prakash, 2005).

More generally, new technologies that increase yields may benefit early adopters while leaving late adopters and non-adopters facing lower market prices without the gains from increased yields (Cochrane, 1993).[10] In the case of borewells in Gujarat, the benefits to early adopters set the early adopters on a fundamentally different economic course than their neighbors, with divergent socioeconomic outcomes even for future generations (Prakash, 2005). Despite these concerns about the impact of technology on the poorest, agricultural technology is a critical factor in improvements in agricultural yields (Fischer, Byerlee and Edmeades, 2009), and multiple macroeconomic studies suggest that growth in the agricultural sector is significantly more effective than other types of economic growth at reducing poverty (Virmani, 2008; Raff and Wagner, 2013). The tension between the role of technology in raising average incomes, and the role of technology increasing inequality raises an important empirical

[10] Willard Cochrane in his 1993 book on the history of American agriculture, argued that the equilibrium gains of agricultural technology adoption accrue to the consumer and not the producer. While earlier adopters of new yield improving or cost lowering agricultural technologies can make a profit, as more farmers adopt the technology, free market commodity prices fall so the earlier adopters as well as the late adopters are no better off than they were before. The real losers Cochrane argues, are the laggards who never adopt the technology at all, yet suffer from lower commodity prices despite no improvements in their yields or reductions in their costs (Kislev and Shchori-Bachrach, 1973; Cochrane, 1993).

question: What are the barriers preventing the poorest farmers from realizing greater benefits from agricultural technologies?

The answer to this question is important, not only to the poorest farmers themselves, but to governments concerned with improving the well-being of their poorest citizens, and to members of the development community concerned with reducing the extent of global poverty and improving household food security. Agrarian households account for 80% of the world's extreme poor (income of less than 1.90 USD per person per day). These households simultaneously produce food and suffer from food insecurity (Kharas *et al.*, 1994; Castañeda *et al.*, 2016). By overcoming barriers to technology access for the poorest farmers, national and local governments and the development community can reduce poverty and improve food security.

This chapter looks at the barriers preventing the poorest farmers from realizing greater benefits from agricultural technologies in Bihar, India (see map, Figure 2.1).

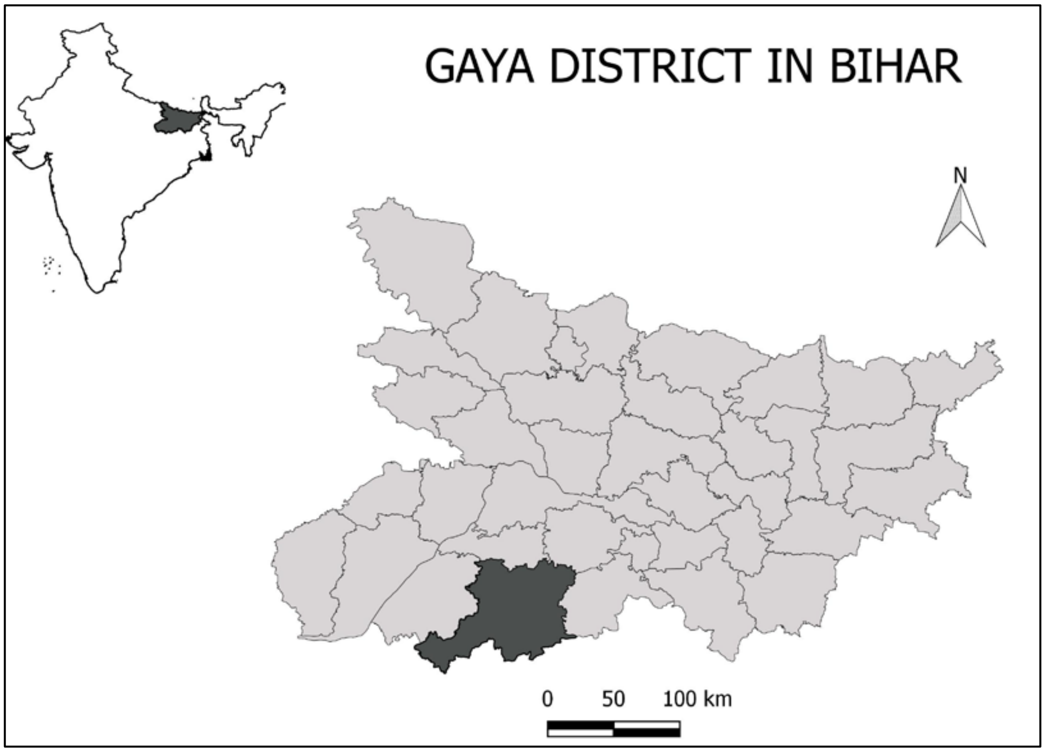

Figure 2.1: Map of Bihar

The map locates the State in the northeastern region of India with a northern land boarder to the plains of Nepal. Map highlights Gaya district in South Bihar where the primary field site is located. Note Bihar is landlocked, bordered by Nepal to the North, West Bengal to the East, Jharkhand to the South, and Uttar Pradesh to the West. A very think strip of West Bengal separates Bihar from Bangladesh.

I structure the rest of this chapter as follows:

- In Section 2.2, I discuss the sociotechnical approach I will use throughout the rest of the chapter. The sociotechnical approach highlights the importance of both the physical and institutional dimensions of the technology in understanding innovation systems. I also identify a set of hypotheses or "sociotechnical causal mechanisms" (STCMs) from the literature, which I use to elucidate the intertwined physical and institutional reasons why some technologies benefit the poorest farmers more than others. I use this set of STCMs in Section 2.6 as a structured approach for analyzing the underlying mechanisms preventing the poorest farmers from benefiting from technology in each case study.

- In Section 2.3, I develop a methodological approach to the study of technology benefits in the agricultural sector. I argue that a revealed preference approach is the best methodology for measuring benefits of technology to farmers. The revealed preference approach, while imperfect, is superior to more commonly used yield or profit metrics. While a full assessment of changes in well-being is the holy grail for measuring benefits from technology, this remains methodologically difficult and a revealed preference approach is the best methodologically feasible approach.
- In Section 2.4, I discuss the historical, political, economic and agro-ecological forces in Bihar that shape the context of the research.
- In Section 2.5, I describe the data and go into more nuanced ethnographic detail of the primary field site in south Bihar.
- In Section 2.6, I use a purposeful selection methodology to select six technology case studies. Section 2.6.1 through 2.6.6 details each of the six case studies using the sociotechnical approach and STCMs.
- In Section 2.7, I discuss my findings focusing specifically on the extent to which each of the 11 SCTMs is a barrier across case studies in preventing the poorest farmers from realizing greater benefits from agricultural technologies.
- In Section 2.8, I conclude with a discussion of the implications of my findings. I discuss the methodological contribution of the chapter to the study of technology, as well the implications of the findings for policy aimed at strengthening the contribution of technology to achieving the Sustainable Development Goals (SDGs).

2.2 Theory: A Sociotechnical Approach

2.2.1 The Sociotechnical Nature of Technology Innovation

This chapter uses the sociotechnical approach discussed in Chapter 1 to investigate the underlying causal mechanisms that prevent the poorest farmers from benefiting from agricultural technologies. For purposes of clarity, I review the sociotechnical approach briefly here. I treat technology not as individual widgets, but as assemblages of artifacts and practices which are inextricably linked to the institutions and actors that undergird the complex processes linking invention with widespread use. Borrowing from Harvey Brooks, I argue that technology is best understood by its function than its physical embodiment in artifacts. Using a functional definition of technology means that it is necessary to conceptualize technology differently and include not only the physical aspects of technology but also "social supporting systems necessary to apply it [technology] on significant scale" (Brooks, 1980).

Thus, to move a technology (whether an artifact or a practice) through an innovation system from *invention* to *widespread use*, requires effective social systems that support the innovation process. A sociotechnical approach widens the lens of technology adoption research to include the social supporting systems fundamental to *widespread* technology adoption and allows for identification of barriers to technology adoption that go beyond the attributes of the technologies themselves to the roles of actors and institutions in both creating and overcoming barriers (Anadon *et al.*, 2016).

The chapter elucidates the intertwined physical and institutional reasons why some technologies benefit the poorest farmers more than others. The research design for this chapter is perhaps the most novel of the three empirical chapters in the dissertation. Rather than using the sociotechnical approach to study a single technology across regional contexts, I focus on a single region and analyzes the barriers preventing the poorest farmers from benefiting from a set of six technologies. By looking across a range of technologies, I identify the most important sociotechnical barriers that prevent the poorest farmers from realizing greater benefits from technology in Bihar.

In order to use the sociotechnical approach, precise language to differentiate between the physical and institutional components of technology is required. To refer to the aspects of technology imbedded in the physical artifacts or practices, I use the term "physical dimensions" of the technology or sometimes simply "the physical technology." The physical dimensions of technology may include technical aspects of design, such as the specifications of an electric pump or irrigation system. Physical dimensions of a technology also include the agronomic practices associated with the system of rice intensification (SRI).

To refer to the social aspects of technology, I use the term "institutional dimensions". Institutions are the rules and norms as well as culture and beliefs that together make up the social supporting systems necessary to apply the physical dimensions of the technology at scale (North, 1990; March and Olsen, 2009). Institutional dimensions include for example, government subsidy programs which change the price of a physical technology that farmers face. However, a given subsidy institution may have specific rules that dictate who is eligible for the subsidy including requirements like socioeconomic status, the availability of land-title documents or other requirements that limit the benefits of the technology to some farmers over others. There may also be more informal norms associated with the subsidy program. For example, extension officers responsible for the program may expect farmers to approach them in their offices to receive the subsidy with some kind of bribe or kick-back. In contrast, an alternate set of norms may send extension officers to the village to advertise the availability of the subsidy program and target their outreach at the poorest communities. The institutional dimensions of technology also include cultural norms, such as the relationships between different social castes in a village that mediate how information about physical technology flows between farmers or how farmers engage in collective action behavior around a specific physical technology.

Of course, the physical and institutional dimensions of technologies interact in complex ways. Two physical technologies that achieve similar goals (e.g. irrigation for a crop) may use different quantities of water (e.g. drip irrigation vs. flood irrigation). In this context, the institutional dimensions which impact the local price of water may influence the benefits farmers realize from using each of the two physical technologies, which in turn may influence their ultimate choice about technology adoption and use. If an institutional change, such as a new electricity subsidy, changes the price of water, the institutional dimensions of both drip and flood irrigation will change. It is this interaction between the institutional and physical dimensions of each technology that will change the relative benefits of the two technologies to farmers.

In this chapter, I evaluate both the physical and institutional dimensions of technology to understand the degree to which different sociotechnical barriers prevent the poorest farmers from accruing greater benefits from technology. Using this logic, a technology may not benefit the poorest because the design of the physical dimensions does not meet the needs of the poorest farmers (perhaps because the technology is not useable on smaller landholdings). A technology may also not benefit the poorest, because the institutional dimensions of the technology skew benefits to wealthier farmers and away from the poorest farmers. For example, a technology may require advanced skills that the poorest farmers have a limited ability to acquire, due to poor educational systems in a given context. Alternatively, the institutional dimensions influencing the price of the technology may make the initial capital investment too high for the poorest farmers to afford.

Both the physical and institutional dimensions of technology interact and are influenced by the particularities of a given context including the local social, political, economic, infrastructural and agroecological conditions. Together, the particularities of a given context can be thought of as the sociotechnical *regime*, which includes the local biophysical conditions (such as land quality, climate, biodiversity) as well as the local sociotechnical conditions, comprised of institutions (including rules, norms, culture, and beliefs) that structure and pattern the innovation system in a given context. Sociotechnical *regimes* are usually stable and do not change easily because they are structured by "semi-coherent" and often unnoticed "set of rules that guide, orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems" (Geels, 2011, p. 5).[11]

2.2.2 Sociotechnical Causal Mechanisms (STCMs)

There are both biophysical as well as sociotechnical reasons why a specific farmer on a specific plot of agricultural land might realize fewer benefits than another farmer on the same plot of land or another farmer on a different plot of land. On the biophysical side, agronomists have a relatively clear understanding of the factors affecting yields including varietals of crops; planting and harvest dates; seed density and spacing; water management; sunlight and temperature requirements; macro and micro nutrients; soil conditions; weeds; diseases and pests; and atmospheric pollutants (Mueller and Binder, 2015). On the sociotechnical side, the causal mechanisms and the relationships between them are more poorly understood. Agricultural economics and development studies are replete with studies that detail particular causal mechanisms. These include inappropriate technology for smallholder farmers and developing country contexts; market failure including poor market linkages between small farmers and regional, national and global commodity markets; poor and missing infrastructure such as roads, irrigation canals and electricity; poor state-led extension services and other knowledge support services; lack of farmer capacity including poor education, health and nutrition; missing or weak farmer organizations or a lack of capacity for collective action on the part of farmers; missing or ineffective land tenure regimes that increase risk for small farmers; poor public policy design; and corruption. Please see Table 2.1 for definitions of 11 STCMs taken from a wide range of literatures in addition to an annotated bibliography of supporting literature for each STCM in Appendix 3.

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[11] Note that in the context of sociotechnical regimes shares much in common with the concept of social-environmental systems (SES) discussed in the Sustainability Science literature.

Table 2.1: Definitions of STCMs and selected supporting literature.

Sociotechnical Causal Mechanisms (STCMs)	Definition	Supporting Literature
1. Lack of financial assets	Lack of sufficient or capital or purchasing power to invest in agricultural technologies.	• Banerjee *et al*. 2014. "Understanding biophysical and socioeconomic determinants of maize (Zea mays L.) yield variability in eastern India." • Dao *et al*. 2015. "Identifying farmers' preferences and constraints to maize production in two agro-ecological zones in Burkina Faso." • Duflo *et al*. 2011. "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya." • Kishore. 2004. "Understanding Agrarian Impasse in Bihar." • Yengoh. 2012. "Determinants of yield differences in small-scale food crop farming systems in Cameroon."
2. Inappropriate technology design	Lack of "fitness for purpose" of available technologies. The appropriateness of technology design will likely vary by region and perhaps by other farmer level characteristics such as landholding size, access to water and electricity	• Chekene & Chancellor. 2015. "Factors affecting the adoption of improved rice varieties in Borno State, Nigeria." • Timu *et al*. 2014. "The role of varietal attributes on adoption of improved seed varieties: The case of sorghum in Kenya."
3. Missing market linkages	Poor market linkages can limit the price farmers receive for their crops, limiting their willingness to invest their capital in technology to raise yields	• Jagwe, Machethe, & Ouma. 2010. "Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda, and the Democratic Republic of Congo." • Jayne, Mather, & Mghenyi. 2010. "Principal challenges confronting smallholder agriculture in Sub-Saharan Africa." • Markelova *et al*. 2009. "Collective action for smallholder market access." • Pradhan *et al*. 2015. "Closing yield gaps: How sustainable can we be?"

Table 2.2 (Continued)

Sociotechnical Causal Mechanisms (STCMs)	Definition	Supporting Literature
4. Lack of access to credit	Limited availability of credit to farmers or insufficient provisions in credit programs to help the poorest farmers with limited collateral access credit.	• Olagunju & Ajiboye. 2010. "Agricultural lending decision: A tobit regression analysis." • Ololade & Olagunju. 2013. "Determinants of access to credit among rural farmers in Oyo State, Nigeria." • Phillip *et al*. 2009. "Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6)." • Kochar. 1997. "Does Lack of Access to Formal Credit Constrain Agricultural Production? Evidence from the Land Tenancy Market in Rural India."
5. Missing Infrastructure	Limited road and other transportation networks; limited or missing electricity supply; limited surface irrigation.	• Gajigo & Lukoma. 2011. "Infrastructure and agricultural productivity in Africa." • Inoni & Omotor. 2009. "Effect of road infrastructure on agricultural output and income of rural households in Delta State, Nigeria." • Narayanamoorthy & Hanjra. 2006. "Rural infrastructure and agricultural output linkages: A study of 256 Indian districts." • Tunde & Adeniyi. 2012. "Impact of road transport on agricultural development: A Nigerian example."
6. Ineffective extension services	Under provision of state led extension services and other knowledge support services either due to insufficient numbers of extension agents or ineffective organizational design and implementation of extension programs	• Baloch & Thapa. 2016. "The effect of agricultural extension services: Date farmers' case in Balochistan, Pakistan." • Davis *et al*. 2010. "Impact of farmer field schools on agricultural productivity and poverty in East Africa." • Zhang *et al*. 2016. "Closing yield gaps in China by empowering smallholder farmers."
7. Lack of individual farmer capacity	Limited access to education and poor quality of education, poor health care facilities, hunger and even poverty can decrease the individual capacity of farmers	• Alene & Manyong. 2007. "The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: An endogenous switching regression analysis." • Croppenstedt & Muller. 2000. "The impact of farmer's health and nutritional status on their productivity and efficiency." • Mani et al. 2013. "Poverty impedes cognitive function". • Narayanamoorthy & Hanjra. 2006. "Rural infrastructure and agricultural output linkages: A study of 256 Indian districts." • Yengoh. 2012. "Determinants of yield differences in small-scale food crop farming systems in Cameroon."

Table 2.3 (Continued)

Sociotechnical Causal Mechanisms (STCMs)	Definition	Supporting Literature
8. Weak capacity for collective action	Weak capacity for collective action impacts the ability of communities either to work together to maintain shared resources such as irrigation systems or to establish collective bargaining power with other actors such as government policy makers. The capacity for collective action in farmer communities is often channeled through farmer organizations such as cooperatives and self-help groups and when these organizations are missing, farmers are forced to bargain individually significantly diminishing their power.	• Jagwe, Machethe, & Ouma. 2010. "Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda, and the Democratic Republic of Congo." • Markelova *et al*. 2009. "Collective action for smallholder market access". • Otieno. 2012. "Impact of farmer groups on crop enterprise productivity and economic welfare of smallholder farmers in South Kivu territories, Democratic Republic of Congo." • Thorp *et al*. 2005. "When and How Far is Group Formation a Route Out of Chronic Poverty?"
9. Structure of land tenure regimes	Lack of formal land tenure regimes as well as poorly informed land tenure laws create uncertainty on the part of farmers and limit investments in agriculture.	• Banerjee *et al*. 2014. "Understanding biophysical and socioeconomic determinants of maize (Zea mays L.) yield variability in eastern India." • Donkor & Owusu. 2014. "Effects of land tenure systems on resource-use productivity and efficiency in Ghana's rice industry." • Henao & Baanante. 2006. "Agricultural production and soil mining in Africa: Implications for resource conservation and policy development." • Phillip et al. 2009. "Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6)." • Place & Otsuka. 2002. "Land tenure systems and their impacts on agricultural investments and productivity in Uganda.

Table 2.4 (Continued)

Sociotechnical Causal Mechanisms (STCMs)	Definition	Supporting Literature
10. Misaligned incentives	Institutional structures embedded in government, NGO and private sector led programs whether intentionally or unintentionally fail to provide the right incentives for farmers (or subgroups of farmers) to invest in agricultural technology. (**Note that this dissertation finds this STCM to be very important in explaining differential benefits across socioeconomic groups of farmers. However, there is minimal additional research looking at this specific causal mechanism. Perhaps because it requires a multi-level perspective rather than only a field based perspective)*	• McCullough & Matson. 2012. "Linking knowledge with action for sustainable development: A case study of change and effectiveness." • Mukherji, Aditi. 2006. "Political ecology of groundwater: the contrasting case of water-abundant West Bengal and water-scarce Gujarat, India." • Songco. 2002. "Do rural infrastructure investments benefit the poor? Evaluating linkages: A global view, a focus on Vietnam." • Phillip et al. 2009. "Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6)."
11. Corruption and Security	Corruption and violence increase uncertainty and risks and transaction costs for farmers and other actors in the agriculture system. This hampers investment in technology and decreases yields.	• Anik *et al*. 2011. "The impact of corruption on farmers' efficiency in rice production: A natural experiment from Bangladesh." • Bromley & Foltz. 2011. "Sustainability under siege: Transport costs and corruption on West Africa's trade corridors." • Fulginiti *et al*. 2004. Institutions and agricultural productivity in Sub-Saharan Africa. • Mandemaker *et al*. 2011. "The Role of Governance in Agricultural Expansion and Intensification: A Global Study of Arable Agriculture." • Ministry of Agriculture. 2006. "Agriculture governance in Bangladesh: A survey of six *thanas*." Agriculture Sector Review, Ministry of Agriculture, Government of Bangladesh, Dhaka.

Figure 2.2 shows the relationship between the biophysical causal mechanisms (BPCM), sociotechnical causal mechanisms (STCM), and variance in the benefits the poorest farmers realize from technology. The figure shows that both sociotechnical and biophysical mechanisms can directly impact the amount of "well-being" farmers realize from their agriculture.[12] Nevertheless many of the impacts of both BCPM and STCM are mediated through farmers' technology use. For example, insufficient water (BPCM 3) can in many cases by ameliorated through the use of a technology such as drip irrigation which increases water use efficiency (WUE), thereby making more efficient use of limited water resources.

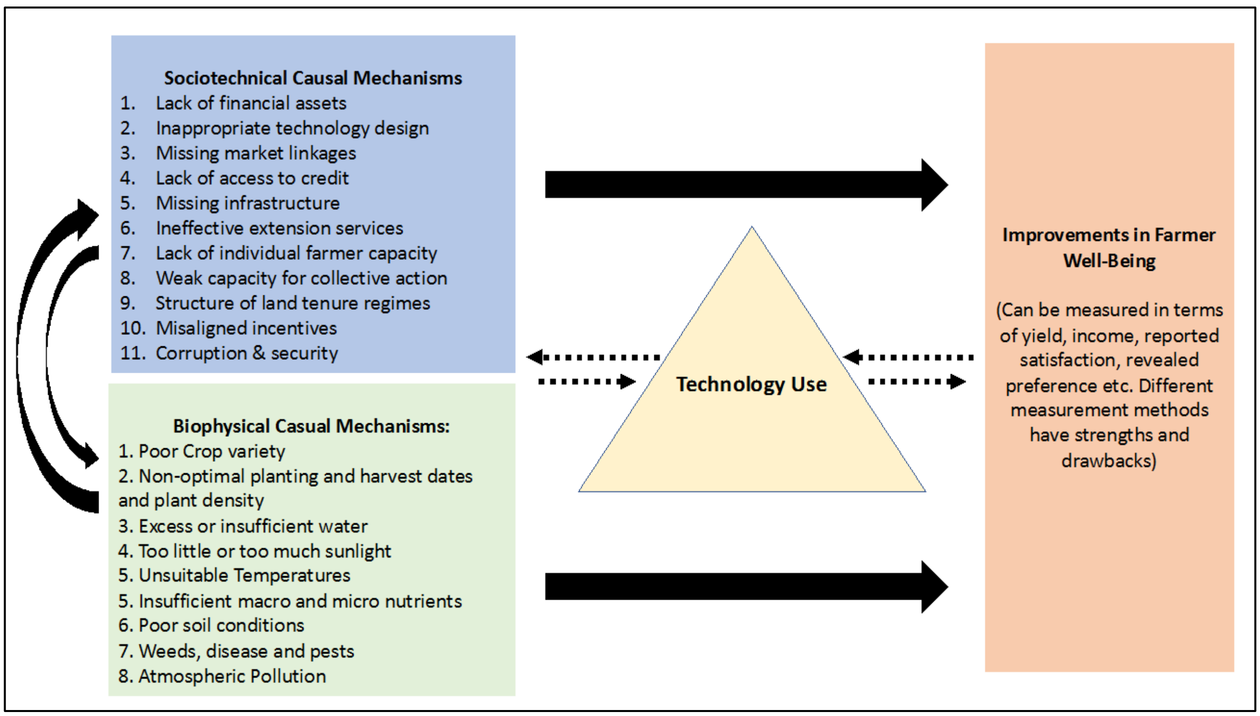

Figure 2.2: Relationship between causal mechanisms, technology use, and farmer well-being.

[12] Note, here I use well-being as the most accurate conceptual definition of what I am interested in measuring as "benefits". The concept of well-being has broad support in the sustainability science literature (e.g Stiglitz, Sen and Fitoussi, 2009; Arrow *et al.*, 2012; Matson, Clark and Andersson, 2016). In Section 2.3, I will clarify my empirical approach to measuring benefits – the revealed preference approach.

These sociotechnical causal mechanisms (STCM) are interwoven and create complex feedback loops both between themselves and with biophysical causal mechanisms (BPCM). For example, missing and ineffective land tenure regimes (STCM 9) increase risk for farmers. This can cause them to invest fewer resources into high yielding seed varieties or fertilizer (BPCM 1 and BPCM 5) thereby reducing yields. Reduced yields lead to food insecurity and reduced profits which hamper investments in education, health and nutrition (STCM 7), which can further deepen the cycles of poverty and low yields.

As seen in the previous example, an intermediate variable connecting each causal mechanism with low yields is technology. Lack of access to credit (STCM 3) prevents farmers from investing in yield improving technology, thereby keeping yields lower than they would have been if credit were more widely available. Reversing the direction of causality, poverty and food insecurity caused by low yields and crop failure, has been shown to decrease farmer cognitive capacity (STCM 7) and diminish farmer ability to adopt new technologies and practices (Mani *et al.*, 2013).

This chapter focuses on one part of this complex relationship – the relationship between the sociotechnical causal mechanism, technology use, and farmer well-being. The chapter is particularly concerned with sociotechnical barriers preventing the poorest farmers from realizing benefits to their well-being from technology use.

2.3 Methods: Revealed Preference Approach

This section argues that for the purposes of the research question, the best way to estimate the benefits that farmers realize from specific technologies is through their own revealed preferences rather than through empirical calculations based on the contribution of specific technologies to yield increases or profit margins. In Section 2.6 I demonstrate significant variance in use of technology across socioeconomic groups of farmers. In almost every case, the poorest farmers are less likely to use a technology than their wealthier peers, but the factor by which the poorest farmers are less likely to use a technology differs significantly between cases. In this section, I argue that treating sustained use of technology as a measure of benefits is the best approach to the study of technology and poverty.

As discussed in Chapter 1, the population of interest in this chapter are the poorest farmers measured in terms of both landholding and caste. This means that technologies are evaluated for their benefits to the poorest farmers, irrespective of their impacts on inequality. The two categories of technologies that meet these criteria are "pro-poor technologies" that benefit the poorest more than other groups as well as technologies that "raise all boats" but may still increase inequality by benefiting wealthier farmers relatively more than the poorest. The other two categories of technologies discussed in Chapter 1 are "technologies for the rich" which have few if any benefits for the poorest and "bad idea" technologies which at least in a specific context (geography or historical time period) offer limited to no benefits across socioeconomic groups. (See Figure 2.3 for the two by two matrix; see Chapter 1, Section 1.3.1 for detailed discussion of the four conceptual categories.)

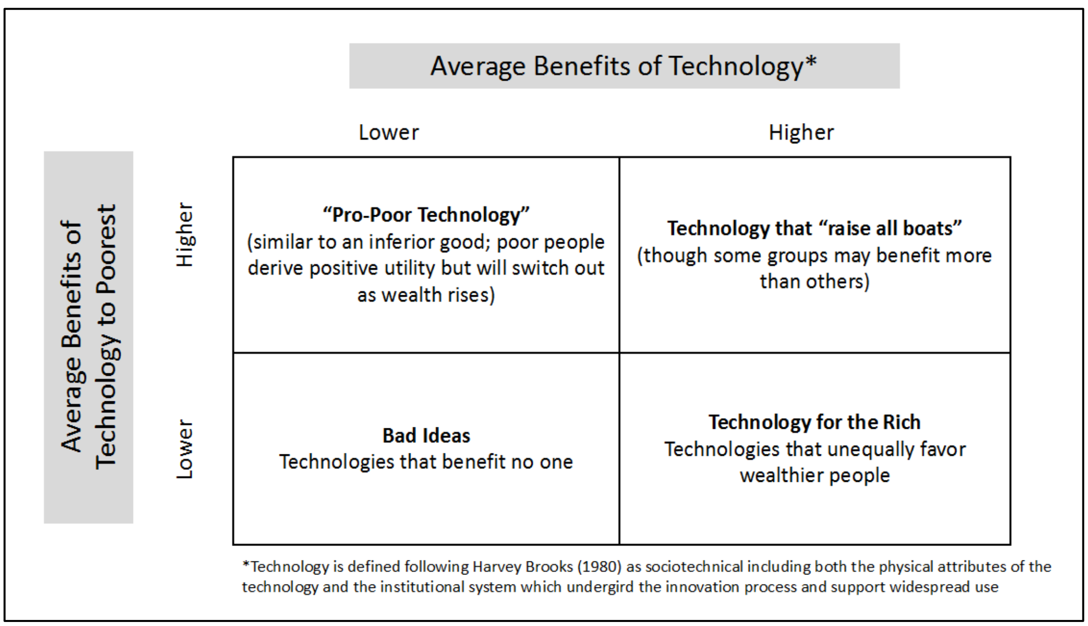

Figure 2.3: Stylized conceptualization of the impact of technology on poverty and inequality.

From a theoretical standpoint, the benefits farmers realize from using a specific technology should be measured in terms of increases in the well-being of a farmer or household. However, in practice, benefits are difficult to measure empirically due to extensive data requirements; the added uncertainty and error associated with on-farm rather than field station research settings; and even methodological challenges in defining what farmer's themselves consider improvements to their well-being. (Stiglitz, Sen and Fitoussi, 2009; Arrow *et al.*, 2012)[13] Below I first discuss issues related to the quantity and quality of data required to calculate well-being improvements empirically in terms of either yield or income improvements and then look at the larger theoretical challenges in constructing a standard definition of what constitutes well-being improvements.

2.3.1 Estimating the Benefits of New Technology

2.3.1.1 Through Measuring Yield Improvements

In practice, the simplest approach to estimating the benefits of the introduction of a new technology is to measure any yield improvements that result from the introduction of the technology.[14] While this is regularly done in controlled field trials on agricultural research stations, understanding the contribution of an individual technology to improved yields in farmer's fields, is much more difficult and requires extensive crop economics surveys (usually conducted on a biweekly basis). Above and beyond the research cost of surveying hundreds of farmers across socioeconomic groups on a bi-weekly basis, there is significant uncertainty about farmers recall ability estimating both input quantities and schedules

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[13] For a more detailed discussion of the concept and use of well-being as a measurement tool for conceptualizing sustainable development, please see Chapter 1, Section 1.6. Also see (Stiglitz, Sen and Fitoussi, 2009; Arrow *et al.*, 2012).

[14] Yield improvements are typically measured in terms of production per unit area (e.g. wheat yield per acre). One area of potential confusion in this measurement is what qualifies as yield. Those interested specifically in the part of the wheat plant that is marketable for sale, may for example only be interested in the yield of the grains, whereas farmers may also be interested in the quantity and quality of fodder produced in their wheat crop as well. What yield does **not** include is any calculation of input costs or not profit from a given plot of land.

(water, fertilizer etc.) and yield output. This is especially so when output is used for multiple purposes (home consumption, sale to the market), or when crops are harvested multiple times over a growing season as is the case with most vegetable crops. These challenges become vastly more complex when measuring the benefits of multiple technologies.

Moreover, even if sufficient quantity and quality survey data were available to understand the individual contribution of multiple technologies to yield improvements in farmer's fields, this would not fully solve the challenge of linking the use of technology by an individual farmer to improvements in well-being. The theoretical challenges can be best articulated through an example: If a farmer's introduction of technology T, leads to increased yields (yt) over average yields prior to the introduction of the technology (ya), then the technology would be said to benefit farmers in terms of increased yields in the amount of yt-ya = yb. Nonetheless increases in average yields do not account for the new costs associated with the technology that can come either in terms of upfront capital investments, changes in the labor requirements associated with using the technology, or complementary technologies required to make the initial technology investment worthwhile. A more nuanced approach measures benefits in terms of increased profits. If a new technology leads to increased yields (yb), increased profits are measured by subtracting any increased costs associated with the use of the technology from the yb and finding an equivalency between the costs and yield increases. This is done by estimating the market price at which the goods are sold at market or if consumed at home estimating their value. Using profits instead of yield increases as a proxy for benefits is thus vastly more complex.

Overcoming all of these barriers is possible when studying the yield benefits of a single technology across a limited number of villages. A good example of this methodology can be found in Burney *et al*. (2010), a study of a drip irrigation system powered by solar energy in West Africa which found improvements both in household income and nutrition in a matched-pair comparison of four villages over the course of a year. Disentangling the impacts of multiple technologies on yields or income would require an enormous data set that would also have to distinguish between the effects of the technology and exogenous factors such as variation in land quality, weather, pest outbreaks, and farmer ability among other variables. Alone, the quantity of data required combined with uncertainty about farmer recall ability, makes this approach technically difficult. For the purposes of a study designed to look at the sociotechnical mechanisms undergirding the variance of benefits where qualitative data can complement the quantitative measurements of benefits, the costs likely outweigh the benefits.

More problematic than addressing the challenges measuring profits as a proxy for benefits, is the fact that the measure of profits in any given year or range of years does not account for the risks farmers face that impact *expected* benefits from the use of technology. If technology T, brings yc benefits after accounting for increased costs and market prices under normal conditions, farmers must also consider the chance that some type of stochastic event such as severe weather or a disease outbreak will negate all or part of their investment. This in turn makes the key variable of interest from a farmer's perspective the expected benefits of technology, taking into account the likelihood of whole or partial crop failure, as well as other variables which impact the benefits farmers realize from increased yields. These could include the cost of all input technologies used, variable market prices, risk of post-harvest losses, alternative uses for various parts of the crop such as fodder for livestock[15] and even personal preferences around changes in the quality or type[16] of their produce when using technology T.[17] Due to the complex factors that go

[15] Early crop improvement programs focused mainly on yield improvements of grains or pest and water stress tolerance. It was only in the 1990s that scientists recognized the importance of the dual purpose of most rice, wheat sorghum, millet and groundnut for both grain and fodder for livestock in many agricultural systems especially in the developing world. Research found that farmers perceive a range of traits associated with the quantity and quality of fodder from different crop varieties and that breeders that focus only on grain yield overlook important attributes of the crop that influence the total benefits farmer's realize from the technology (Parthasarathy Rao and Hall, 2003).

[16] For example, I found in Bihar that it was relatively common for farmers who had enough land to plant two varieties of rice – a higher yielding variety for sale to the market, and a second often lower yielding variety which is of preferred taste and quality for home consumption.

[17] The challenge of measuring benefits or utility across individuals has long been identified in the welfare economics literature where marginal utility is generally assumed to be decreasing, but the shape of individual utility functions is usually unknown, making it difficult to infer the which individuals get more or less utility from an added unit of a given good or service. Moreover,

into the expected benefits farmers realize from technology including farmer specific preferences that may not remain stable across individual farmers in an village, deriving an empirical estimate of the benefits in terms of well-being is at an estimate with significant uncertainty.

2.3.1.2 Through Revealed Preferences

A second approach to measuring benefits is through an approach similar to revealed preference theory in the economics of consumer behavior. This strand of economics pioneered by Paul Samuelson assumes that consumers reveal their true preferences through their purchasing decision (Samuelson, 1954). Using a revealed preferences approach to estimating benefits farmers derive from technology means that a researcher can interpret a farmer's decision to use a technology over multiple seasons or years as a signal that the farmer derives positive benefits from the technology. This assumption is supported by an extensive literature going back to the Nobel Prize winning economist Theodore Schultz who developed the theory of the "poor but efficient" farmer. Schultz argued that even for poor farmers, decisions about technology investments were the result of rational decision makers who were both risk averse and cash constrained due to their poverty, yet still operated at their personal efficiency frontier given the constraints of poverty (Schultz, 1966, 1980). This argument ran contrary to contemporary perceptions which often assumed that small farmers especially in the developing world behaved according to tradition rather than in response to economic incentives which characterized the modern world. In contrast, Schultz assumed that farmers – like all humans – behaved rationally with respect to their own preferences but faced constraints that other groups who had greater access to capital and faced fewer stochastic risks in their businesses might not face. Schultz believed that these constraints would affect their decisions. Schultz's finding, with the exception of some evidence of irrational behavior with

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it seems likely that the shape of utility functions may be correlated at least in some ways with socioeconomic categories. So, failing into account for co-variance in the shape of utility functions and socioeconomic groups in a study of variance of benefits across this groups would lead to significant challenges of interpretation.

respect to investments in fertilizer in Sub-Saharan Africa (Duflo *et al.*, 2011), have largely been confirmed by the literature (Duflo, 2006; Mueller and Binder, 2015). Even in the case of the irrational behavior observed in the fertilizer study, the irrational behavior was associated with non-use rather than use of the technology (we will come back to the complexities of how to interpret non-use of technology later in this section). The preponderance of evidence suggests that the repeated use of a technology by a farmer can be interpreted as a revealed preference that implies positive benefits from the technology.

The revealed preference approach to estimating technology benefits has been used in a limited number of other studies in agricultural economics. Lichtenberg (2004) developed a revealed preference approach to study the demand for multiple conservation technologies using technology adoption data from farmers in Maryland, USA. Lichtenberg argues that the revealed preference approach overcomes the limitations of a stated preference approach used by previous scholars where farmers are less likely to give their true preferences for technology when questions about technology benefits are merely hypothetical and actual cash and time investments are not made. Lichtenberg also found that the revealed preference approach created the opportunity to study patterns of complementarity and substitution between conservation technologies when farmers chose to use multiple technologies at the same time. A second study by Asrat *et al*. (2010) used revealed preferences to study the preferences of farmers in Ethiopia for different crop variety traits by estimating the mean willingness to pay for each crop variety attribute (e.g. high yielding, short duration, draught resistance).

2.3.2 Limitations of Revealed Preference Approach

2.3.2.1 Estimation of Size of Positive Benefits

This chapter borrows from the revealed preference approach to technology adoption used by Lichtenberg (2004) and Asrat (2010) by assuming that a farmer's use of a technology over multiple years or seasons implies that she derives net positive benefits from use of the technology. The revealed preference approach is limited in that it cannot estimate the size of the positive benefits. Rather, the use of a technology by an individual farmer means only that the benefits the farmer derives from the technology are greater than the benefits she believes she would derive from using alternative technologies or no technology at all.

While the revealed preference approach is limited because it does not quantify the extent of the benefits a farmer realizes from a given technology, for the purposes of this chapter, which is concerned with the relationship between benefits and socioeconomic class, a simple binary variable (either an individual farmer benefits from technology T or he does not benefit from technology T) is sufficient for gaining some empirical traction on the research question.

That said, to compensate for the limitations of the revealed preference approach, I also asked farmers for their own opinions about the relative benefits they derive from each of the technologies they use. I use the data on perceived size or extent of benefits from each technology in the next section, both in order to construct a matrix for case study selection and qualitatively in the six case studies.

2.3.2.2 Non-use of a technology

The state of non-use of a technology by a farmer is more difficult to interpret. In theory, non-use could mean one of two things: either, the physical dimensions of the technology do not provide positive benefits to the farmer at the field-level – in which case, the farmer would not use the technology in its current form even if it were readily available at the field; or, the institutional dimensions of the technology create barriers to use of the technology even if the farmer would benefit from the physical dimensions of the technology. A final potential explanation for non-use of technology is that the "poor but efficient" model of farmer behavior is not entirely accurate. With the growth of behavioral economics, some scholars argue that above and beyond the constraints poverty places on farmer decision-making as a result of larger institutional forces (lack of credit, social safety nets, secure land tenure) the state of poverty may have specific behavioral implications that impact farmer decision-making (Duflo, 2006). The idea that all humans are not entirely rational in a neo-classical sense, but rather "boundedly rational" is an emerging field of research in behavioral economics (Thorgeirsson and Kawachi, 2013). That the poor could have specific behavioral characteristics that are not entirely self-maximizing, which are a result of the very fact of their poverty is entirely plausible. Duflo *et al*. (2011) found evidence of some boundedly rational farmer behavior in Western Kenya. They found that Kenyan farmers were using significantly less fertilizer than they would if they were behaving according to neo-classical models of human behavior even after taking account the institutional dimensions of the fertilizer technology in the region. Because fertilizer was widely available locally at low cost and in highly divisible units, institutional barriers such as cost or access to credit did not easily account for the low rates of use of the physical technology. Instead through controlled field experiments, they found evidence of bounded rationality in this case bounded willpower or a bias towards present outcomes over future outcomes. Farmers procrastinated going to purchase fertilizer either because they had other things to do or wanted to spend cash on hand on other goods. Despite the challenges that bounded rationality presents for a revealed preference approach to measuring benefits, most evidence of the impacts of bounded rationality on farmers' production decisions has been associated with non-use rather than use of technology. For this reason, despite the evidence of bounded rationality which challenge the "poor but efficient" model of farmer behavior, the chapter treats use of a technology as a revealed preference that the technology leads to positive benefits. But on the flip side, the explanations for non-use of technology must now include not only barriers in the physical and institutional dimensions of technology, but also barriers related to behavioral characteristics of farmers that may be correlated with their specific socioeconomic group. Fortunately, behavioral dimensions of farmer decision-making are easily included in an ethnographic approach to the research question. Thus, in order to understand why a specific farmer or in this case a specific socioeconomic group of farmers are or are not benefiting from a technology requires looking at the physical and institutional components of the technology in question, as well as at the behavioral responses of specific groups of farmers within the context of a given setting.

2.3.2.3 Technologies with negative benefits?

Despite the extensive literature supporting the "poor but efficient" or at least the "boundedly efficient" farmer hypothesis, there is some concern in the literature that under certain circumstances farmers may use a technology with negative benefits. The most prominent (and controversial) documentation of this comes from the case of Bt Cotton in India, which activists and some scholars have blamed for farmer suicides in India (Shiva *et al.*, 2000; Shiva and Jafri, 2004).[18] A technology that leads to farmer suicide should certainly not be interpreted as a technology that brings positive well-being benefits to farmers. The link between Bt cotton adoption and farmer suicide is however controversial. Research conducted by the Food Policy Research Institute (IFPRI) found no evidence of increased rates of farmer suicides after the introduction of Bt cotton in India (Gruère and Sengupta, 2011). Moreover, the IFPRI study found that Bt cotton had on average increased yield and incomes of farmers in India. However, the authors could not rule out a link between individual suicides and Bt cotton. They found that in specific districts and years, the use of Bt cotton combined with severe drought and crop failure may have led to increased farmer indebtedness linked to reginal spikes in suicides in specific years. The authors' point out that it is unlikely that the physical dimensions of Bt cotton are to blame as much as regionally specific institutional dimensions. These include lack of irrigation, poor extension services and information dissemination on best practices for Bt cotton cultivation, predatory private sector actors selling inferior seed varieties, and in some cases falling market prices for cotton. In an average year, for most farmers, Bt cotton brings positive benefits, but stochastic risk coupled with the specific institutional

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[18] Bt cotton is a genetically modified cotton variety, which produces within the plant itself an insecticide to bollworm, a major cotton pest, thereby reducing the need for external spraying of pesticide on the crop.

dimensions of the technology which differ by region, and the high capital investment associated with the use of Bt cotton – which is more than triple the price of conventional hybrid seeds – can lead to disastrous outcomes for farmers (Qaim *et al.*, 2006). This is particularly true in areas where farmers go into debt either to formal credit institutions or informal money lenders to finance technology investments. While concern over reports of technology leading to farmer suicide or farmer indebtedness more broadly casts a shadow over the revealed preference approach to the study of benefits of agricultural technology, it is worth remembering that farmers themselves are often aware of risks and the stochastic nature of their livelihood. It is also why a revealed preference approach based on quantitative data alone is insufficient to fully understand the sociotechnical relationship between technology use and benefits and further bolsters a mixed methods approach to the research question.

2.3.2.4 Use of second-best technologies

A final limitation on the revealed preference approach worth discussing is the use of second-best technologies as coping mechanisms when first-best choices are not available. In a study of the response of Indian farmers to the increased cost of diesel (which raises the cost of groundwater irrigation when electricity is unavailable), Shah (2007) observes the myriad ways farmers cope when the shifting sociotechnical landscape impacts their ability to use a first-best technology choice. He found that farmers use a variety of coping mechanisms including switching to different technologies (such as using subsidized cooking fuel instead of diesel to power their pumps) or switching to crops where are either riskier or less remunerative. While Shah's study is an empirical example of farmers using technologies they would rather not use if they had access to their first choice, he does not demonstrate that farmers derive negative benefits from these second-best technology choices they are forced to make. Rather their benefits are less than they would be if they had access to a different technology set. This study explores this nuance of the revealed preference approach in more detail in the case study on electric motor pumps (EMPs) in Section 2.6.4.

In summary, there are a number of limitations to the revealed preference approach to measuring technology benefits. The first discussed previously is that a farmer's use of a technology over multiple season implies that the farmer realizes positive benefits from the technology, but it does not rank this benefit in any ordinal sense so that relative benefits of technologies can be compared. Of course, many technologies are often inter-dependent (it would make little sense to use high yielding seed varieties (HYV) if you do not have fertilizer) so having an ordinal ranking may prove less useful than one might expect and a qualitative approach may better capture the contingencies across technologies. The second limitation is that while use of technology can be interpreted as a revealed preference, non-use as discussed in the previous paragraph is more complex to interpret and benefits from the use of a qualitative as well as institutional approach to sociotechnical systems. The third limitation and the largest risk is that farmer's sometimes use technology from which they do not derive positive benefits. In fact, with the stochastic nature of agricultural production, it is almost certain that in some year's technology investments will be wasted due to crop failures. The concern then is twofold: 1) Are farmers using a technology when not just this year's benefits, but the expected benefits (given appropriate risk assessments) are also negative? 2) Are there trends across socioeconomic groups so that for some groups, expected benefits are more likely to be negative and if so what causes these differences? 3) Even if expected benefits are greater than zero, are the consequences of failure of a technology so great that one might still wish to choose a precautionary approach to their use and promotion (e.g. when farmers go into enough debt that their long-term financial security is threatened)? This study does its best to control in particular this third limitation through qualitative fieldwork, but also acknowledges that this concern may not be fully dealt with by the methodology.

While all three approaches to quantifying benefits including yields, profits and revealed preferences, have drawbacks, the revealed preference approach has the advantage of both requiring a practicable data collection process, which triangulates both quantitative and qualitative data. Moreover, from a broader epistemic perspective, using revealed preferences combined with qualitative interviews allows the farmers' voices themselves to guide the research process and findings, helping to guard the researcher against the problem of omitting or overlooking important variables in farmers' objective functions. Failure to understand the full scope of farmers' objective functions has in the past led to failure of the agriculture research community to properly understand the needs of the poorest farmers and the full set of sociotechnical opportunities and constraints they face (Ashby, 1997). This approach also shares much in common with the farmer first model of agricultural research and extension pioneered by Robert Chambers and the Institute for Development Studies in 1989 (Chambers, Pacey and Thrupp, 1989; Scoones and Thompson, 2009).

2.4 Background: Bihar's Economic Miracle in an Agrarian Context

In July 2015, I attended a conference at the Maurya hotel, one of the more luxurious hotels in Patna, the capital of Bihar. The conference was called "Resurgent Bihar: An impossible dream?"[19] A leading English language newspaper in Bihar, The Telegraph, organized the conference which was set up as a panel debate asking the question whether the recent improvements in Bihar's economy, infrastructure and security would continue, or if in contrast "Resurgent Bihar" would turn out to be "an impossible

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[19] Indeed, if you read the article about the conference in *The Telegraph,* you will find a picture of me and my colleague Nooper Sen in the audience. The caption "women in audience use their laptops" attempts to capture the overall message of the conference – Bihar is now a state where women are empowered and where modern technologies are in widespread use. The message was perhaps undercut by the setting of the conference in one of the nicest hotels in the city, the red carpet-style entrance (complete with a photography wall or "logo board"), and the selection of two highly-educated women from outside Bihar both using expensive Apple laptops to demonstrate this point. Of course, the entire conference was also in English. https://www.telegraphindia.com/1150718/jsp/bihar/story_32218.jsp

dream." Despite the sensationalized title of the debate, the stakes were very real and immediate. With impending elections in Bihar, that were seen by many as a referendum on the technocratic governance style and development agenda of the current Chief Minister, Nitish Kumar, public opinion on the matter was critical.

Nitish's tenure as Chief Minister, which began in 2005, had transformed Bihar's economy. During the 1990s, Bihar's economic growth had stagnated and Bihar had fallen behind the rest of India on almost every development indicator (Singh and Stern, 2013). The situation had become so bad, that many Indians from outside the state were afraid to visit. After Nitish Kumar's election in 2005, growth in real per capita income increased dramatically, from 0.9% between 1991-2005 to 10.4% between 2006 and 2012. Studies also showed real improvements on multiple development indicators including crime, health (particularly infant mortality and vaccinations), and education (see Table 2.2 for descriptive data on Bihar).

Table 2.5: Selected social, economic and agricultural indicators for Bihar and India as a whole.

Selected Indicators	Bihar	India	Sources
Population 2011	104 million	1.2 billion	(UNDP, 2011)
Share of population to total country	8.6%	NA	(Sinha, Ahmad and Singh, 2016)
Share of land area of total India area	2.9%	NA	(Sinha, Ahmad and Singh, 2016)
Population growth rate (2001 - 2011)	2.3%	1.6%	(Govt. of India, 2001)
Percent population rural (2011)	88%	69%	(Govt. of India, 2001)
Nominal NSDP (or NDP) per capita at factor cost (2013-14, base of 2004-05)	USD 480.0	USD 1434.7	(Reserve Bank of India, 2015)
Nominal NSDP (or NDP) per capita - **Agriculture** at factor cost (2013-14, base of 2004-05)	USD 97.3	USD 203.3	(Reserve Bank of India, 2015)
Compound annual growth rates in per capita NDP and NSDP (1995-1999)	1.5%	5%	(Mukherji and Mukherji, 2012)
Compound annual growth rates in per capita NDP and NSDP (2010-2012)	14%	7.5%	(Mukherji and Mukherji, 2012)
Human development index 2005	0.449	0.575	(Mukherji and Mukherji, 2012)
Poverty ratios: Tendulkar methodology (2009-10)	53.5	29.8	(Mukherji and Mukherji, 2012)
Percent population rural	88.7%	68.84%	(Govt. of India, 2001)
Hunger index rank	15 out of 17 states	NA	(Menon, Deolalikar and Bhaskar, 2009)
Percent underweight children under three years (2005-06)	58%	46%	(Kumar, 2011)
Percent workforce dependent on agriculture	74%	53%	(Planning Commission, 2011; Hoda, Rajkhowa and Gulati, 2017)
Average landholding	0.96 acre	2.8 acre	(Government of India, 2012)
Literacy rate (2011)	63.8%	74.0%	(Mukherji and Mukherji, 2012)
Percent villages with road connectivity (2009)	57%	62%	(Kishore, Sharma and Joshi, 2014)

The stellar performance of Bihar's economy between 2006 and 2012, led many Indian pundits to declare the recent improvements in economic and social indicators a "miracle" (e.g. Panagariyal, 2012) – albeit a miracle engineered by a man. Multiple books quickly followed that extoled Nitish's successes with titles like "Nitish Engineering: Reconstructing Bihar" (to which the Dali Lama himself wrote a forward calling Nitish "not only a man of ideals, but someone who takes action and tries to put them into practical effect" (Sinha, 2013, p. 5), and "Bihar Breakthrough: The Turnaround of a Beleaguered State" (Chakrabarti, 2013). Many of these books were published by Nitish's supporters with evidence sometimes selectively chosen to support the narrative of Nitish Kumar as uniquely responsible for the drastic turnaround in the state.

Other sources provided a more even-handed analysis of Bihar's development trajectory. One such edited volume, "The New Bihar: Rekindling Governance and Development" (Singh and Stern, 2013), took a more modest view of Bihar's successes, while also noting the tremendous hurdles that remain. The book was edited by two prominent authors, Professor Nicholas Stern, Chair of the Centre for Climate Change and Economics Policy at London School of Economics and President of the British Academy (the UK's national body for humanities and social sciences), and N.K. Singh, a member of Parliament in India. The book includes essays by Amartya Sen, a Nobel Laureate in Economics, and by M.S. Swaminathan, a man revered as the father of India's Green Revolution. While the essays in the book are more circumspect in their evaluations of Nitish's achievements, the very fact that this level of star-power came together to publish a book about a single state in India, underscores the degree to which the development community sought to showcase Bihar's success.

Yet despite impressive economic growth over the past 10 years, Bihar, with a population of more than a million people, remains the poorest state in India (Acharya, 2013). Moreover, the percentage of the rural population – 88% of the population – living below the poverty line declined only marginally during the first five years of Nitish's government (see Table 2.3).

Table 2.6: Percentage of the population below poverty line.

Source: (As adopted from Acharya, 2013; Columns 1,4, and 7 from Report of the Expert Group to review the Methodology for Estimation of Poverty, Government of India, Planning Commission, November 2009; Columns 2, 3, 5, 6, 8, and 9 from Press Note on Poverty Estimates, 2009-10, Government of India, Planning Commission, March 2012)

States	Rural			Urban			Total		
	1993-94	2004-05	2009-10	1993-94	2004-05	2009-10	1993-94	2004-05	2009-10
Andhra Pradesh	48%	32%	23%	35%	23%	18%	45%	30%	21%
Bihar	**62%**	**56%**	**55%**	**45%**	**44%**	**39%**	**61%**	**54%**	**54%**
Chhattisgarh	6%	55%	56%	28%	28%	24%	51%	49%	49%
Gujarat	43%	39%	27%	28%	20%	18%	38%	32%	23%
Jharkhand	66%	52%	42%	42%	24%	31%	61%	45%	39%
Madhya Pradesh	49%	54%	42%	32%	35%	23%	45%	49%	37%
Orissa	63%	61%	39%	35%	38%	26%	59%	57%	37%
Rajasthan	41%	36%	26%	30%	30%	20%	38%	34%	25%
Tamil Nadu	51%	38%	21%	34%	20%	13%	45%	29%	17%
Uttar Pradesh	51%	43%	39%	38%	34%	32%	48%	41%	38%
West Bengal	43%	38%	29%	31%	24%	22%	39%	34%	27%
All-India	**50%**	**42%**	**34%**	**32%**	**26%**	**21%**	**45%**	**37%**	**30%**

Indeed, over the five years between 2005 and 2010, rural poverty dropped by only one percentage point. Whereas during the oft critiqued government of Nitish's predecessor, Chief Minister Lalu Yadav, the rate of rural poverty dropped by six percentage points between 1994 and 2004 (or an average of three points over five years, in contrast to Nitish's one). The inability of Nitish Kumar's economic miracle to reach Bihar's poorest citizens was at the heart of the discussion that night at the Maurya Hotel. The question on everyone's mind during the conference was how to make Bihar's economic growth more inclusive.

What went unsaid during the debate at the Maurya, but what is almost certainly true, is that for growth to be inclusive in Bihar, growth must not only take place in the industrial and service sectors, but in the agricultural sector. Despite the strong economic growth in Bihar between 2006 and 2012, the growth was concentrated in the construction and services sectors (see Table 2.4).[20] At the same time, the share of agriculture in Bihar's net domestic product had fallen dramatically from 47.9% in 1993-94 to 15.4% percent in 2011-12. The imbalanced growth across sectors in the first five years of Nitish's government is likely why despite the "economic miracle", the percentage of the population living below the poverty line, especially in rural areas, barley declined.

Table 2.7: Share of selected sectors in Bihar's Net Domestic Product

(Percentage shares of NDP at constant prices. Adapted from Acharya, 2013, based on data from the Central Statistical Organization of India)

Year Range	Agriculture	Manufacturing	Construction	Trade, Hotels, Restaurants
1993-94	47.9%	4.5%	3.6%	15.2%
2000-01	37.1%	5.4%	3.5%	16.0%
2004-05	26.5%	4.9%	7.0%	23.0%
2011-12	15.4%	4.3%	12.1%	35.0%

Growth in the agriculture sector is important for poverty reduction. A study comparing economic growth, growth in the agricultural productivity and poverty reduction across multiple states in India, found that while agricultural growth has a relatively minor impact on overall gross domestic product, agricultural growth has significant impact on the incidence of rural poverty. Specifically, the study found that every 1% increase in agricultural growth, results in 0.45% rate of poverty reduction (Virmani, 2008). Similar results have been found in other empirical studies (Irz *et al.*, 2001; de Janvry and Sadoulet, 2010).

[20] As Singh and Stern (2013, p. xxviii) point out, "the share of construction in Bihar's net domestic product increased from 3.6 to 12.1 percent between 1993-94 and 2011-12, while the share of trade, hotels and restaurants increased from 15.2 percent to 35 percent over the same period. In contrast, the share of manufacturing has been stagnant at 4.5%." The concentration of growth in these sectors led me to joke with my colleagues in Bihar (only somewhat tongue-in-cheek) that the growth in Bihar's economy had been spurred less by Nitish's policies than by the arrival of so many development professionals who were using all of the new hotels, restaurants and roads.

Despite the importance of agricultural productivity growth in ensuring the inclusivity of economic growth, an analysis done by the International Food Policy Research Institute (IFPRI) in India, found that over the past five decades, Bihar has had the slowest agricultural productivity growth rate of any state in India. More troubling for a state where 88% of the population is rural and at least 74% of the workforce is dependent on agriculture for their livelihood, the per capita and per worker value of agriculture has shrunk over the past four decades (Kishore, Joshi and Pandey, 2014).

Since the election of Nitish Kumar in 20005, there have been some success stories in the agricultural sector (dairy is one example, winter maize is another). Nonetheless, productivity especially among Bihar's staple crops, rice and wheat, remains far behind other Indian states (Hoda, Rajkhowa and Gulati, 2017).[21] In many ways, the Green Revolution which contributed so much to poverty reduction and economic growth in states like Punjab and Gujarat, never came to Bihar (Edwards, 1974; Parayil, 1992; Bhalla and Singh, 2001). In order to understand stagnation in Bihar's agricultural sector, it is necessary to briefly trace the arch of Bihar's intertwined agricultural and political history.

2.4.1 Landscape Level Context

When the British arrived in India, the colonial government identified the region that now includes Bihar, Jharkhand and West Bengal (formally known as the Bengal Presidency) as India's breadbasket. To capitalize on the agricultural potential in the region, the colonial government built India's first agricultural research and teaching institute in Samastipur, a district in modern North Bihar. While multiple locations across the country were considered as potential sites for the research institute, Bihar eventually won out (RAU, 2017). Construction began on the institute in 1905 and was largely complete by 1907 (see Figure 2.2).

[21] Cereals, including rice, wheat and maize account for 79% of the cropped acreage in the state (Hoda, Rajkhowa and Gulati, 2017).

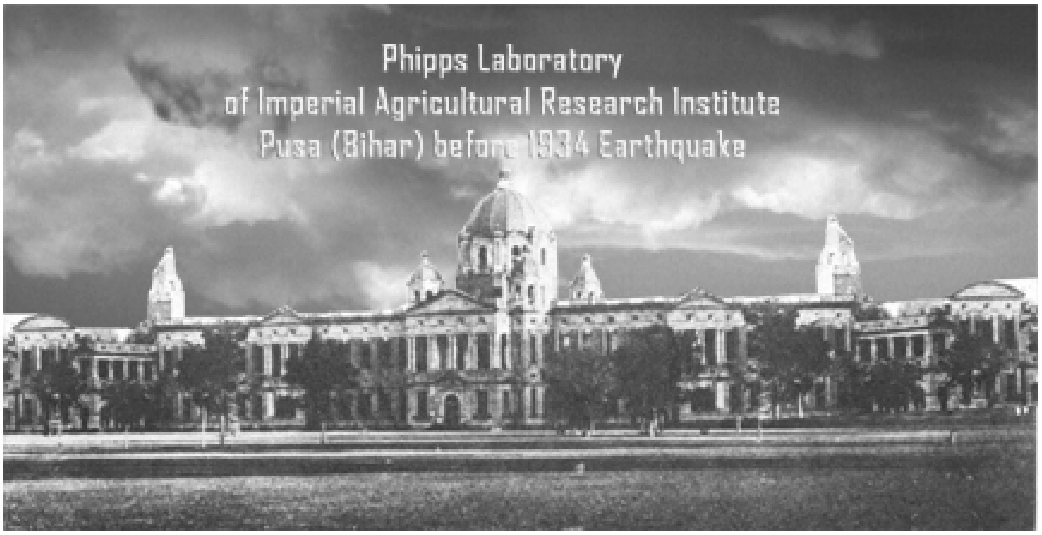

Figure 2.4: Phipps Laboratory at the Imperial Agriculture Research Institute (IARI).

IARI was located in Samastipur Bihar prior to the earthquake of 1934 when the institute was moved to New Delhi. The institute is still in Delhi and still has the same acronym, though the I now stands for India rather than Imperial. There is still an agricultural research center in Bihar, called Rajendra Agriculture University (RAU) which has lesser status and funding than the original institute build in Samastipur (Source: RAU, 2017).

The center was at first named for its location in the town of Pusa, but by 1918, the research institute was given "imperial status" and was renamed the Imperial Agriculture Research Institute (IARI). IARI flourished during this era, developing improved plant varieties including wheat, rice, chilies, tobacco, linseed, mustard, pulses and vegetables. Work was also done on pest and pathogen control as well as animal husbandry and agronomy.

The glory of IARI in Bihar would be short lived. In 1934, a massive earthquake destroyed much of the institute including the central Phipps Laboratory. Instead of rebuilding IARI in Bihar, the colonial government saw the shifting trends not only in agricultural production in the country, but also in the seat of political power, which was also shifting from nearby Kolkata to New Delhi (Guha, 2007). Accordingly, the government rebuilt IARI not in Bihar, but in New Delhi where it remains to this day. This move left the research center in Samastipur with significantly lower status and fewer resources.

The shift of IARI to New Delhi presaged a significant decline in the strength of Bihar's agricultural sector. There are multiple reasons for the decline in Bihar's agricultural productivity relative to the rest of the country. Almost certainly, the colonial land tenure system established in the Bengal Presidency, known as the *zamindari* system had major implications for the growth of Bihar's agricultural sector (Banerjee and Iyer, 2005; Mukherji and Mukherji, 2012). Under this system, land rights were given exclusively to large landlords known as *zamindars* who were responsible for collecting land revenues for the colonial government from an entire village or group of villages. Landlords were free to set their own terms with the peasant cultivators and could dispossess any peasant who did not meet these terms. The *zamindars* were entitled to keep whatever revenue remained after paying the British revenue demand. In this way, the *zamindari* system essentially gave all property rights to the large landholders, leaving them with an extraordinary level of economic and social power over the villages they were liable for, and the villagers within them.

Even after the end of colonialism and the official abolition of the *zamindari* system circa 1950, institutional vestiges of the *zamindari* system continued to impact agricultural growth in the state. Banerjee and Iyer for example found that regions of India where property rights were given to large *zamindars,* had significantly lower agricultural investments and productivity in the post-independence period, than regions where these rights were given to peasant cultivators. The authors use an institutional explanation to explain this divergence – "differences in historical institutions lead to very different policy choices" (Banerjee and Iyer, 2005, p. 1190).[22]

Despite the fact that Bihar was the first state to officially abolish the *zamindari* system in 1947, the reform was never given any real teeth (Chintu and Kumar, 2017). Both land redistribution and reforms in

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[22] The *zamindari* system stands in sharp contrast to the *ryotwari* system, prevalent in other parts of colonial India, under which revenue was collected directly from peasants by the colonial government and linked to output, avoiding the perverse institutional incentives created by the *zamindari* system.

tenancy practices failed, due largely to the continued political and economic power of the large landowners (whom many small farmers still refer to as *zamindars*).

While several new attempts at land reform in Bihar have been made since the 1950s, these reforms have all suffered from implementation failures (Ministry of Rural Development, 2009; Rorabacher, 2008; Wilson, 1999). Nitish Kumar attempted once again to address the issue of land reform when he was first elected, forming a Land Reforms Commission in June 2006. The Commission purportedly authored a final report in 2008, but the results were never made public. Since commissioning the report, the issue of land reform has not been addressed by Nitish's government due to the complex political realities of such an effort (Bandyopadhyay, 2009; Banerjee, 2009; Chintu and Kumar, 2017).[23]

In addition to the structure of land tenure regimes in Bihar, other factors also played a role in the failure of the Green Revolution in the 1970s to improve productivity in the state, including both severe floods and droughts. Bihar suffers from frequent and often devastating floods. 73% of the state's total geographical area is designated as flood prone (Kishore, Sharma and Joshi, 2014). The floods wreak havoc in terms of human lives lost, loss of livestock, loss of crops and devastation of infrastructure. Most of Bihar's flood prone districts are in North Bihar, but a failure to manage the complex river system that brings both copious water and rich alluvial soil to the state on an annual basis, impacts farmers throughout the state.

In the South (where the primary field site for this project is located), floods are less common, but droughts frequently ravage farmer's livelihoods. Large parts of Bihar experienced droughts in four out of

[23] Indeed, Nitish Kumar came to power by bringing together a coalition that was made up of both the wealthiest and the poorest people in the state. While Lalu had controlled the state on the platform of lower caste empowerment, the benefits had largely accrued to OBC castes including his own *Yadav* caste. To beat Lalu in the 2004 election, Nitish brought together a coalition of UC and SC/ST castes who expected reforms in law and order, better economic growth and overall a more technocratic approach to development policy (Witsoe, 2013). However, Nitish's reliance on the upper castes also likely influenced his decision to shelve the contested issue of land reform.

the five years between 2009 and 2014 (Kishore, Joshi and Pandey, 2015).[24] The problem of droughts is likely to become even greater in the future as the Indian Council of Agricultural Research (ICAR) estimates that 24 out of the 38 districts in Bihar are extremely vulnerable to climate change (Sehgal *et al.*, 2013). While the droughts are less costly in terms of loss of human life, they increase risk aversion among farmers and impact technology investment decisions. Even when droughts are not officially declared, many farmers I interviewed believed that the monsoon had become increasingly erratic in the past decades.

A final important piece of the puzzle explaining both Bihar's poor economic growth prior to 2005, as well as its stagnant agricultural productivity growth, is Bihar's recent political history. Beginning in 1990, Lalu Prasad Yadav was elected chief minister of Bihar. Lalu rose to power on a social empowerment platform, championing the plight of the backward and scheduled castes who had long labored with few political or economic rights. Jeff Witsoe, in his book *Democracy Against Development* explains that in order to realize his goal of lower caste empowerment, Lalu marginalized the professional bureaucracy whose ranks were filled mostly with India's upper castes (Witsoe, 2013). In order to avoid filling open positions with upper caste administrators, Lalu instead chose to leave many critical government positions unfilled. Perhaps as a result of his barebones government or as a rebuke to the central government, he also failed to go through the necessary administrative hoops to receive funding allocated from the central government for Bihar's rural and economic development. While Lalu's strategy may have succeeded in excluding the upper castes from positions of power, it also left important government functions such as agricultural extension and rural credit unions in a state of disrepair (Witsoe, 2013).

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[24] Kishore *et al*. (2015) note that: "The years 2009–2013 have been the driest 5 years in the last 113 years in Bihar. Of the 38 districts in the state, five experienced droughts in all five years between 2009 and 2013; 14 experienced droughts in four out of these five years; another 14 saw three years of drought; while the remaining five saw two years of drought."

The state's infrastructure also declined during the Lalu era with many villages that had once been electrified losing their electricity supply (Mukherji, 2005). Once electrical current was no longer supplied to the wires, the wires were stolen and repurposed or sold. Today, driving through rural Bihar, you see a landscape dotted with concrete electricity polls without wires linking one to the next. Some concrete polls have been knocked down and turned into improvised (and dangerously effective) speed bumps to slow motorcyclists down as they go through villages. This visual of electricity polls converted into grassroots speedbumps serves as a reminder of the state of disrepair of Bihar's infrastructure Lalu left in his wake at the end of his tenure as chief minister in 2005 (see Figure 2.5).

Figure 2.5: Concrete electricity polls turned into improvised speed bumps in Gaya district, Bihar.
(Photo Credit: author)

The decline of Bihar's infrastructure also contributed to Bihar's stagnant agricultural growth. This was especially true for irrigation. While other states developed robust groundwater irrigation systems in the 1970s and 1980s, limited electricity in Bihar made irrigation for Bihari farmers much more expensive. This is because Bihari farmers were forced to continue to rely on diesel engines to pump groundwater when farmers in other states were transitioning electric motor pumps, which provided water at a much lower marginal cost (Kishore, 2004). Today, the vast majority of groundwater irrigation in Bihar is still powered by diesel, forcing farmers to practice deficit irrigation and hampering yields (Kishore, Sharma and Joshi, 2014).

In 2005, Nitish Kumar, a reformist minded politician ousted Lalu Prasad. Nitish was seen by the political elite and the Indian bureaucracy as a technocratic ‘breath of fresh air’. From the perspective of Indian policy makers and the international community of development organizations, Bihar once again had the potential to flourish. Donor funding and international development practitioners and scholars flooded into the state with the goal of reviving Bihar’s lagging economy and improving the well-being of Bihar’s people.

The importance of the agricultural sector in addressing rural poverty did not escape Nitish Kumar when he came into power. Improving the agricultural sector was not only key to his policy objectives, but also to his electoral strategy. Bihar is one of the least urbanized states in India with 88% of its population living in rural areas, most of whom depend on agriculture for at least part of their income and food security. Finding policy solutions to jumpstart Bihar’s rural economy was essential to his continued popularity among his electoral base. In 2008, Nitish launched the State’s first Agriculture Road Map and followed that with a second road map released in 2012 (see Figure 2.6) (Government of Bihar, 2008, 2012).

Figure 2.6: 2012-2017 Agricultural Road Map[25]

Chief Minister Nitish Kumar (right) with the President of India, Pranab Mukherjee (left). President Mukherjee visited Bihar to participate in the official launch of the 2012 Agricultural Road Map (pictured). October 3, 2012. (Photo Credit: Aftab Alam Siddiqui)

The 2008 Road Map acknowledged Bihar's potential and challenges: "Though endowed with good soil, adequate rainfall and good ground water availability Bihar has not yet realized its full agricultural potential. Its agricultural productivity is one of the lowest in the country, leading to rural poverty, low nutrition and migration of labor" (Government of Bihar, 2008, p. 3). The document goes on to underscore the critical nature of agriculture to the state's development agenda. "With nine out of every ten persons from Bihar living in villages, and with three out of every four in Bihar employed in agriculture, a road

[25] See tables in Appendix 2 for budget breakdowns of both the 2008 and 2012 Agricultural Road Maps. This were compiled by the author from long reports. The Bihari government did not explicitly breakdown the budget into tables in either Road Map, but rather provided the data that comprises these tables throughout the chapters of each Road Map.

map for agriculture is not about farming alone, but it is about the lives of persons of the State"(Government of Bihar, 2008, p. 4).

The Agriculture Road Map outlined five major goals including increased incomes for farmers, food security, nutritional security, increased farming employment opportunities, and finally "agricultural growth with justice" to focus specifically on poor and marginalized groups including women and marginalized castes. The 2008 Roadmap allocated a total of 532 million dollars to Bihar's Agricultural sector under 11 separate schemes (Government of Bihar, 2008). These schemes included plans to improve the quality and availability of seeds in the state, soil health management, crop protection, farm mechanization, transfer of technology, improved extension services, improved online portals for the agricultural sector, integrated farming demonstrations in specific "demonstration villages", soil and water conservation, micro irrigation, and agricultural marketing and development. Perhaps at odds with the plan's professed interest in 'agricultural growth with justice', by far the largest portion of funding (37%) went to agricultural marketing and development, a line item which is almost certain to disproportionately benefit wealthier farmers who are already producing significant surplus for sale and who can benefit from improved access to better markets, prices and cold storage facilities. In contrast, improved funding for extension services, at 3% of the 2008 Road Map budget, was unlikely to significantly change the functioning of this critical service in ways that would benefit the poorest farmers.

In 2012, Nitish published a second Agriculture Road Map, this one significantly increased funding to the agriculture sector to 1.8 billion dollars (Government of Bihar, 2012). This plan also significantly raised the percentage of funds directed at agricultural extension services to 34.5% of the budget. It also strongly backed one specific technology – the System of Rice Intensification (see Section 2.6.2) – which was both seen by Nitish and perhaps more importantly sold to the public as a specifically "pro-poor" technology investment. Over the five-year period between 2012 and 2017, the Road Map allocated 7.9% of the total 1.8 billion to the System of Rice Intensification.

The reorientation of Bihar's sociotechnical regime under Nitish Kumar was goal oriented – improving law and order, spurring economic growth, reducing poverty (Basu, 2013; Singh and Stern, 2013). The 2008 and 2012 Agriculture Road Maps demonstrated that Nitish Kumar had a clear understanding of the links between agriculture and inclusive economic growth.[26] At the same time, Bihar's farmers are not homogenous and agricultural policies and programs as well as other changes in Bihar's sociotechnical regime likely impact farmers across socioeconomic spectrums differently. This chapter is written in the context of the changing sociotechnical regime facing farmers in Bihar, and looks at how the benefits of these changes have been distributed across socioeconomic groups of farmers.

2.5 Data: Triangulating Using Ethnography and Survey Data

My interest in Bihar began in 2011 when I first visited the state to learn about the adoption and popularity of a new technology for rice cultivation – the System of Rice Intensification (SRI). During this trip, it quickly became clear that the recent upheavals in Bihar's political economy (discussed in Section 2.4) were fertile ground for a larger study on agricultural innovation systems and the ways in which the structure of these systems impact the lives and livelihoods of farmers in different social and economic groups. An abrupt discontinuity between the policies of the former chief minister Lalu Yadav (1990 to 2005[27]), and the policies of the current chief minister, Nitish Kumar (2005-present[28]), reoriented the

[26] Bihar's Agriculture Road Map was the first Road Map specific to the agriculture sector published by any state in India. Moreover, the Bihari Government recently published a new 2018 Agriculture Road Map. Unfortunately, the 2018 Road Map was published too recently to be productively included in the analysis here.

[27] In fact, Lalu Yadav was Chief Minister only from 1990 to 1997, when he was convicted of corruption. However, his wife, Rabri Devi, took over as Chief Minister after Lalu was imprisoned. Throughout his imprisonment, Lalu continued to wield power in the state using his wife as a proxy. For analytical purposes, the Lalu-Rabri era is treated as a single political era from 1990 to 2005.

[28] Like Lalu, the era of Nitish Kumar is punctuated by a brief period during which another leader from his party assumed the mantle of Chief Minister after Nitish's party was badly defeated in a mid-term election and Nitish stepped down as a result, appointing Jitan Ram Manjhi in his place. In the subsequent election in the fall of 2015 Nitish won re-election and was reinstated as the Chief Minister of Bihar. For analytical purposes, I treat the entire period from November 2005 to present as the Nitish era.

institutions and infrastructure in Bihar, transforming the sociotechnical regime facing the agricultural sector.

I hypothesized that a change in the sociotechnical regime, would be methodologically useful. Changes in the sociotechnical regime could open up an opportunity for discussion in qualitative interviews, as well as a place to look at changes in patterns in quantitative data. The intuitive sense I had on my first visit turned out to be correct. First, I found in the quantitative survey data an abrupt shift in farmer agricultural technology adoption that began after the new Chief Minister, Nitish Kumar, was elected in 2005, and peaked around 2010. Second, the discontinuity in the sociotechnical regime between the Lalu and Nitish eras inspired passionate discussion across a state where almost everyone from auto-rickshaw drivers, to farmers to businessmen have strong political views (which they rarely shy away from expressing). By asking concretely about the links between broader changes in the political economy of Bihar and changes in the farmers' livelihoods and agricultural practices, I acquired rich and unexpected data that was much more illuminating than the answers farmers shared when I asked about the past three decades. While interviews with farmers often began with a question about changes in their agricultural practices since 1990, the more interesting answers – the ones that linked to institutional structures and underlying causal mechanisms – often came when I asked specifically about changes between the Lalu and Nitish eras. For example, famers across Bihar ascribed the increased availability of improved seed varieties to increased law and order in Bihar, which was one of the key changes in the sociotechnical regime introduced by Nitish Kumar.

The empirical investigation for this chapter is based on fieldwork conducted between 2011 and 2016 in Bihar including multiple visits between 2011 and 2014 and more than a year of fieldwork between September 2015 and January 2016.[29] I conducted research in multiple settings including individual villages, local markets and regional markets, and in the state capital, Patna. I interviewed agricultural input dealers, agricultural commodity traders, local politicians, state, district and block level bureaucrats, agriculture extension officers, local NGOs leaders, international donor agency staff, international private sector company representatives in the state, agriculture researchers, local reporters and university faculty. I visited research and development projects around Bihar and interviewed farmers about their experiences, shadowed private sector input dealers as they traveled to local villages to convince farmers to buy their seeds and equipment, and attended many agriculture fairs, government organized farmer trainings and state level development conferences run by international NGOs and international research organizations (see Table 2.5).

[29] During this time, I was also traveling to other parts of India and Nepal for separate research projects on drip irrigation and solar powered irrigation pumps, however the bulk of my time was spent in Bihar.

Table 2.8: List of interviews and participant observation conducted in Bihar as part of fieldwork.

Note that the list excludes ethnographic work in Bathani village which is difficult to quantify as much of the learning consisted of repeated interactions with the same individuals over long periods. That said, many of the other interviews in reality consisted of repeated interactions. In these cases, individuals are listed only once even when discussions with informants occurred at more than one sitting.

Interview / Participant Observation Type	**Sample Size**	**Types of Data Gathered**
State level public sector actors (e.g. Agriculture Production Commissioner)	15	Information on government priorities and programs for rural development.
District level public sector actors (e.g. District Agriculture Officer, Block Agriculture Officer).	12	Information on government program implementation and evaluation of technology in Gaya district. *Note that many of these actors were interviewed multiple times over multiple years with ongoing relationships.*
Private sector actors (e.g. MIS company representatives, local seed vendors, local diesel engine vendors, representatives multi-national seed companies).	32	Information on agriculture technology and agribusiness trends. Private sector observations of rural sector and government programs. *Note that many of these actors were interviewed multiple times over multiple years with ongoing relationships.*
NGO actors (Both leadership and staff of local and international NGOs).	23	Evaluation of technologies; technology policy, government programs and barriers facing poorest farmers. *Note that many of these actors were interviewed multiple times over multiple years with ongoing relationships.*
Bihar-based academics (including agronomists, soil scientists, economists, sociologists among others).	15	Overall impressions of development policy in Bihar under Chief Ministers Lalu Yadav and Nitish Kumar. Evaluation of barriers to inclusive rural development.
Journalists	5	Overall impressions of development policies in Bihar with specific focus on agricultural policy.
Political events attended	3	Observed government actors including Nitish Kumar engage with constituents around development agenda.
Development conferences observed / participated	8	Included a mix of highly international development conferences and conferences with a more domestic audience.
Farmer extension & training events observed	12	Attended government organized trainings focused on the system of rice intensification; use of pesticides and direct seeded rice-wheat cropping systems. Observed the interactions between trainers and farmers.
Farmer focus groups conducted	13	Focus groups conducted with groups of farmers usually around evaluations of specific technologies including system of rice intensification (SRI); drip irrigation (MIS) and solar irrigation pumps (SIP).
Farmer interviews (outside Bathani village)	40	This is an approximate amount for the number of farmers I interviewed outside Bathani village, excluding the survey. It is difficult to estimate the total number of farmers I interviewed individually especially when those interviews took place in informal settings such as markets or at other agriculture related events.

Perhaps most importantly, I immersed myself in a single village, Bathani[30], to serve as a cornerstone of my analysis. I spent several months traveling to Bathani on a daily basis, leaving my rented room around 7am and returning at dusk. While I had originally hoped to live in the village, my local contacts felt that there was too much risk involved for a foreign female to stay in a remote village overnight. This is because there is an ongoing low-level Naxalite insurgency in much of rural Bihar. [31] In fact, there are some parts of rural Bihar where power is firmly in the hands of the Naxalite insurgents and where government officials largely avoid visiting day or night. While the part of Bihar where Bathani is located is more firmly under the control of the state government, most of my colleagues felt that my security could not be guaranteed at night, unless I chose a different village very close to a major city which would undermine the research design. I eventually had to compromise, renting a room in a guest house in a nearby smaller city and traveling to Bathani by motorcycle to spend the day immersed in the village. The motorcycle trip took 30 to 45 minutes. I spent weeks at a time commuting to Bathani interspersed with time in the district capital Gaya, the state capital Patna, and traveling throughout Bihar. This helped me to understand my experience in Bathani in the context of the larger sociotechnical regime facing the agricultural sector in Bihar. In total, I spent over 15 months in the field in 2014 and 2015, in addition to several trips to Bihar prior to 2015. My fieldwork concluded in January 2016.

To prepare for this ethnographic approach, I learnt Hindi over the course of several trips to India and developed strong comprehension skills (and much more modest speaking, reading and writing skills). While fluent Hindi would have of course been ideal, as a foreign woman, traveling alone in Bihar was never an option. I therefore hired a local translator, Pranav. Pranav's usual day job was as a part-time

[30] Bathani is a pseudonym I selected for my primary field site to maintain the anonymity and privacy of the village. The names of the hamlets or tolas in Bathani have also been given pseudonyms. Other villages in the data set are described as villages 2-12 (though I do include the actual districts where each of the villages is located).

[31] The Naxalite insurgency is an ongoing conflict between some Maoist groups known as Naxalites and the Indian government. The Naxalites control territory in the Indian states of Bihar, Jharkhand and Andhra Pradesh.

employee for a local NGO working on female empowerment. While he was not trained as a translator, his local knowledge and the fact that most of his family worked in agriculture in the Gaya district made him an invaluable part of my research process. Pranav and I worked as a team in the field. He would usually translate my questions into Hindi and other local dialects. However, Pranav only sometimes needed to translate responses back into English when I felt I had not fully understood the nuances of a response. We developed a specific set of hand signals so he would know whether I wanted responses translated back into English or not. This greatly improved the ease and fluidity of conversations with farmers in Bathani. My ability to understand spoken Hindi made it possible for me to capture nuances in conversations with farmers that might be 'lost in translation' when communicated through a translator who may not have a complete grasp of the goals of the research program or understand when new relevant themes emerged (an important part of grounded research) (Glaser and Strauss, 1967; Charmaz, 2014).

I complemented my ethnographic research in Bathani with a survey conducted in January 2016 in both my primary village and an additional 11 villages in both South Bihar (seven villages) and North Bihar (four villages) for a total of 12 villages which I refer to throughout this paper as the 12-village survey. I used the results of the 12-village survey to triangulate (Jick, 1979) my qualitative understanding from Bathani and wider qualitative fieldwork across Bihar (see Appendix 2 for descriptive statistics of the 12 villages).[32] The 12-village survey included both quantitative and numerous qualitative or open-ended

[32] The 11 additional villages were selected semi-randomly from the 2011 census. Specifically, I purposely selected three districts: Gaya, Jehanabad and Madhubani for their varied characteristics including distance from Patna (Bihar's capital city) and whether they were located in North or South Bihar. In each of these districts, I randomly selected four villages using the list of villages in the 2011 census, however I first constrained the set of villages from which I drew the random sample to villages with more than 100 households where at least 60% of adults gained their primary income from agriculture in order to ensure that the villages selected had a large enough agriculture sector that non-use of technology was not due to lack of interest in agriculture. Within each village, a stratified sampling approach was used. The survey team first recorded the general descriptive data on the village including the number of *tolas* and breakdown of castes by *tola*. They then randomly sampled households at the *tola* level to ensure that the sample was approximately representative of the caste composition of the village. The survey team limited respondents to households engaged in agriculture either on their own land, as a sharecropper, or tenant farmer before conducting the survey. This limited the sample to households that could speak with experience to the issue of agricultural technology adoption. Thus, if a household worked exclusively in brick kilns or as migrant labor in another state, they were not sampled. It is also worth noting that I made every effort to speak to the head of households for each survey. There are advantages and disadvantages to this as it certainly excludes the voices of women farmers. However, based on my fieldwork in Bathani, I felt that

responses. I travelled with my survey team to understand the context of each of the additional 11 villages where the survey was conducted including the overall electricity situation in each of the villages, their proximity to local and regional markets and input dealers and other factors that may influence the benefits farmers derive from agricultural technology and the barriers farmers may encounter in the technology adoption process.

Over the course of the fieldwork for this project, I became a careful observer of agricultural technologies, asking farmers about the technologies they used, their benefits, drawbacks and tradeoffs. I studied the decisions of farmers with respect to use of technology both in Bathani my primary field site, but also on field visits to many other parts of Bihar as I traveled with private sector companies, extension officers, NGOs and international aid organizations to the villages where they were working. Not only did I want to understand how particular technologies came to be used by farmers in Bihar, I was also interested in the technologies that were not there, but perhaps should have been. For example, the only time I found a farmer using drip irrigation in the field was when I explicitly went to the field with a list of farmers who had received a subsidy for the technology.[33] The lack of drip irrigation technology was particularly conspicuous due to a government program offering a 90% subsidy on drip irrigation, which had been ongoing in Bihar since 2006 (see Section 2.6.3).

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response quality around technology adoption was likely to be higher when speaking to the head of household. As the aim of this study was to understand the sociotechnical causes barriers to technology use at the household level, this seemed like the right tradeoff to make. A separate study of its own could be done looking at the inter-household impacts of technology use. (If I were going to begin such a study, I would start with the overwhelming number of households that still do their threshing of paddy by hand with female household labor rather than rent the relatively inexpensive threshers that are widely available on the market for low rent. This include threshers both powered with a human foot, but far less backbreaking than the manual method with no tools and even electric threshers which require only single-phase electricity. From everything I could tell in Bathani, the choice to not rent a thresher was simply a matter of sufficient female household labor and lack of concern for the drudgery of the work involved.)

[33] I also found a farmer using drip irrigation in the 11-village survey. The farmer turned out to be one of the largest farmers in the data set from Bihar's colonial landlord or *zamindar* caste, who used his drip irrigation which he purchased with a 90% subsidy on his profitable teak farm.

Overall, my fieldwork focused on understanding technology adoption in its sociotechnical context including the actors and institutions that are inextricably linked with the availability of technology at the local level. The chapter looks at the technologies in use in the 12-village dataset (as well as the technologies in limited use) to understand the barriers preventing the poorest farmers from realizing greater benefits from the available technologies in Bihar.[34, 35]

2.5.1 Technology Adoption and Changes in the Sociotechnical Regime

One insight from the 12-village survey – which reinforced my qualitative findings and original intuition about Bihar as a field setting – was that Bihari farmers have indeed experienced significant change over the past two decades with respect to the technologies they use. In the 12-village survey, farmers were asked when they began using a technology (conditional on having answered that they use the technology in the first place). The data in Figure 2.7 shows very low rates of use of all of the technologies prior to 2000. Moreover, large spikes around 2005 and 2010 in most graphs underscores the likely relationship between the changing sociotechnical regime in the state, the increased focus on agricultural development embodied in the 2008 and 2012 Agriculture Road Maps, and increased technology use by farmers.

[34] Because of the focus on technologies in limited and widespread use, this chapter does not address the invention stage of the innovation system. One question that is left open at the end of the chapter is why there are no pro-poor technologies in Bihar. Whether this is because of missing incentives for invention, or because this category of technologies is intrinsically small, is left as an open question.

[35] One significant drawback of the research design with respect to the issue of poverty is that it does not in general address benefits with respect to the needs of landless households who do not either take land on lease or sharecrop. While I did my best to understand the impact of technology on labor, the overall methodology which uses technology use as a proxy for benefits, does not leave room for easy inclusion of this marginalized group. It is a drawback of this methodology for studying the distributional impacts of technology.

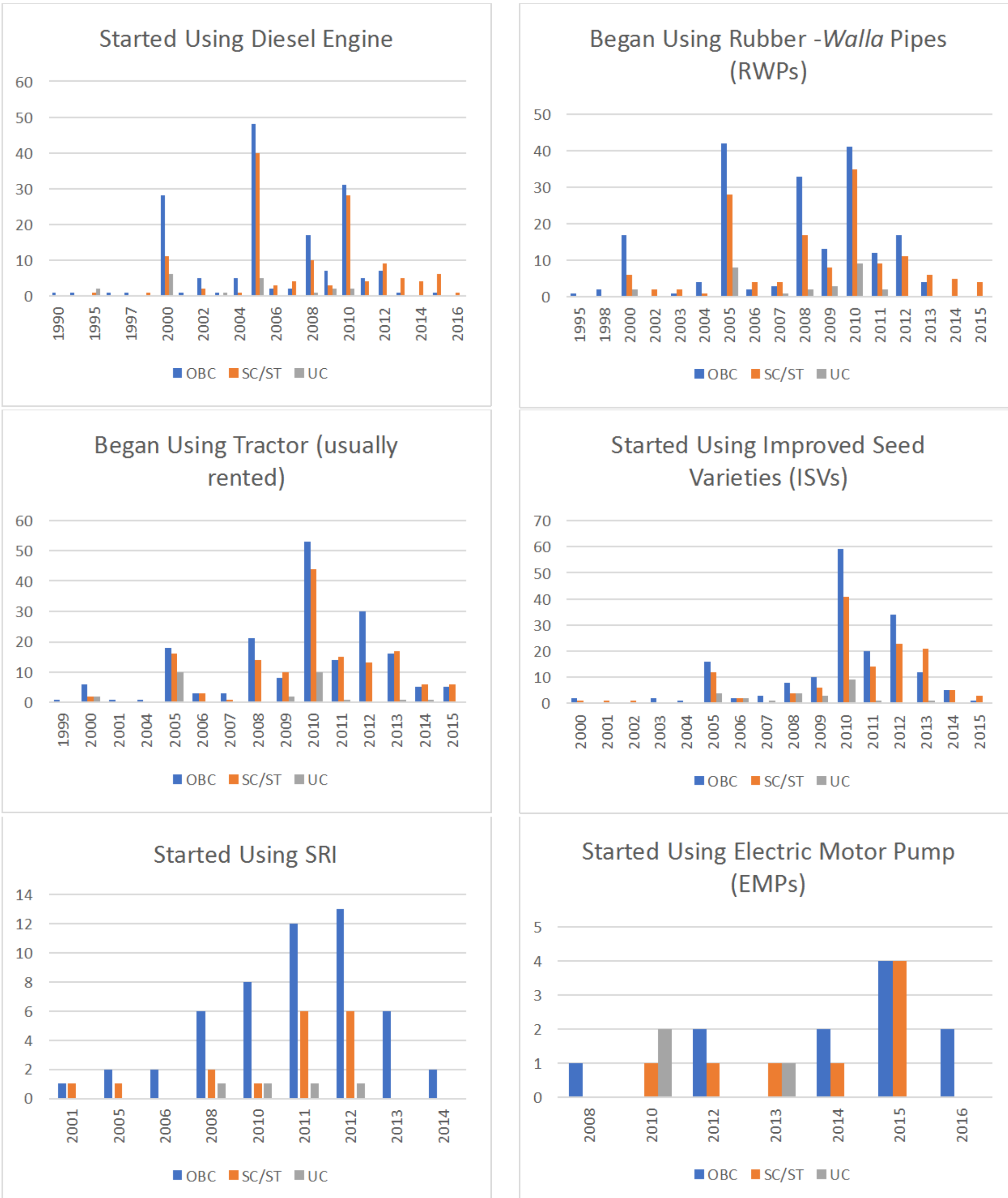

Figure 2.7: Technology adoption in Bihar since 1990.

Y-axis is number of households (HH) in the 12-village survey who said to have started using a specific technology in a given year since 1990 (total HH sample size 412; includes sharecropping HH).

Perhaps the most striking graph in Figure 2.7 is for improved seed varieties (ISV). ISVs were not in common use until 2005. This is decades after the Green Revolution with its combination of improved seeds, fertilizers and controlled irrigation that had transformed the agricultural systems of many other parts of India (Parayil, 1992). Figure 2.7 should, of course, be viewed with some skepticism. Farmer recall on the year of technology adoption is imperfect. The data tends to cluster around five and 10-year intervals (e.g. 2000, 2005 and 2010). This is likely an artifact of farmers' tendencies to give one of these "multiple of five" years as an approximation for when they began using a technology. Nevertheless, based on longer discussions with farmers, I am confident that the technology adoption timeframes should be accurate within three to five years of the date given. This means, for example, that improved seed varieties (ISVs) did not enter widespread use until after 2005 with a significant peak in 2010. Understanding what drove the widespread adoption of ISVs in Bihar, so many years after other regions of India, is one of the goals of the case study on ISVs in Section 2.6.6.

The fact that many agricultural technologies began to scale into widespread use in Bihar decades after they had been adopted in other parts of India, means that it is possible to study the ways in which actors and institutions influence technology adoption and in particular, which groups benefit and which do not in real time. In many ways, this makes Bihar an excellent field setting for the empirical investigation of the sociotechnical mechanisms undergirding the distribution of benefits of agricultural technologies. This is because farmers are currently involved in the messy process of deciding whether or not to adopt new technologies, and are available to talk about the reasons for their adoption or non-adoption in real-time.

At the same time that Bihar is a good case study because of the immediacy of the change, it is also in other ways a poor case study because the long-term dynamics of technology adoption and the associated distribution of benefits remain unknown. This is in contrast to states such as Punjab or Gujarat where Prakash's 2005 study of groundwater extraction captured the socioeconomic implications of technological change over multiple generations (Prakash, 2005). This chapter on Bihar is limited in its historical scope. For example, as I discuss in Section 2.6, the transition from diesel engines to electric motor pumps (EMPs) is so recent, it is impossible to say for sure how the distribution of benefits will ultimately be allocated across socioeconomic groups. What is clear from other work looking at groundwater markets in India, is that the way benefits are ultimately distributed will be highly dependent on both infrastructure and institutions created by state and national level actors. In the case study on EMPs (Section 6.4), I go into further detail about the different possible outcomes for the poorest farmers in Bihar as electric motor pumps become more widely available. By drawing on scholars such as Prakash (2005), Mukherji (2006) and Shah (2009) and their work on groundwater economies such as Gujarat and West Bengal, it is possible to reflect on the possible futures for Bihar's changing irrigation landscape.

The overall picture that emerges from the adoption data in the 12-village survey is that the shift from the Lalu to Nitish period strongly coincided with a shift in rates of agricultural technology adoption. This suggests that Nitish's technocratic approach to development did lead to changes in the agriculture sector. Assuming – as I have in the methods section of this chapter – that continued use of technology can be interpreted as benefits of technology, the rest of this chapter seeks to understand the extent to which different socioeconomic groups of farmers benefited from the changes in the agriculture sector led by the changing sociotechnical regime under Nitish Kumar.

2.5.2 Bathani: Primary Field Site

Bathani, my primary field site is located in Gaya district in South Bihar bordering the State of Jharkhand. Gaya is known for the city of Bodhgaya where the Buddha is said to have attained enlightenment. Other than the district capital, also called Gaya, and nearby Bodhgaya, the district is largely rural, agrarian and poor. The majority of farmers in the district are subsistence farmers with landholdings of 0.2-0.3 ha and agriculture incomes averaging USD 250 per year (Govt. of India, 2001).

The farmers in Gaya district also suffer from droughts and water insecurity. Three out of five years between 2010 and 2016 were officially designated as drought years by the government. Even in years without droughts, with the exception of the monsoon season, farmers need access to irrigation to grow crops. Unconstrained by water, farmers in Gaya district can grow three crops per year: summer (March-June), monsoon (July-October) and winter (November-February).[36] But in reality, many farmers are only able to grow a single crop per year due to either lack of access to, or high costs of water.

Despite the drought conditions in the district, the water scarcity most farmers face is not physical. Groundwater tables are relatively high (15-30 feet) and pumping groundwater requires relatively shallow borewells (50-100 ft) compared to other states in India where borewells can be deeper than 1000 feet (e.g. Gujarat and Karnataka). Moreover, significantly larger groundwater withdrawals (as compared to current withdrawals) are sustainable due to the hydrology of the region which is frequently renewed through rivers and runoff from the Himalayas (Central Ground Water Board, 2013).

Instead, the barriers to water access for farmers are financial. Underinvestment in surface irrigation infrastructure by the State has left farmers with no other choice than to pump groundwater. Without access to surface irrigation, farmer's lift groundwater using either diesel engines or electrical motors. In states like Gujrat and Punjab (major agriculture producers in India) almost all farmers have access to the electric grid (though intermittency issues mean that farmers often rely on a combination of electric pumps and diesel engines (Smith and Urpelainen, 2016)).

In contrast to the Western States, Bihar's power situation is bleak (or at least was bleak at the time of fieldwork). As of 2009, nearly 40% of villages in Bihar were not connected to the electricity grid (Oda and Tsujita, 2011) and Bihar's annual per capita energy consumption (122 kWh) was the lowest among

[36] The major monsoon crop is paddy (rice). Winter crops when grown include wheat, pulses, mustard and maize. Summer crops which are rarely grown by most farmers worked with are usually robust cover crops and for farmers who have economical access to surface irrigation, vegetables and sugar cane (which takes 18 months to mature).

Indian states (Oda and Tsujita, 2011).[37] The high cost of diesel, especially in comparison to the highly-subsidized electricity provided in Western India, translates to high and often unaffordable costs of irrigation for Bihari farmers. Indeed, farmers in Bihar likely pay about twice as much for water as their Gujarati peers (Kumar, Scott and Singh, 2013). The combination of limited surface irrigation, limited grid connectivity and expensive diesel means that almost all irrigation pumps in Bihar operate on diesel and in villages without electricity, farmers are forced to rely either on increasingly expensive diesel, or increasingly erratic monsoon rains for their monsoon (paddy) crop. Farmers that rely on the monsoon for paddy often simply forgo winter and summer crops or only grow crops on a portion of their landholding.

Bathani (see Figure 2.8) is a beautiful village with an undulating landscape. It is a mid-sized village approximately 20 kilometers from the district headquarters with a population of just under 200 households. The village is located next to a winding tree-lined riverbed. Except during the monsoon season (July – September) the river is dry, yet just below the sandy surface, water percolates ensuring that the vegetation around the river remains lush even in the summer/dry season.

[37] The focus of Nitish's government on extending electricity access has almost certainly improved this figure.

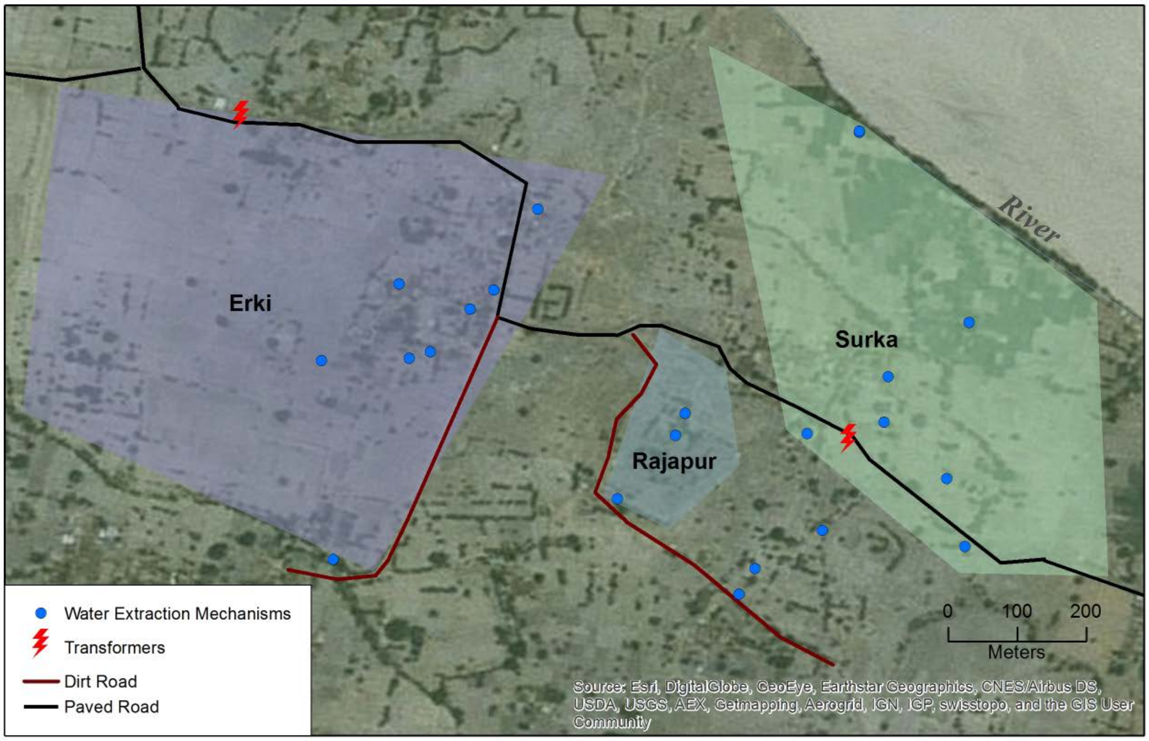

Figure 2.8: Map of Bathani village in Gaya district.

Map highlights the three tolas or hamlets Surka, Rajapur and Erki. Blue dots show locations of wells and red bolts show locations of the newly introduced transformers. Note that not all wells in Bathani are created equal as some are able to provide water 24 hours a day, while others allow farmers to pump water for at most of few hours before running dry. The types of wells by tola are listed in Table 2.6.

Two and a half kilometers away from Bathani, a larger village, Roh, is a focal point for multiple agricultural villages in the Area. Roh's Friday market is a bustling place where many farmers from Bathani go both to sell their agriculture produce, but also to buy inputs such as seeds, fertilizers and other farm equipment and generally to interact with the larger community. Like any market town serving multiple villages, it is a social space where farmers talk politics, meet with important local power brokers whether official representatives of the State or wealthy businessmen and landholders. It is also a place to learn about new agriculture technologies and practices. It is here that opinions about the value of different technologies are often formed. Private seed, fertilizer and other input supply stores line the main market street. Thus, while much of my ethnographic fieldwork took place in Bathani, I also spent a lot of time in

Roh learning from input dealers and market middle-men and farmers from other villages who often approached me and wanted to talk.

I selected Bathani as the primary site for several reasons. First, it is distant enough from the district headquarters that agriculture makes up a substantial portion of most household's labor activity and income. Second, Bathani is made up of three tolas or hamlets (Surka, Rajapur and Erki), which differ both in the caste[38] composition, socioeconomic status and access to natural resources.[39] Third, three-phase electricity[40] was introduced to one of the tolas (Surka) shortly before my research began. Three-phase electricity (rather than single-phase) is required to run motorized water pumps to lift groundwater. When I began my fieldwork, it had just become available in one *tola*, but not the other two. The introduction of three-phase electricity particularly motivated my selection choice because I wanted to observe in real-time how the introduction of electricity shaped farmer decisions about technology adoption across Bathani's *tolas* and socioeconomic groups.

Surka *tola* (see Table 2.6) is the wealthiest of the three *tolas* measured in terms of landholdings as well as caste composition. The 74 families in Surka, own a total of 58 acres. This works out to an average of 0.79 acres per household. When only OBC households in Surka are considered the average goes up

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[38] I use the terminology in common use in Bihar to refer to different caste groupings and occasionally refer to specific castes (e.g. *Yadavs*) with reference to the larger category they are generally categorized in. The caste groupings include: 1. "upper castes" (UC). These castes have traditionally formed India's elite. In Bihar, the major forward castes have traditionally controlled the vast majority of agriculture land. The lower castes are grouped into several categories. The first, known as "other backward castes" or OBCs are generally the most socially and economically empowered of the lower castes. Scheduled Castes and Scheduled Tribes (SCs and STs) are a level below OBCs in terms of the social and economic empowerment. It is also worth noting, that the most common way to refer to the three caste categories is to use acronyms to describe OBC and SC/ST castes but to use the full words when describing UC castes (upper castes). I find this discrepancy unfairly biased and use acronyms in most cases to describe all three groups. I sometimes continue to use the full spelled out version when the use of the caste category is meant as an adjective rather than a noun (e.g. upper caste hegemony; lower caste empowerment).

[39] Generally, in Bihar, different *tolas* in a single village will have significantly different compositions of castes and sometimes religions.

[40] Three-phase electricity as opposed to single-phase electricity is needed to run the size of electrical motors necessary for lifting water for agriculture purposes. Without three phase electricity, farmers must rely on diesel powered pumps to access groundwater for irrigation.

significantly to 1.15 acres. Surka is roughly evenly divided between OBC and SC/STs castes with slightly more OBCs than SC/STs. The largest caste group in Surka are *Yadavs* who belong to the OBC caste category. Moreover, two large *Yadav* families account for approximately 40% of the population in Surka. This ensures the *tola* is extremely close-knit. Over the course of my fieldwork, I observed the *Yadavs* of Surka working together to solve problems and invest as a group in new technology – unmistakably a strong example of collective action supporting technology adoption. In addition to being locally powerful, the *Yadav* caste also gained more state-wide power during the era of Chief Minister Lalu Yadav who belongs to the same caste. Despite the transition from Lalu to Nitish, *Yadavs* maintain a significant hold on local political institutions in the Gaya district.

Table 2.6: Bathani Village descriptive data by tola.

Functional wells are defined as wells where farmers can extract water from well using a diesel or electric pump set for at least 8 hours in a 24-hour period. Many of the other wells, particularly in Rajapur would give water for 1 to 3 hours a day, which is insufficient to guarantee water for irrigation for most purposes.

Tola Name and Caste (Number of Households)	Average HH Members	Average Land Owned per HH (Acres)	Total Wells Owned	Functioning Wells* [Non-functioning wells]
Surka (74)	6.3	0.79	11	9 [2]
OBC (39)	6.3	1.15	5	5 [0]
SC/ST (35)	6.2	0.39	6	4 [2]
Rajapur (17)	6.2	0.26	3	0 [3]
OBC (2)	6.5	0.20	0	0 [0]
SC/ST (15)	6.2	0.27	3	0 [3]
Erki (70)	5.8	0.42	8	6 [3]
OBC (22)	5.0	0.84	6	5 [1]
SC/ST (48)	6.2	0.25	2	0 [2]

Rajapur *tola* is located across the road from Surka and up a small hill. Relative to Surka, Rajapur is small both in terms of number of households and landholdings. There are 17 families in the *tola* who own a total of 4.42 acres or an average of 0.26 acres per household. The *tola* is overwhelmingly made up of families from SC/ST castes. Only two families in Rajapur belong to an OBC caste and these families live close to the border between Rajapur and Surka and tend to associate more with residents of Surka than Rajapur. Apart from the two OBC households in Rajapur, most residents of Rajapur are excruciatingly poor. Residents of Rajapur regularly skip meals (an average of 1.8 times per week) because of a lack of food availability. This is in stark contrast to Surka and Rajapur tolas where less than 10% of households report skipping any meals due to lack of food availability. The food scarcity in Rajapur is especially acute in monsoon season when the paddy crop is in the field but before harvest. Many households in Rajapur earn extra income by processing liquor from the fruits of local trees which the men in Rajapur drink (often to excess) and sell to their neighbors in both Surka and Erki (though the *Yadavs* from Surka would never admit to drinking).

Finally, Erki *tola* consists of a wider variety of castes than either Surka or Rajapur. The economy of Erki is more diversified than Rajapur or Surka with several shop owners as well as residents who earn their incomes outside of the village as drivers, construction workers in the district headquarters, and migrant laborers to other states. There are 70 families in Erki who own 29 acres of land. This average land holding is 0.42 acres per family. Overall interest in agriculture in Erki is lower than in Surka where the Yadav families in particular have been investing heavily in improving the productivity of their land. In many ways interest in agriculture in Erki is also lower than in Rajapur where agriculture, despite being capital and land constrained, is essentially for food security and survival. The waning interest in agriculture in Erki has made for an interesting dynamic – while some households in Erki have moved away from agriculture by opening stores in Roh or working in Gaya for daily wage labor, others have chosen to invest heavily in agriculture often renting land from their neighbors who want to exit agriculture without selling their land.[41] As more and more households move their household labor out of

[41] In other cases, households in Erki give out their land on a sharecropping basis to neighboring households in Erki or to farmers from Surka or Rajapur *tolas*. While the residents of Rajapur are in the direst need of the extra income they could earn through sharecropping, residents of Erki expressed strong preferences to work with farmers from Surka who they viewed as more skilled and more socially acceptable than those from Rajapur.

agriculture, the families in Erki who have chosen to specialize in agriculture are increasingly investing in technology. This includes borewells both as a source of irrigation water for their own land, but also as a source of revenue generation by selling water to other farmers. In many ways, Erki is a potential model for a sustainable future for Bihar's small landholders, where some must inevitably go into other industries. In turn this reduces land scarcity for those farmers who remain, allowing them to invest in more productive agricultural systems.

Farmers across all three *tolas* in Bathani almost exclusively cite water availability as their primary constraint to improved agricultural productivity and income. Out of 127 households in Bathani who responded to a survey question about their biggest barrier to increased agricultural earnings, 121 named access to or cost of water as the primary barrier. Only six households did not name access to or cost of water as their primary barrier. Of those six, four named capital constraints more broadly, which in all likelihood includes cash to purchase diesel or buy water from other farmers. The other two households named a lack of human capital resulting from disability and ill health of a family member.

However, despite the uniform opinion in Bathani that water is the biggest barrier to agricultural productivity, both economic and physical access to water varies dramatically between the three *tolas.* The variation in access to water is due to the physical geography and hydrology of Bathani, but also to capital investments in water extraction infrastructure including open wells and borewells and other irrigation infrastructure by private farmers as well as government actors.

In addition to Surka's significant advantages in terms of landholding per capita, Surka *tola* is also endowed with a higher overall availability of groundwater as well as easier access to water in the sandy riverbed. Surka relies heavily on borewells as well as open wells. Farmers in the *tola* own a total of 11 wells, nine of which provide water 24-hours a day. The two semi-functional wells belong to two SC/ST families. Both of these wells are open wells with a depth of about 50 feet and run for approximately two hours before needing to go through a process of recharge which takes four to five hours. In addition to

Surka's wells, a government subsidized project in 2014 constructed a PVC pipe from the riverbed to the center of Surka's agricultural land. The PVC pipe from the riverbed significantly reduced the quantity of diesel required to pump groundwater (because the necessary lift from the river bed is very limited) and thereby the unit cost of water for the farmers in Surka. In order to receive the PVC pipe connection, the farmers in Surka who belonged to the politically powerful *Yadav* caste, lobbied (and bribed) their connections in the district headquarters to secure the subsidy. After the construction of the PVC pipe, the village was able to expand both their winter and summer area crops and adopt higher value vegetable cultivation in these seasons.

The introduction of the three-phase power transformer on the road through Surka in the spring of 2015 also significantly impacted the cost and accessibility of water to farmers in Surka. The transformer was installed on the main road that passes through Surka hamlet. There were rumors in the other two *tolas* that the Yadav families in Surka had used their political connections not only to ensure the three-phase power came to Bathani, but to dictate the location of the transformer on the road closest to their land. These rumors were however never corroborated by anyone in Surka (whereas the farmers in Surka freely told me about their efforts to secure the PVC pipe).

All farmers in Surka knew that the high water-tables in their *tola* combined with newly affordable energy for pumping groundwater could transform both their productivity and profits. Over the course of my fieldwork, farmers in Surka began connecting their wells to the transformer at their own cost and labor, and began to make additional investments in new borewells.[42] These investments were all made because the monthly flat-rate cost of electricity at 220 *rupees* (approximately 3.30 USD) was significantly

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[42] This includes what I assume to be the dangerous work of stringing their own electricity wires from the transformer to their borewell using for lack of a better word homemade electrical poles and without supervision by any kind of state electricity agency or licensed electrician. At first I thought farmers in Bathani were stealing electricity, but I was told by multiple sources that they would later register their homemade connections with the government or face fines. In this way, the cost of creating a within-village grid was entirely born by the households themselves.

lower than the cost of pumping water with diesel. In addition to major investments in technologies that could be supported by access to electricity, farmers across Surka were also investing in almost all technologies at higher rates than the farmers in the other two *tolas.*

Unlike Surka, Rajapur hamlet has little access to water for agriculture and even drinking water is limited. The 17 families in Rajapur own a total of three wells (excluding two government-built hand-pumps which are intended for drinking water but are often used as an extremely labor-intensive source of water for small kitchen gardens). The three wells in Rajapur are all open wells with a maximum depth of 50 feet. Because the topography of Rajapur is uphill and farther from the river than either Surka or Erki, the three open wells in Rajapur have extremely limited functionality. Two of the wells run for one to two hours per day before they must be left to re-charge for several hours. The third well in Rajapur is completely unusable except during monsoon when it is sometimes used to store residual water.

The water scarcity in Rajapur not only impacts the agriculture decisions farmers make, but also permeates every aspect of the daily rituals in the *tola.* In the mornings and evenings, a line often forms around the two government-built hand-pumps which are used for everything from drinking water to washing laundry. Despite their limited utility, the two functioning open wells are used by the farmers in Rajapur to their maximum capacity. Because of the limited availability of water in Rajapur, most farmers do not own their own diesel pump, but rather rent them from farmers in Surka for the hour or two that the well is functional. This rental relationship adds an added dimension of uncertainty to their lives because their neighbors in Surka only rent out their diesel pumps when they are not otherwise in use and often do not clearly communicate availability with their renters.

In terms of water availability, Erki like Rajapur has no access to the river, but its land resources are low-lying compared to Rajapur so that a much higher fraction (50%) of Erki's wells are functional. There are eight wells in Erki, five of which function for 24-hours a day and three of which have limited functionality of around three to four hours a day. Like in Surka, the SC/ST castes are more likely to own the semi-functioning wells in Erki and the OBC castes are more likely to own fully functioning wells. Farmers in Erki wish that the government had also built a PVC pipe for them when they did the one in Surka, but their wish did not materialize.

The socioeconomic transition in Erki from an economy based on agriculture to one based on increasingly diversified wage-labor has also allowed individual farmers to specialize in agriculture. One OBC household in Erki (whom I will discuss in greater detail in Section 5.2) owns two of the most powerful wells in Erki which currently run off of powerful diesel engines. Moreover, towards the end of my fieldwork, when farmers in Erki received the good news that a three-phase transformer would be installed on the road belonging to a neighboring village but on the outskirts of Erki's agricultural land, this same farmer began immediately to allocate money toward the construction of a new borewell on his cousin's property nearest the new transformer. It is likely that by the time I go back to Bathani, not only will this household be the main provider of irrigation for the entire tola, but it will also be operating much of the agricultural land through leasing and sharecropping arrangements with neighbors. This consolidation dynamic is only possible however because of the access to water (and now electricity) in Erki. Similar dynamics would be unlikely to emerge in Rajapur where the inferior topography limits the potential value of land and thus the desire of farmers with more capital to use the land on a sharecropping or leasing basis.

The variation in both physical and economic access to water across the three tolas in Bathani significantly impacts the benefits farmers derive from their land. Farmers in Surka have almost unfettered physical access to water and their economic costs for extracting water are also the lowest across the three tolas. Even before the transformer was installed on the road in Surka, the PVC pipe connected to the riverbed reduced the cost of lifting groundwater by about 20-30%. In Rajapur, irrigation water is both physically and economically inaccessible for many families. Finally, in Erki, physical water access is significantly better than in Rajapur, but limited compared to Surka. Costs in Erki are also higher (though the costs will also likely decrease in the future with the introduction of the new transformer on the outskirts of Erki).

The differential access to water in each of the three *tolas* impacts cropping intensity (see Table 2.7). Cropping intensity is a common measure of the number of times a crop is planted per year in a given area. In theory, the climate and agroecological conditions in Bihar can easily support three crops per year on a given piece of land. In contrast, in Bathani average cropping intensity is 1.91 crops per year, but this aggregate number smooths over significant inter-*tola* and inter-caste variation. OBC farmers in Surka for example, grow an average of 2.06 crops per year – meaning that a small fraction of the land in Surka is planted in all three seasons.[43] In contrast in Rajapur SC/ST households plant an average of 1.69 crops per season, meaning that a significant fraction of their land is only under cultivation during the monsoon season, usually with relatively low value rice. In contrast, Surka's farmers with more physical and economic access and control over their water are increasingly transitioning towards higher value vegetable crops. However, the highest cropping intensity in Bathani is reserved for the OBC farmers of Erki. These farmers however tend to focus more on rice and wheat than higher value vegetable crops due to scarcity of household labor. Because of this, the value of output is highest in Surka, despite the slightly higher cropping intensity in Erki.

Table 2.7: Cropping intensity in Bathani by tola and caste.
Note that only in Surka are some farmers able to plant more than two crops per year.

Household Caste	Surka	Rajapur	Erki	Bathani
OBC HH	2.06	1.72	2.12	1.96
SC/ST HH	2.09	1.67	1.96	1.86
All households	2.07	1.69	2.00	1.91

[43] As the survey question asked about cropping intensity in the previous year, it is likely that cropping intensity rose significantly in Surka after the installation of the three-phase transformer. This was not captured by the data.

The easy accessibility of water for irrigation in Surka, has not only given the farmers in the *tola* the opportunity to increase their cropping intensity and specialize in high value crops, they have also benefited from more help from district level extension agents and even from NGOs. Whenever outside technical support comes to Bathani it tends to naturally concentrate in Surka *tola.* This is not because the NGOs or extension agents are necessarily overtly discriminatory against Rajapur or Erki, rather it appears that outside actors rightly identify that their jobs will be much easier of they work with farmers who *can* benefit from their help *because* of the very fact that they have sufficient access to water for irrigation. The outside actors *hope* that if they can "plant the seed" of new technology in Surka, that it will spread to the other *tolas.* Despite this hope, the extent to which cross-*tola* knowledge and technology transfer in Bathani actually happens is very limited, due in part to limited information flows between OBC and SC/ST castes, but mostly due to the differential availability of water for irrigation which in almost every case lubricated (pun intended) the technology adoption process.

2.5.3 Ethnography of Three Households

The relationship between ownership and access to land and other capital assets, historical caste dynamics and the ability to invest in agricultural technologies can be illuminated through thick descriptions of three families in Bathani. I chose these three families as particularly illustrative examples of the important sociotechnical dynamics impacting the degree to which different socioeconomics groups of farmers in Bathani benefit from technology. In this section I describe the opportunities and constraints these three families (A, B and C) face with respect to their agricultural technology adoption decisions and how these decisions are mediated by the intertwined forces of social caste, historical land rights and resource endowments. In Section 2.6, I draw on the experiences of these families to add thick descriptions to the case studies.

Table 2.8: Land, water and well-being of three families in Bathani Village.

Attribute ↓	**Surka**	**Rajapur**	**Erki**
Names	Family A	Family B	Family C
Caste	OBC	SC/ST	OBC
Household size	4	3	8
Household literate	4	0	4
Number household members work in agriculture as primary daily activity	1	3	6
Number of times a member of household must skip meal per month	0	2-7 depending on season	0
Landholding	2 acres	2.2 acres	1 acre
Land in family since	1920s	1979	1950s
Water for irrigation source	1 borewell powered by electric motor (recently constructed). Borewell can pump water 24 hours a day.	1 open well (28 ft). Borewell is dry and has not been used since 2007. Only use rainwater for irrigation.	2 borewells powered by diesel engines. The two borewells can pump water 24 hours a day
Water seller or buyer?	In the past, would buy water. Now with new borewell no longer needs to buy water.	Does not sell or buy water. No irrigation source available even for purchase.	Water seller. Family earns approximately USD 310 annually selling water to 10 neighbors.
Number of crops grown per year	2 crops (rice in monsoon; wheat in winter)	1 crop (rice in monsoon)	3 crops (rice in monsoon, wheat in winter, vegetables on half acre in summer). Leases additional land in monsoon and winter seasons.
Technologies adopted past 10 years	Electric motor and borewell; diesel engine; tractor; improved seeds; rubber pipes; intercropping;	Diesel engine (no longer used as of 2014); tractor	Hybrid seeds; diesel engine; tractor; new vegetable crops; rubber pipes
Biggest barrier to improved agricultural income	Water	Water	Water
Reported changes in household well-being over past 10 years	**Improved*:*** *"Economic condition has gotten better and we are investing in education for our children."*	**Deteriorated*:*** *"Because of financial constraint and deteriorated health agriculture has suffered."*	**Remained Same*:*** *"We have much less land in our household due to dividing land between brothers, but investments in technology have helped maintain our standard of living."*

2.5.3.1: Family A

Family A is from the majority *Yadav* caste in Surka and owns two acres of land. The husband and wife are both in their early 40s and have two children, one son (14 years old) and one daughter (16 years old), making their landholding per household member amongst the largest for the residents of Surka. They have no plans to have additional children, so it is likely that the son will inherit the entire property without the need to subdivide the land into increasingly fragmented parcels.

Family A's primary residence is in the center of the residential part of Surka *tola* amongst multiple *Yadav* homes. Their home is one of the nicer homes in the *tola* made from both brick and mud (rather than just mud). They have a bed for every member of the household which is rare for households in Bathani. They are also among four households in Bathani that have both an electric fan and a kerosene stove, which allows the wife and daughter to cook without breathing in the smoke of the more traditional biomass burning stoves found in most homes in Bathani.

However, despite the comforts of their home, it is almost impossible to find any member of the family at home day or night. Instead, the entire family relocated to a tent closer to their agricultural land which is across the road from the residential part of Surka. They did this because they were the first family in Bathani to take advantage of the new transformer and invest in a new borewell. In addition to the borewell, they invested in an electric pump and 200 yards of electric wiring to bring electricity from the transformer on the main road in Surka to their plot which is located north of Surka closer to Rajapur *tola*. The total cost of the entire investment was 59,000 *rupees* (approximately 900 USD). To protect their investment, they sleep, cook, eat and work in a small tent they built next to their borewell and electric pump.

Their investment was not without risk. A nearby borewell built in a neighboring village never reached the water table and at a construction cost of about 39,000 *rupees* (approximately 600 USD or about 30% more than average annual household income in Bathani) was essentially sunk. At first, Family

A used their borewell cautiously, fearing that running the borewell 24 hours a day would over-tax the water supply and leave them with nothing in return for their massive investment. Slowly, they became more confident that unlike their neighbor, their investment decision was going to yield positive returns and they began to pump more and more water every day.

In addition to the borewell and electric pump set which they began using in the fall of 2015, Family A has adopted multiple technologies in the past 20 years. They began using diesel engines off-and-on in the late 1990s, but the location of their land and lack of nearby well (until the construction of their new borewell) made frequent irrigation difficult. The family therefore mostly relied on rainfall, with occasional supplementary irrigation which meant dire circumstances for their paddy crop (they left their land fallow in the winter and summer seasons).

Using supplementary irrigation became significantly easier in 2008 when many farmers in Bathani started using rubber pipes to transport water between wells and their fields. The rubber pipes replaced dug channels as a means of transporting water from wells to fields, significantly reducing labor requirements. For Family A, the rubber pipes were especially beneficial because they allowed them to transfer water over a road from an adjacent village at a higher elevation than their land. They paid their neighbor a total of 87 *rupees* (approximately 1.3 USD) per hour of irrigation (62 *rupees* for field, and 25 *rupees* for the pump rental).

In 2010, Family A began using high yielding paddy after seeing the success other farmers in Surka had had with a shorter duration paddy variety. The short duration variety benefited their family for two reasons. First, the faster growing variety meant fewer necessary irrigations in the event of drought, decreasing the likely cost of cultivation. Second and perhaps more importantly, the shorter duration seeds meant that their paddy could be harvested sooner, allowing for a winter wheat crop to be planted on time. Indeed, before 2010 the family did not bother to grow a winter crop both because of the difficulty of irrigation before the introduction of rubber pipes, and because the paddy crop was usually not harvested in time to ensure a good yield on their wheat crop before the summer heat. Now, with the addition of shorter duration paddy seeds to their technology portfolio combined with the availability of irrigation due to the introduction of rubber pipes, they were able to prepare their field in time to plant winter wheat. They also began renting a tractor in 2011 to prepare the field more quickly between paddy and wheat crops. They were able to prepare their two acres in one afternoon hour at a cost of around 2,700 *rupees* (approximately 42 USD).

In 2015, Family A adopted the practice of intercropping wheat and mustard. They did this because they observed that their neighbors growing wheat were able to harvest an additional small mustard crop for home-use without impacting the wheat yield, so they began this practice as well. This was something they had not thought about before, mostly because they were not thinking about winter crops at all.

Family A both understand the future value of their recent agricultural investment in a borewell, electric pump, and electrical wiring to connect to the transformer, and the husband and wife have sacrificed to be able to improve the productivity of their landholding. Before the construction of the borewell, the husband spent the winter and summer seasons outside Bihar, working as a clerk for a storeowner in the city of Kolkata (the capital of nearby West Bengal and formerly known as Calcutta). He would return to Bathani to help his family with the monsoon paddy crop. This sacrifice allowed Family A to earn enough money to pay the capital investment to build the borewell and connect electricity wires to the new transformer. While the husband is in Kolkata, the wife and her son are responsible for most of the agricultural labor on their land and for making decisions about which technologies to use, how, when and what to plant. Despite the scarcity of household labor, they still manage to ensure both their children continue their education and they want both of their children to attend post-secondary school. Because the husband is often away, labor saving technology such as tractors are necessary so that the wife and children can manage the two acres without him. They know that some of their decisions do not maximize their yields. For example, they helped to transplant paddy using System of Rice Intensification (SRI) methods in another family's fields in Surka and saw the yield benefits that SRI created. They still decided not to use SRI on their own fields for the time being, both because of their limited access to water (prior to the borewell), and because the increased labor investment required was not possible without more family labor available.[44] They also use the most time efficient method for planting wheat seeds in the winter (broadcast seeding) even though they know their yields would be higher if they went through a more laborious process of line seeding their fields. Even so, the family calculates that their reduced incomes now, will be compensated for in the future because they can now afford bigger ticket items like the borewell and the electric motor. They hope that one day the husband will no longer need to migrate to Kolkata. Instead they want to practice higher value agriculture on the land they own. Family A sees the investment in the borewell, electricity connection and electric motor as the first step towards realizing this goal. However, for the time being, the husband still plans to return to Kolkata seasonally at least until they see if their investment decisions yield positive returns.

Family A was always one of my favorite families to visit in Bathani. Not only were they always welcoming, but they both had novel insights and perspectives on my questions every time I saw them. They also had an advantage that many of their peers in the Bathani lacked – they had both completed significant education. The husband had finished the 10th grade and the wife had completed school through to the 6th grade. Both parents as well as their 16-year-old son and 18-year-old daughter can read and write. The parents are also certain that both their son and daughter need to stay in school. They know that in the long run their children's ability to move out of agriculture will improve their family's well-being more than any investment in agriculture they would be able to make in the short term.

The family felt that their well-being had significantly improved over the past 20 years and attributed the causal driver of all improvements to their education. Without their education, the husband

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[44] Note: There is a controversy about whether SRI takes more time or simply more skill (see Chapter 3). However, the perception of Family A was that SRI requires more labor. They gave two reasons for not adopting SRI – lack of water and lack of labor.

would not have his job in Kolkata, and the wife would not be able to make the complex tradeoff decisions about which new technologies to invest in and which ones to pass up, while her husband earned money in another state.[45] Whenever I asked a question about agriculture, the husband uncharacteristically for most male heads of households in Bathani deferred to his wife's opinion, as he readily recognized that she was the family member who was most familiar both with the technologies and economics of their business.

When I left Bathani for the last time, Family A were still getting used to owning an electric pump and the deepest borewell in Bathani (at 110 feet). They pay 220 *rupees* per month for the electricity connection to the borewell and they estimate they only need about 1/3 of the total operating time of the pump to water their own land (though they were not even certain of this). They say they eventually plan on selling water to other households, but, so far, they have only given water to other members of the *Yadav* caste. They feel uncomfortable charging other *Yadavs* for water that they are able to pump at zero marginal cost despite the significant upfront capital investment they made in their irrigation system. They have also not considered selling (or giving) water to families in Rajapur village despite the fact that the location of Family A's borewell is ideally located to provide water to Rajapur *tola*.

2.5.3.2: Family B

Not far from Family A's borewell, towards the Southwest corner of Rajapur *tola*, lives Family B. Their family is significantly poorer in terms of overall well-being than Family A. Family B live with their one unmarried adult daughter. Their son has moved to Patna to work in construction and rarely visits. The husband is 75 years old and his wife is 68. They both come from the *Manjhi* caste which is a scheduled caste that has traditionally been heavily discriminated against in Bihar. Neither the husband nor the wife can read or write. They live in a one room mud hut with 4.5 foot ceilings.

[45] When I asked about trends in well-being, the husband pointed to the fact that he and his son both wear jeans every day, something he said his family would not have been able to afford just 10 years ago.

Family B has minimal assets including one diesel pump, one cow, two chickens and three pigs, but they are raising the pigs on a "sharecropping basis", so they will only get one third of the profit from the pigs, despite doing all of the labor to raise the pigs. The sharecropping situation arose because Family B did not have the money to buy the piglets when they were born. So instead, a neighbor from a nearby village invested the capital to buy the piglets. In exchange for his investment, this neighbor will get two thirds of the profits (likely in the form of meat after the pigs are butchered). Taking care of the pigs takes approximately two hours of household labor daily. Their land is barren except in monsoon because it is far away from the river and up a slight hill and they have little to no access to irrigation. Instead, they take the pigs to the river to forage daily. The walk to the river with the pigs takes about 15 minutes and the pigs need to forage for at least an hour and a half. Each pig will likely sell for 2500 *rupees* leaving Family B with about 830 *rupees* (about 12.8 USD) per pig. Given that raising the pigs takes six to nine months and approximately two hours of household labor per day, this works out to an hourly wage of around 4 *rupees* (approximately 0.06 USD). Nevertheless, since Family B is raising the meat not to sell, but to consume and with very low household income and no alternative labor options at their advanced age, they believe that the time investment is worthwhile.

Yet on paper compared to many other farmers in Bathani, Family B is comparatively well off. In 1979 when he was 39 years old, the husband received a plot of land from the government under a land redistribution program. The size of the plot at 2.2 acres is substantial compared to average landholdings in Bathani and especially in Rajapur where the average landholding per household is 0.26 acres. Moreover, Family B has the land title documents in their name, giving them a deeper sense of security than many other households in Rajapur have. The land even came with a shallow dug well (28 feet) that was there before they received the land from the government, but unfortunately the well has gone completely dry. Because the well is now dry, they no longer have any use for their diesel engine.

Family B's land is also uphill from most other nearby wells (with the exception of the new borewell Family A recently constructed), making it difficult for Family B to buy water from another farmer, even if the cost of water were not a constraint. Because of the physical scarcity of water, Family B's field remains empty in the winter and summer. They are able to plant most of their land in the monsoon season with rice, but even this crop often struggles if the monsoon comes too late or not at all. Usually however, they manage to produce enough rice during the monsoon to feed their family for four months of the year, the other eight months of the year they buy rice and wheat from the ration shop, from the local market or from neighbors. On average, they do not have food to eat for two meals per week, and the scarcity is particularly acute during the monsoon while their rice crop is in the field. The only way the family survives is through remittances their son sends home from the money he makes working in construction in the state capital, Patna. Annually, he is able to give his family 10,000 *rupees* (approximately 150 USD), which keeps the family from starvation.

The lack of water for irrigation, as well as their own declining health, prevent the family from extracting value from their relatively large landholding. No other farmers want to take their land on a sharecropping basis in the summer or winter seasons because of its poor access to irrigation. They have only adopted two new technologies over the course of the past 20 years. In 2005, they purchased a used diesel engine, but by 2014, they were forced to stop using the diesel engine and rely on the rains because their well was too dry to make the diesel engine useful. They also started using a tractor in 2012. The husband's health was declining and ploughing their field with a bull was increasingly difficult. Ploughing their land annually costs 2,970 *rupees* (approximately 46 USD) for which they do not see a yield increase, only time saved, an asset they actually have plenty of if their health were better. Overall, between their declining health and the failed well, family B feels that their family's well-being has greatly deteriorated over the past 10 years.

2.5.3.3: Family C

In contrast, Family C, an OBC household from Erki *tola* have one acre of land and two borewells which function 24 hours a day throughout the year. Both of Family C's borewells use powerful diesel engines to pump groundwater. As of the end of my fieldwork, Family C was in the process of investing in an additional borewell that could be connected to a new transformer which was being installed on the border of Erki. Family C was paying a cousin to install the well on their property, which happened to be by the road near the new transformer. Family C planned to invest in an electric motor to pump groundwater from this borewell as soon as it was finished. My fieldwork ended before the borewell was complete and I was unable to observe the long-term outcomes of this investment.

Over the past 20 years, Family C has adopted several new technologies. They built their first borewell and bought their first diesel pump in 2005 after the death of the husband's father when the husband and his brothers divided their landholdings. After 2005, Family C only had one borewell and used it mostly to irrigate their own acre of land, though they did sell a small amount to a neighbor. However, after 2010, when rubber pipes became widely available, Family C realized that the physical characteristics of rubber pipes made the business of selling water more lucrative because it became easier to sell more water more quickly to more farmers. They also knew that their land, situated in a depression, had a very high water table that could likely sustain a second borewell. So, in 2011, they invested in an additional borewell and diesel engine and began to focus more on the business of selling water.

By 2015, family C's two borewells provided plentiful water. This access to water ensures that Family C can generate significantly more value from their one acre of land than Family B can from their 2.2 acres. In addition to their own acre of land, Family C leases an additional half acre of land in the winter and monsoon seasons. With two borewells that run for 24 hours a day, Family C has more water than they can use on their own land. They sell surplus water to their neighbors making a net profit of approximately 20,000 *rupees* annually (about $310 USD). This profit has allowed them to invest in other technologies. In 2012, they began investing in the most expensive paddy seed variety available – hybrid seeds – which had recently become available. They found that with hybrid paddy their yields more than doubled. With increased water availability, they also began growing vegetables in the summer season (increasing their cropping intensity to three crops per year). Finally, because they had the cash flow, they started using a tractor to plough their field in 2012 to save time and backbreaking labor.

In the final days of my fieldwork, Family C was investing in a third borewell (discussed above) on a far corner of Erki which they will be able to connect to the new three-phase transformer. They also hope to be able to extend wiring from the transformer in Bathani to their existing two borewells, but they are uncertain if the distance (approximately 550 meters) is too great and wanted to get more experience with the first electric pump before they did this. They also hope that in the meantime another transformer will eventually be installed by the government somewhere on the main road through Erki.

Despite the fact that Family C's costs will drop significantly when they begin to use electric motors for pumping groundwater, they have no plans to decrease the price they charge for water and are looking forward to the increased profit margins. Family C recognizes that if additional farmers invest in electric motors and begin to sell water, the market price for water will decrease. However, for the time being, they feel that most of their neighbors do not have the capital to invest in electric motors, wiring and even new wells required to make use of the transformers. They plan to use this to their advantage to reap large profit margins from selling water and reinvest the money elsewhere.

Family C is even contemplating buying more land in Erki if other farmers are willing to sell. They think that with the introduction of three-phase electricity, the potential value they can get out of the land in Erki is high, if only they had more land to cultivate. With two daughters and four sons, they have plenty of household labor and they hope to buy more land to improve the well-being of their family. Family C knows that many of the households in Erki are more focused on other forms of wage labor and practice agriculture as a secondary income and food security strategy. However, they also know that

Bihari people rarely sell their land unless they are forced to, so in the meantime they are hoping to take more land from their neighbors on lease.

2.5.3.4: Cross-Family Synthesis

The differential access that each of these three families has to water in Bathani is not accidental. Rather, it is rooted in historical contingencies which were strongly influenced by the opportunities available to their respective castes in colonial and post-colonial Bihar, as well as by local inheritance practices.

Family A's land has been in their family for several generations, at least since the 1920s. The paternal grandfather of Family A had just over six acres of land which was distributed between three sons. In the case of Family A, the father was the youngest of the three sons and because of this, while he inherited an equal share of land, he was allocated the lowest quality land after his elder brothers chose higher quality plots closer to the river. Indeed, Family A's land is up a hill from the main part of Surka *tola* and far from the river. It was not until the introduction of three-phase electricity that Family A saw the potential for real profit margins from their land.

Family C's paternal grandfather purchased their land shortly after the end of British colonialism. The land had once belonged to a *zamidar*. After the colonial government left, Family C's ancestors along with other *Yadav* families put social and political pressure on the new government and the landowner to sell off his land to local peasants. While no official government intervention took place, the *zamindar* was eventually induced to sell his through a combination of local popular pressure and fear of future land reforms. The four acres Family C's paternal ancestors bought from the *zamindar* were slowly subdivided as sons inherited portions of their father's lands. Each son continued to cultivate land with significant water resources and Family C ultimately invested in not one but two borewells so that they could earn more money selling water.

In contrast, in the 1950s Family B's caste was socially and economically marginalized and had no connections that could help their family buy land. Family B only received land in 1985 under a program to redistribute government wasteland to SC/ST farmers. Not only does Family B's land lack access to water, it is also positioned on a hill which retains very little residual moisture after the monsoon season. The topography of Family B's land makes it impossible for them to grow anything in the winter or summer seasons.

Each of the three families discussed in this brief ethnography have different historical experiences of access to both land and water – experiences that were shaped by their social caste, colonial and post-colonial histories, and the interaction of these institutional factors with the physical factors of geography and climate. These historical experiences created and still create distinct sets of opportunities and constraints for the ways in which they can benefit from agricultural technologies with implications for their overall well-being.

When asked to rate changes in their family's well-being over the past 10 years, Family A said their lives had improved, Family B said their well-being had deteriorated, and Family C said their well-being had remained the same. The experience of these three families are representative of the broader trends in the three *tolas* in which they live. In Surka, 40% of households felt their well-being had improved over the past 10 years (see Table 2.9).

Table 2.9: Perceived changes in well-being in Bathani.

Tola Name and Caste (Number of Households)	Perceived Change Household Well-being (past 10 years)		
	Improved	Remained Same	Worsened
Surka	**40%**	**41%**	**19%**
OBC (40)	48%	40%	13%
SC/ST (28)	29%	43%	29%
Rajapur	**28%**	**44%**	**28%**
OBC (2)	50%	50%	0%
SC/ST (16)	25%	44%	31%
Erki	**24%**	**35%**	**42%**
OBC (20)	25%	50%	25%
SC/ST (52)	23%	29%	48%

It is likely that these aggregate trends in well-being – just as for the three families discussed in detail – are deeply influenced by access to water, something that is most available in Surka and least available in Rajapur. The availability of water in Erki lies somewhere between Surka and Rajapur with high inter-household variability in access to water in the *tola.* This inter- household variability and especially the failure of many older wells in Erki, while newer deeper borewells have succeeded, is at least partially responsible for the high percentage of Erki's population who say that their well-being has declined over the past 10 years.

However, water access does not explain all of the differences in reported well-being. Rather, Surka is also doing better than the other two *tolas* because the households in Surka come from only two castes (*Yadav* and *Chaudhary*) and the close-knit caste networks in Surka have supported collective investments in productivity enhancing technologies including the PVC pipe (for which they invested social capital as well as financial capital). In a second example, while I was in Surka, I witnessed many of the heads of households conduct a group meeting to decide how their families would jointly undertake a major investment in electrical wiring to extend the three-phase electricity supply from the transformer on the main road into the heart of Surka's agricultural land. It was hard to imagine a similar collective meeting taking place in Erki, let alone Rajapur.

The contrast between the well-being of families A, B and C is also instructive because it demonstrates the complexities of assessing poverty and wealth from either landholding or caste perspective. Without the benefit of ethnography, Family B would appear to be twice as wealthy as Family C, and about equally wealthy to A if wealth is measured in terms of landholdings. In contrast, Family C comes from a traditionally "higher" caste than Family B, so if caste as a metric is used, a researcher might surmise that Family C is likely to be wealthier than Family B and equally wealthy to Family A. In reality, the proximate driver of the differences in the well-being of these three families is access to water. For example, despite the fact that Family C owns only one acre, significantly less than Family B, they are able to reap much more income from their land and invest in additional technology. The difference is driven not by the size of their respective landholdings, but rather by the quality of their landholdings with respect to water access. At the same time, Family A's landholding is larger than Family C's, but their water access (at least until recently) was not as good as Family C's. The introduction of three-phase electricity may change the calculus between the relative agricultural incomes of Family A and Family C, giving the family with the larger landholding advantages over the family with higher water tables, but this remains to be seen.

At the same time, this exploration also indicates that in many ways caste may be a better single metric for overall socioeconomic well-being than landholding. This is because caste is a strong determining factor not only in quantity of land ownership but also in quality. This qualitative assessment is supported by econometric analysis of the impact of caste on income inequality in India, which found that at least one-third of the average income/probability differences between UC/OBC and SC/ST households is due to "unequal treatment" or discrimination against SC/ST castes rather than specific attribute of their household income generating profile (Borooah, 2005). For this reason, in Section 2.6

while I use both caste and landholding as measures of socioeconomic inequality, I tend in the qualitative discussions to focus more on caste than landholding.

2.6 Analysis: Understanding Variance in Benefits of Technology to Farmers

In this section I study six technology case studies in order to understand the causal mechanisms that prevent the poorest farmers from benefiting from agricultural technology in Bihar. I analyze each case study using the sociotechnical approach discussed in the theory section. Section six is organized as follows:

- First, I identify 11 technologies potentially available to farmers in the region on the basis of the 12-village survey. These 11 technologies are not the entire set of technologies in use in Bihar, but rather the set of technologies that farmers identified as having adopted since 1990.[46]
- I then analyze the factors by which the poorest farmers are less likely to use each of these technologies compared to wealthier farmers in the data set.
- Finally, I purposely select six technologies from the list of 11 for case studies. I then analyze these cases using the sociotechnical approach and sociotechnical causal mechanisms (STCMs) discussed in Section 2.2.

Respondents in the 12-village survey identified 10 technologies which they had started using since 1990. These technologies included diesel engines, tractors, improved seed varieties, large diameter rubber pipes, vermi-compost, electric motor pumps, intercropping, new crops, the System of Rice Intensification and drip irrigation. To this list, I added an 11th technology that was not identified in the 12-village survey

[46] This for example excludes the traditional bullock and plough. Bihar's farmers have been using this technology for far longer than two decades.

– solar irrigation pumps. I added this technology because while no farmer sampled in the 12-village survey had adopted the technology, the technology is available in Bihar through a generous subsidy program and has been identified by both international actors and the Indian central government as a "pro-poor" technology. I added this technology to the list because I wanted to study a case of 'missing' "pro-poor" technologies.

For each of these 11 technologies, I measured use rates for households across caste and landholding categories (the two proxies I use for well-being). Use rates were calculated based on households who said they currently use a technology, have used it for at least a year, and plan to use it in the future.[47] Based on the use rates, I calculated the factors by which the poorest farmers are less (or more) likely to use a specific technology compared to wealthier farmers in the dataset. Table 2.10 shows the factors by which the poorest farmers are less likely to use each of the 11 technologies (see Appendix 2 for the underlying data used to create this table).[48]

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[47] Recall that, using the revealed preference methodology discussed in Section 2.3, I measure benefits in terms of use. Under this approach, a farmers' continued use of a technology is a "revealed preference" indicating that they derive benefits greater than zero from the technology.

[48] The survey excluded households who practice agriculture only as laborers for a daily wage (often paid in rice and wheat). Rather, the survey focused on farmers who either own their own land or produce crops on land they lease or sharecrop. While landless households who earn income through daily wage labor are often the poorest of the poor, decisions about technology use are not their own, nor in general do they capture the benefits that accrue from the use of technology.

Table 2.10: Factor by which poorest farmers are less likely to use a technology than wealthier farmers. This table is based on data from the 12-village survey.

Number of Farmers in Category →	Caste Category Upper Caste (OBC and UC) - 248; Lower Caste (SC/ST) - 250	Landholding Size* Marginal (<2.5 acres) - 283; Non-Marginal (>2.5 acres) – 55
Technology	**Factor by which a lower caste farmer is less likely to use a technology compared to an upper caste farmer**	**Factor by which a marginal farmer is less likely to use a technology than a non-marginal farmer**
Diesel engine	1.01	1.16
Tractor	0.98	0.95
Improved seeds	0.93	0.92
Rubber pipes	0.89	0.93
Vermi-compost	0.69	0.31
Electrical motor pump	0.63^	1.23^
Intercropping	0.58	0.67
Introduced new crop	0.52	0.93
System of Rice Intensification	0.34	0.34
Drip Irrigation	*NA*	*NA*
Solar Irrigation Pumps	*NA*	*NA*

NA: The study also includes technologies that are available in Bihar, but are not in widespread use. These include drip irrigation and solar irrigation pumps. Both drip irrigation and solar irrigation pumps are in limited use in Bihar, but there was insufficient data captured by the survey to calculate these factors. The 12-village survey captured only one UC farmer using drip irrigation; the 12-village survey captured no farmers using solar irrigation pumps. The reason that these 'missing' technologies or technologies in limited use are included is precisely to understand the barriers to widespread use of these technologies and especially the barriers to use by the poorest farmers.

** In India, standard classifications run from marginal to large. In Bihar, the majority of farmers fall in the marginal category of <0 to 2.5 acres. Small farmers have 2.5 to 5 acres. Semi-medium farmers have 5 to 10 acres. Medium farmers have 10-25 acres. Large farmers have 25 acres or more. Here I compare likelihood of adoption between marginal farmers (n=283) and all other landholding categories (n= 55).*

^There is an interesting discrepancy in the factors by which the poorest farmers are likely to use electric motor pumps between the likelihood measures by caste and by landholding size. This is driven by two factors. First, total adoption of electric motor pumps in Bihar is still very low. There are a total of 21 electric motor pump users out of 412 household in the 12-village survey. The other reason that the likelihood factor is so different between caste-based and landholding-based metrics is that farmers from OBC who fall into the higher-end of the marginal landholding category owning approximately 2-2.5 acres are often the first to adopt electric pumps because they need these pumps to earn sufficient profits from their small landholding to provide for their family. This is the case for example with Family A in Bathani. Family A (also from an OBC caste) made the rational calculation that with diesel engines, the income from 2 acres was not sufficient for their four-member family. In contrast, by investing in a borewell and electric motor pump, family A would be able to earn sufficient income from their 2 acres that the husband would no longer have to travel seasonally to Kolkata for wage-labor.

What is immediately clear from Table 2.10 is that the poorest farmers are less likely to use almost all of the 11 technologies than their wealthier peers. However, the factor by which a poor farmer is less likely to use a technology than a wealthier farmer differs significantly across technologies. The poorest farmers are equally likely if not slightly more likely to use diesel engines. In contrast, the likelihood that an SC/ST farmer will use the System of Rice Intensification is only 0.34 compared to OBC and UC farmers.

Returning to the two-by-two matrix of technology types discussed in Chapter 1 and again in Section 2.3, the fact that the likelihood factor for almost all technologies falls below 1 and none fall significantly above 1, means that in the context of Bihar, there are no technologies that are specifically "pro-poor". In other words, no technology benefits the poorest farmers more than other socioeconomic groups. Rather, some technologies in this data set do a better job of benefiting both wealthier and poorer farmers (technologies that "raise all boats"), while other technologies benefit the wealthiest farmers to a far greater extent than the poorest farmers ("technologies for the rich"). Diesel engines – as discussed in section 2.5.2 – are quickly becoming "bad idea" technologies, but farmers are only able to stop using these technologies if they have access to electricity to run electric motor pumps.

I selected the six case studies using purposive selection methodology common in qualitative research and focused on diverse cases (Seawright and Gerring, 2008).[49] I chose to focus on diverse cases, in order to understand the range of barriers preventing the poorest farmers from realizing greater benefits from technology.

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[49] Seawright *et al*. (2008) review a number of case selection methods for qualitative research. In qualitative research, they argue, cases can be selected purposively. Selection methods include typical, diverse, extreme, deviant, influential, most similar, and most different. For this study, I used a diverse case study selection method which is useful for two or more cases that exemplify diverse values for pre-selected criteria. Seawright *et al.* argue that "diverse cases are likely to be representative in the minimal sense of representing the full variation of the population" (p. 297).

Drawing from the 11 technologies identified by farmers in the 12-village survey, I selected six case studies for diverse values along two dimensions:

1. Variation in benefits from each technology across socioeconomic groups. Using the results presented in Table 2.10, I selected case studies for variance in the factor by which the poorest farmers are less likely to adopt a given technology compared to wealthier farmers.
2. Variation in benefits users realize from each technology. This measurement excludes assessment of farmers who do not use a technology and captures only the actual benefits realized by users.[50]

[50] As discussed in Section 2.3, the revealed preference approach to benefits does not quantify the extent of benefits a technology provides, it only signifies that the benefits are positive. Whether or not the poorest farmers benefit from technologies that offer large, average or small benefits is also an interesting dimension of variance.

Distribution of Benefits from technology	Benefits to Technology Users		
	Low benefits	**Moderate benefits**	**High benefits**
Poorer farmers capture more benefits			
Benefits evenly distributed across social groups	- Diesel Engine	- **Rubber Pipes**	- Tractor - **Improved Seeds**
Richer farmers capture more of the benefits	- **Solar Irrigation Pumps**	- Vermi-Compost - Intercropping - **System of Rice Intensification**	- **Electric Motor Pumps** - **Drip Irrigation** - New Crops

Figure 2.9: Benefits of technology realized across socioeconomic groups.

Three by three matrix compares benefits to technology users (columns) and variance in benefits across socioeconomic groups (rows). The technologies in bold are the technologies I selected for the case study. I selected a case study from each cell except diesel engines because electric motor pumps and diesel engines are so closely interlinked, that I cover the interesting sociotechnical dynamics of diesel engines in the electric motor pump case study. I also selected drip irrigation as a case of a "missing technology" that is very beneficial to users, but almost solely adopted by wealthier farmers in Bihar. The figure is color coded where the red cell shows a technology that is both not accessible to the poorest, nor are users realizing benefits from it. The empty blue cell, would be a technology that is both "pro-poor" and delivers high benefits to users. Such a technology does not appear to exist in Bihar. It is an empirical question as to whether such a technology exists in other places or in other sectors.

I categorized technologies into a three-by-three matrix (see Figure 2.9). The y-axis captures variance in benefits across socioeconomic groups. The x-axis captures the benefits that technology users realize from the technology. [51] For example, a relatively small number of farmers in Bihar have adopted

[51] Data on relative benefits is based on several sources of data including a survey item asking farmers to list their most important technology investments, a survey item asking farmers what technology they would invest in if they had a certain amount of capital and my own qualitative assessment based on extensive discussions with technology users (for example, users of MIS generally report high satisfaction due to increased yields, higher quality yields and less labor) but most farmers are unaware of the benefits of MIS, so few farmers stated that they would invest in MIS if they were given the capital. Evaluating the different sources of data, I ranked benefits to farmers that actually use a technology without taking into account whether the technology

drip irrigation (MIS) or solar irrigation pumps (SIP), however, the farmers who have adopted MIS reported significant benefits from the technology during field visits. In contrast, SIPs are only available to wealthier farmers, and the benefits to adopters are also small.

I selected one case study from each of the populated cells in the three-by-three matrix. Where more than one technology fits within an individual cell, I selected the case study pragmatically based on which technology offered particularly nuanced and varied insights. The six case studies included solar irrigation pumps (SIP), the system of rice intensification (SRI), drip irrigation (MIS), electric motor pumps (EMP), rubber water delivery pipes (RWP), and improved seed varieties (ISV) (see Figure 2.10 for photographs of each of the technologies selected for case studies).

I ordered the six case studies from bottom left to top right in the three-by-three matrix. This means that the first case study I analyzed, solar irrigation pumps, was the worst performing of the six case studies in that it had the lowest benefits to technology users, as well as the least benefits realized by the poorest farmers out of the six case studies. The last case study I analyzed, improved seed varieties, was the best performing technology in that it had the highest benefits to users, as well as the greatest benefits realized by the poorest farmers of the six case studies. (The only logic to this ordering of case studies was an effort to start with the bad news and end with the good).

would be appropriate for non-users. I did this in order to have a qualitative assessment of the extent to which users were benefiting from the technologies they had access to for the x-axis.

Solar Powered Irrigation Pumps

System of Rice Intensification

Drip Irrigation

Electric Motor Pumps

Rubber Pipes

Improved Seed Varieties

Figure 2.10: Photos of each of the six technology case studies. (Photo Credits: Author)

Because two of the technologies selected (solar irrigation pumps and drip irrigation) are not in widespread use, in addition to asking about these technologies in the 12-village survey and in Bathani, I also obtained lists of subsidy recipients from the government. I then visited a random sample of farmers from each list to learn more about the farmers' experience with these two technologies. The reason that I included these two technologies in the study is that they are technologies that are 'potentially available' to farmers in Bihar but are not in widespread use. Moreover, both of these technologies are heavily subsidized by the state and central governments and are thus of interest due to the amount of financial and institutional support behind these technologies in the innovation system. Finally, while the results of my analysis demonstrated that wealthier farmers accrued greater benefits from drip irrigation and solar irrigation pumps, at least in the case of solar irrigation pumps there is a strong case to be made that the physical dimensions of the technology itself has the potential to benefit the poorest farmers. By looking at the case of solar irrigation pumps, I can analyze why a technology with potential to be "pro-poor", is performing like a "bad idea technology".

The first case study, solar irrigation pumps (SIP), has low benefits to technology users, with the majority of any benefits accruing exclusively to the richest farmers. As I discuss in more detail in the case study, the poor performance of the technology on both criteria is not intrinsic to the physical dimensions of the technology. Rather, a sociotechnical analysis will demonstrate that the interplay between physical and institutional dimensions of SIP resulted in these outcomes in Bihar.

The second case study on the system of rice intensification (SRI) has moderate benefits to users. The case is surprising because SRI is a technology that has been widely promoted as "pro-poor", but the factor by which the poorest farmers are less likely to adopt SRI, is the biggest (measured both by caste and landholding) out of all 11 technologies analyzed in Table 2.10. In other words, in Bihar, the poorest farmers are the least likely to use SRI compared to their wealthier peers, compared to any of the other technologies studied.

The third case study on drip irrigation (otherwise known as micro irrigation systems or MIS) has been adopted by very few farmers across Bihar. Adopters tend to be some of the wealthiest farmers in Bihar. For the farmers who do use MIS, reported benefits of the technology are very high as the technology both raises yields and decreases labor costs.

The fourth case study on electric motor pumps (EMP) is difficult to categorize because adoption rates are still low due to the scarcity of three-phase electric power lines in Bihar. What is clear is that benefits to these adopters are very high. What is harder to determine is how the benefits of the technology will be distributed across socioeconomic groups as the technology becomes more widely adopted (a process which is currently underway with the continued expansion of the three-phase power grid). For this reason, the variance in benefits of EMP will be discussed using both available data today, as well as potential pathways given research on the impact of institutional variation in the experience in other states in India. Despite the challenges of pinning down EMPs on the criteria of interest, I felt that including them in the discussion was important as they are likely to play an increasingly large role in Bihar's agricultural landscape and under the right circumstances will have the potential to significantly benefit Bihar's poorest farmers. Moreover, the case of EMPs is in many ways also a case of diesel engines (a technology with low benefits to adopters but where the benefits of the technology are evenly distributed across socioeconomic groups) as EMPs cannot be understood without reference to diesel engines.

The fifth case study is on large diameter rubber pipes, which are known locally in Bihar as rubber-*walla* pipes (RWP). Adoption of the RWP is widespread and benefits of adoption are distributed relatively evenly across socioeconomic groups. This technology is not one that the agricultural technology research community tends to focus on. Yet, the increased adoption and widespread use of the technology in Bihar in the early 2000s, brought specific benefits to the poorest farmers by improving the functioning of water markets, decreasing friction between farmers in the water transportation process, and reducing labor requirements.

Finally, the sixth case study on improved seeds varieties (ISV) has high average benefits to adopters and benefits are distributed relatively evenly across socioeconomic groups. The performance of ISV on the two criteria of interest is perhaps not surprising – the agricultural research and development community has long praised the performance of improved seed varieties as a "scale neutral" technology with the potential to equally benefit small and larger farmers (W. Ruttan, 1977; Feder *et al.*, 1985). What is unique about this case is that unlike in western India (the heart of the Green Revolution) where high yielding rice and wheat varieties were widely adopted by farmers in the 1970s, most farmers in Bihar began using improved seed varieties only relatively recently. This case explores the reasons this technology achieved scale so much later in Bihar than in other states in India (Section 2.6.1 through 2.6.6). Each of the case studies is organized as follows:

1. Description of technology, situating it in the context of India and Bihar.
2. Overview of findings from the 12-village survey paired with a thick description of the sociotechnical drivers underpinning variance in benefits across socioeconomic groups. The thick description relies on fieldwork in Bathani village as well interviews with other stakeholders outlined in Section 2.5. Where possible, I do my best to highlight examples from Families A, B and C discussed in the ethnography in Section 2.5.3 in order to provide tangible examples of general findings.
3. Analysis of the role of each of the STCMs identified in the theory section (2.2.2) in preventing the poorest farmers from realizing benefits from the technology. I group the STCMS for each technology into three categories: a) **High** means that the SCTM is a large barrier limiting the poorest farmers from realizing benefits from the technology; b) **Medium** means that the STCM plays a moderate role in preventing the poorest farmers from benefiting from the technology; and c) **Low** means that the STCM plays little to no role in preventing the poorest farmers from

benefiting from the technology means that the STCM plays little to no role in preventing the poorest farmers from benefiting from the technology.

Before delving into the six case studies, it is worth reviewing a few important concepts developed up until this point in the chapter. The sociotechnical causal mechanisms (STCMS) discussed in Section 2.2.2, were adapted from several literatures as explanations for low agricultural yields or incomes of farmers. It may be helpful to refer to the table summarizing each of the 11 STCMs, their definitions and supporting literature in Section 2.2.2 before reading the six case studies. In each of the case studies, I evaluate the extent to which each STCM is a barrier preventing the poorest farmers from benefiting from the technology in the context of Bihar. Readers can also find a matrix summarizing the findings from the STCM analysis across the six case studies at the beginning of Section 2.7. It may be helpful to refer to this matrix as readers go through the case studies. Finally, as a lot of my data is presented in terms of caste based socioeconomic categories, it's worth reminding readers that UC castes (also known as upper castes or general castes) are the most economically and socially well off castes in Bihar. OBC castes (or other backward castes) fall below UC castes in their socioeconomic status, but come above ST/ST castes (or scheduled castes and scheduled tribes), the two groups that are the most marginalized in the Indian caste system. Using caste as a proxy for wealth (and well-being), I assume that in general UC castes have greater wealth than OBC castes who have greater wealth than SC/ST castes. While this is certainly an assumption on the individual level, in Bihar where caste based identities are deeply entrenched, in general, caste and wealth are correlated (see for example the discussion of the demographics of Bathani in section 2.5.2).

2.6.1 Solar Irrigation Pumps (SIPs)

A solar irrigation pump (SIP) is a technology for lifting water for the purposes of irrigation. While SIPs usually lift groundwater, they can also be used to lift water from ponds, canals, rivers and other water bodies. In Bihar, SIPs are thought of by many actors as a promising technology because they allow farmers to pump groundwater without diesel engines in areas that are not connected to the electric grid. Several studies have demonstrated that in spite of the high upfront capital costs, the lifecycle costs of using solar for pumping groundwater are lower than diesel based pumping systems (Odeh, Yohanis and Norton, 2006; Kelley *et al.*, 2010). SIPs also reduce greenhouse gas emissions, black carbon and short-lived climate pollutants such as NOx, which are all emitted by diesel engines. The dual benefits of reducing costs for farmers and reducing emissions of greenhouse gases and other pollutants have made SIPs a technology of interest within the international development community, as well as to Indian policy makers (Burney *et al.*, 2010; World Bank, 2013; Kishore, Shah and Tewari, 2014; Maithani and Gupta, 2015). SIPs are particularly attractive to international donors, who see the technology as a chance to leapfrog agricultural systems in India over fossil fuel intensive production systems (found in the United States and other parts of the developed world) to renewable agricultural arrangements (Bengtsson and Nilsson, 2015).

From the perspective of farmers, SIPs require a high upfront capital investment. While prices are declining due to the decreasing cost of solar panels, a good estimate for the price of a 2hp system (the most common system in Bihar) is 2,500-3,500 USD (though private companies have set significantly higher prices particularly through government procurement processes). Even at a cost of around 3,000 USD, the price is far more than most Bihari farmers can afford. Yet, a 2hp system can pay for itself in less than five years provided water from the system is used at close to maximum capacity.[52] This payback

[52] In Pakistan, where farmers are investing in larger pump sets, with payback periods of a single year, I found payback periods of less than a year. Maithani and Gupta (2015) calculate for India in general that the internal rate of return (IRR) on SIPs under

period assumes that the alternative option to SIP for pumping groundwater is a diesel engine with a high marginal cost. If SIP units are instead installed in fields that are also served by agricultural electricity connections (or will soon be served by these connections), with cheap flat-rate monthly tariffs, SIPs will have a much longer payback period. In summary, for famers who can afford the upfront capital cost of the SIP unit and who do not have access to the electric grid, SIPs have the potential to mitigate the high marginal cost of diesel.

The multiple benefits of SIPs spurred many states across India to establish a subsidy program to promote the technology and help farmers overcome the high upfront costs of the systems (e.g. Kishore, Shah and Tewari, 2014; Durga *et al.*, 2016). As of the 2015-2016 fiscal year, there were approximately 13,000 SIPs installed in India, but government officials envision an ambitious target – 1 million SIPs by 2021 most of which will be heavily subsidized by the central and state governments.

At the time of fieldwork for this project there were multiple efforts to catalyze SIP technology in Bihar including:

- A government run pilot program in Nalanda district, which started in 2012 with 34 cooperatively managed 7.5hp SIP units;
- A subsidy scheme across all districts of Bihar, which was implemented by the Bihar Rural Energy Development Agency (BREDA) that subsidized the SIP system at 90% of cost for a 2hp system;
- Multiple NGO pilot projects including projects by Green Peace and GIZ (a German development agency similar to USAID in the US);

current economics is 10% for replacement of diesel pumps with solar pumps. They also say that if solar pumps lead to yield benefits that the IRR would likely be higher. However, upfront costs of an SIP is about 10 times the cost of conventional diesel pumps. The large upfront cost of SIPs is the argument the government has used to subsidize the technology.

- A second subsidy scheme in the planning phases run by the National Bank for Agriculture and Rural Development (NABARD) which was scheduled to be rolled out across India in 2015-2016 and subsidize 40% of the cost of the SIP unit, with 40% covered by a bank loan and 20% paid for up front by recipients.

The biggest SIP program at the time of the fieldwork for this project was the BREDA subsidy scheme which was called the *Bihar Surya Sinchai Kranti Yojna* (Bihar Solar Irrigation Revolution Scheme). BREDA deployed 1,560 SIPs across Bihar between 2013 and 2016. Under the BREDA subsidy scheme, due to the high subsidy and fiscal burden on the government, the overall number of subsidized units available per district was capped. This created high demand for the subsidy program as it was both highly lucrative for those who received it (90% of cost) and also scarce. In contrast, NABARD subsidy scheme was designed to overcome the capacity constraint and allow as many applicants as qualified to apply for the system. The NABARD scheme would also allow applicants to choose a higher capacity system between 2 and 10hp instead of being limited to the 2hp systems under the BREDA scheme. At the time of the fieldwork for this project, only the BREDA program had been implemented in the field. Therefore, the fieldwork focused on institutional dimensions of the BREDA scheme, although I also met with officials and bankers involved in the NABARD scheme, as well as the other actors in Bihar involved in SIP innovation systems.

2.6.1.1: Sociotechnical Analysis of SIPs in Bihar

In the 12-village survey, no household had adopted SIPs.[53] Despite the absence of this technology from the data set, it is an interesting case to discuss because of the level of government support behind the

[53] Despite the lack of SIP adopters in the data set, SIPs were not entirely missing from the survey. In the open-ended responses on technology needs, three farmers in the same village mentioned wanting an SIP unit after they had seen one in a neighboring

technology, both from the Government of Bihar and the central government in New Delhi, as well as general interest from NGOs and international donors. Due to the absence of data on SIP adoption from the 12-village survey, I conducted an additional set of seven field visits and farmer focus groups with a randomly selected set of households from a list of 42 BREDA subsidy recipients in Nalanda district (see Table 2.11).[54] Much of the data for this case study comes from these interviews. Additionally, I visited three 7.5 hp community managed SIP units in Nalanda district and interviewed the farmer groups who use them, and three NGO-led projects (two in Gaya district and one in Vaishali district). I also interviewed private sector actors and government actors who promote SIPs in Bihar and across India and South Asia (ICIMOD, 2015).[55]

Overall, the results of my fieldwork showed that SIPs are the worst performing technology of the six case studies, both in terms of access to the technology by the poorest farmers and in terms of benefits to current adopters. However, the poor performance of the SIP systems in Bihar on the two criteria of interest is not intrinsic to the general inappropriateness of the technology in the context of Bihar. Rather, both the formal rules and the informal norms of the BREDA subsidy scheme limit the benefits the poorest farmers realize from SIPs. At the same time as the subsidy program excludes the poorest farmers, it also puts the highly-subsidized SIP units in the hands of farmers who will get the least benefit from them (namely those who have or are likely to soon have access to cheap flat rate electricity). There are clear implications from this case study for how the institutions structuring SIP access in Bihar, can be changed

village. They were impressed with the technology, and felt that it could help them overcome the high cost of water which limited their agricultural productivity and cropping intensity.

[54] Nalanda district is in south Bihar and is the district directly bordering Bihar to the northeast. Nalanda district is the home district of the Chief Minister Nitish Kumar and has relatively high grid penetration. This probably affected my findings.

[55] I have also visited SIP projects in multiple other states in India and in Nepal. I have also worked with a private sector company, JAIN Irrigation Systems Ltd. and PRAN, on a joint project to develop a community model to support SIPs in Bihar.

to overcome the sociotechnical barriers limiting the benefits the poorest farmers realize from this technology.

Table 2.11: SIP field survey conducted in Nalanda district in November 2015 and December 2016.

Ca-ste	Land hold-ing (Ac)	Subs-idy (Y/N)	Electr-icity (Y/N)	SIP in Use? (Y/N)	Description of Benefits from SIP to Farmer	Approximate Payback Period	
						Farmer Invest-ment	Full System Cost
UC	10	Yes	No	No	The SIP was used for one year before it was abandoned because the well where it was built failed. No attempt was made to fix well or move the unit to a new location. The farmer now uses diesel pump for irrigation.	Never	Never
UC	16	Yes	Yes (22 hr/day)	No	The SIP unit is not in use and stands next to a working borewell that is connected to the electric grid. After the farmer received the SIP unit, he was dissatisfied with the quantity of water pumped and limited hours. As he already had a flat rate electricity connection, he discontinued use of the SIP unit. He does not intend to sell the SIP unit to another farmer.	Never	Never
UC	NA	Yes	Yes (22 hr/day)	Yes	The owner of the SIP unit is a local elected official. He does not use the unit on his fields but has gifted it to his constituents to use for free. While there is an electricity nearby, the command area where the unit is installed is small and the SIP provides sufficient water for one ha. With the SIP unit, the community no longer has to pay the monthly flat rate fee for an electricity connection. But given the availability of electricity next to the field, any calculation of payback period must be done using the cost of electricity rather than diesel.	135 years	For practical purposes never
OBC	6	Yes	No	Yes	This SIP unit has brought significant benefits to the farmer and will have a payback period for the farmer of three to four years. Before he used diesel to irrigate in winter (wheat) and when needed in monsoon (rice). The SIP system allowed him to grow three crops per year: rice in the monsoon and vegetables in the winter and summer. The farmer pointed out that the irrigation schedule of vegetables matches well with the output of the SIP.	3-4 years	30-40 years

Table 2.11 (Continued)

Ca-ste	Land hold-ing (Ac)	Subs-idy (Y/N)	Electr-icity (Y/N)	SIP in Use? (Y/N)	Description of Benefits from SIP to Farmer	Approximate Payback Period	
						Farmer Invest-ment	Full System Cost
OBC	5	Yes	Yes (10 hr/day) domes-tic use only	Yes	The farmer saw the SIP subsidy program advertised in the newspaper and indicated that he paid some bribe to be put on the list of subsidy recipients. While the system had only been installed a few months at time of field visit, the farmer calculated that the payback period for his portion of the cost would be about six years. If the electricity connection in the village is upgraded to three-phase however he would switch to an electric pump.	6 years	60+ years
UC	7.4	Yes	Yes (18hr/ day)	Yes and No	This farmer received two subsidized SIP units (one in his own name and one in his father's name). He is using one and has stored the other in a barn. He has purchased a CCTV camera to guard the SIP unit and other equipment on his farm. He is also a dealer of multiple agri-input companies and uses both drip and sprinkler irrigation on his crops. He has an agriculture electricity connection, so it is unclear why he is using SIP as well.	Unit 1: 135 years Unit 2: Not known	Unit 1: For practical purposes never Unit 2: Not known
OBC	16	Yes	Yes (10 hr/day) domes-tic use only	Yes	This farmer said he had paid a bribe to be put on a list for the SIP unit. At time of field visit, this farmer had only recently received the SIP unit, so calculating payback periods was difficult. A rough estimate based on the farmers intended use of the SIP unit is six years.	6 years	60+ years

Out of the seven households I interviewed, four were UC and three OBC castes. No farmer came from a SC/ST caste. All of the farmers had landholdings between 5 and 16 acres, putting them in the semi-medium and medium landholding categories (this puts them in the top 5% of landholdings in Bihar).[56] One UC household with 7.4 acres of land actually was the recipient of not one, but two SIP units through the BREDA scheme. The household applied for and was awarded the two units in the name of two adult male members of the household. They were able to do this because their fragmented landholdings were titled under different names and while the local agricultural officers knew that the two men operated one farm, it was easy to disguise this fact in the official subsidy application paperwork.

A great deal of the variance in who benefits from SIPs in Bihar can be explained by the incentive structures created by the institutional design of the BREDA subsidy scheme. In order to receive a BREDA subsidy, farmers are required to apply through their local agriculture officers which are coordinated at the district level. To qualify for the subsidy, they must have more than one acre of land (including official land title documentation), a functional borewell on which the SIP unit will be installed and need to contribute 10% of the total cost of the SIP system (around $450 USD). In order to target the BREDA subsidy at small and marginal farmers, the official terms of the subsidy policy state that eligible farmers may not have more than 5 acres of land.[57] It was clear from the limited sample that this rule is not followed: the average landholding of the seven households was approximately 10 acres. Moreover, only one of the seven households interviewed would have qualified under the 5-acre maximum rule. When I asked a BREDA official in Patna about the discrepancy, he insisted that all applicants had less than five

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[56] A similar survey in three districts in North Bihar of 31 SIP subsidy recipients under the BREDA program found that average landholding for recipients was 5.48 acres. This project did not differentiate by caste (Durga *et al.*, 2016).

[57] In India, the larger category of “small and marginal farmers” are those farmers with less than five acres of land. Marginal farmers have up to 2.5 acres and small farmers have between 2.5 and 5 acres. The classification system, which encompasses all of India is somewhat inaccurate for a state like Bihar where relatively speaking five acres is a lot of land. Only about 10% of farmers in Bihar have more than 2.5 acres of land.

acres of land. But at the local level, with fragmented landholdings which are often in the names of different household members, the rule is easily overlooked.

The benefits from the BREDA subsidy program are further skewed towards the wealthiest farmers by the limited number of units available per district. This encourages corruption because wealthier farmers interested in the novelty of the technology and the social status of owning a conspicuous piece of equipment, bribe government officials to receive SIPs under the subsidy programs.[58] Two out of the seven farmers interviewed said that they had paid a bribe to local officials to ensure they received the subsidy through the BREDA scheme.[59] Nevertheless, these same farmers who have the capacity to influence agriculture officers, are also more likely to have access to Bihar's expanding electricity supply. They quickly learn that despite the free energy from the solar panels (as opposed to the flat rate electricity from the grid), the quantity of water the systems can pump simply cannot compete with their electric motors. In response, they to discontinue the use of their SIP units.

Even without bribes, the design of the subsidy program favors wealthier farmers who read the newspaper and regularly engage with district level officials. The main channel of information about the subsidy program was an advertisement in the local newspaper, and while literacy rates in Bihar are on the rise, SC/ST farmers have the lowest literacy rates (while the average literacy rate in Bihar is 63%, literacy rate for SC/ST farmers in the 12-village survey was 49%).

A second reason why the poorest farmers are less likely to apply for the BREDA subsidy program is that even if the poorest farmers learn about the program in the newspaper or via word of mouth, to get

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[58] While a similar study by Durga *et al*. did not necessarily speak to evidence of out-right bribery in the BREDA scheme, it did find that the "higher subsidy component limits the total number of pumps available which often means that they end up with influential village elite" (Durga *et al.*, 2016, p. 2).

[59] Interestingly, the two farmers who paid bribes are using their SIP units more effectively (leading to a faster return on investment) than the farmers who did not say that they paid a bribe, but were probably pushed to the front of the line simply by their local elite status. This indicates that willingness to pay a bribe for technology may at least mean that the technology will be well-used.

on the list of potential recipients, farmers must first apply at the district agriculture office. Based on my interviews and ethnographic work, for SC/ST farmers, even approaching the district level agriculture officers can present challenges of discrimination, not to mention the transaction costs of travel and time.

Finally, to apply for the subsidy program farmers must also have their land titles, one acre of land, and own their own borewell, all of which the poorest farmers are least likely to have. While the differences between wealthy and poor farmers in terms of possession of land title documents is relatively small, 96%, 93% and 83% for UC, OBC and SC/ST respectively, well ownership is distinctly more biased towards wealthier households. Whereas 24% of UC households have their own well, only 5% of OBC and 4% of SC/ST farmers own wells.

While the poorest farmers have very limited access to the BREDA subsidy program, the benefits of SIPs accrued by recipients of subsidized SIP units were also in most cases very low. In fact, three of the eight SIP units included in the survey (recall that one household had two units) were not operational and were left standing unused in the field after only a few months to a year of use. The reasons the three households were not using this expensive piece of equipment were varied, but all demonstrated the inappropriateness of the technology in the context where it was deployed.

In one household, the SIP unit was installed on an open well that had failed and the farmer had gone back to using diesel.[60] Despite the failure of the well, the low cost paid by the farmer for the SIP unit gave him little incentive to fix the well or move the unit to a new location. He also said that the unit had not been as effective as he had anticipated – the discharge of the SIP system was lower than what would have been provided by a diesel motor and the intermittency of the system on cloudy or fogging days also

[60] The fact that the SIP unit was installed on an open well shows that the formal rules for the subsidy program were often ignored in order to give local elites access to the subsidy. According to BREDA, the SIP unit should have been installed on a borewell. This is likely the case because shallow open wells are significantly more likely to fail, destroying the value of the SIP unit unless it is moved to another location. The design of the SIP units in Nalanda district do not lend themselves to be easily transported to a new location.

limited its utility. When I suggested the farmer call the company for after-sales service which they were in theory required to supply, it was clear he felt the transaction costs were not worth it because the SIP technology had not met his needs.

This farmer's problems with the SIP unit were illustrative of the complaints of many farmers. Because the SIP unit provided through the BREDA scheme was limited to 2hp, the capacity of the system was far less than the diesel engines Bihari farmers are familiar with. This, combined with the fact that the SIP units do not work at night or in foggy conditions greatly decreased their utility by increasing transaction costs and decreasing the control farmers had over their irrigation schedules. This problem is caused by the design of the SIP units under the BREDA scheme, which are installed on borewells in a way that it is not possible to use a diesel engine with the same borewell. This is a problem because the SIPs do not work at night or when there is cloud cover and farmers often need to use their borewells at night. However, this design decision is not intrinsic to SIP technology. In Nepal, a project I work with designed a system that allows farmers to switch from SIP to diesel in less than 10 minutes. This gives farmers more flexibility to use solar energy when available, while also ensuring they can water their crops in a timely manner when solar radiation is not available, without having to construct an additional borewell. Because the poorest farmers are unlikely to have one borewell, let alone two, they are less likely to be willing to devote their only borewell to an SIP system.[61]

The second SIP unit that was not in use had been installed in the field of a wealthy and politically connected UC farmer. Indeed, this farmer's standing in Bihar was such that when his father passed away, the chief minister, Nitish Kumar, came to sit with the family. The farmer's SIP unit was installed in a field where there was already a three-phase agricultural electricity connection and he quickly learned that

[61] I encountered this problem first hand when working with the NGO PRAN to pilot a SIP scheme in a remote village, Badilbigha. Despite initial enthusiasm for the SIP units, farmers became reluctant to use their own wells for the project once they learnt about the limitations of the technology and we decided we would need additional funding to not only install three SIP units but also build the borewells to go with them.

the functionality of a SIP unit was inferior to his electric motor pump (EMP). The SIP unit stood in his field next to a borewell with an electricity connection for a flat rate of 220 *rupees* per month (a little over three dollars) and was now equipped with a wooden bed under the solar panels and used exclusively as an umbrella to protect farmers against rain and sun. At a cost of over 4,000 USD to Bihar's government, this is an expensive umbrella.

The final SIP unit that was not in use belonged to a family that had received two SIP units, one under the son's name and another under the father's name. The household only installed one SIP unit and saved the other for future use. When my translator, who could no longer help himself, tried to convince this farmer that the SIP equipment would depreciate over time in the barn and that he should sell it if he did not want to use it, it became clear that the prestige-value of having the SIP unit sitting in the barn outweighed the financial benefits of selling it for his household.

Out of the seven households surveyed, there was one example of a more positive outcome in terms of the criteria of interest – benefits to the poorest and benefits to adopters. One of the poorest farmers in the sample, an OBC farmer who owned only three acres of land and leased an additional three acres, improved his well-being substantially when he received a SIP unit through the BREDA scheme.[62] The farmer reported that the SIP unit had improved both his income and his family's diet. With the SIP unit, he had transitioned from a rice-wheat rotation in two seasons, to a rice-vegetable-vegetable rotation where he grew vegetables in both the winter and summer seasons. He estimated that he would recoup his investment of 450USD in three to four years if not sooner. When I asked him how he had heard about the subsidy program, he was one of the few farmers who had read about it in the newspaper and then went to sign up with his local block level agriculture officer who helped him apply. He said he did not pay a bribe

[62] While 6 acres is small compared to the other SIPs recipients, it is still a significant landholding in the context of Bihar. That said, half of the farmers' 6 acres were leased from another farmer. Using his own landholdings, he would be classified as a small farmer and indeed actually eligible for the BREDA subsidy scheme.

and while he was not politically connected per se, he had worked for the railway for 35 years before retiring and he knew many other government employees through his time in public service.

Despite the value this farmer realized from the SIP unit, he was not using it at full capacity. He estimated that he could probably sell water at least five days per month and still have sufficient water for his own crops. But he said that selling water would take a lot of his time and effort and the transaction costs for him to sell water only a few days per month were not worth his effort.

Out of the eight SIP units, only three were likely to have payback periods to the farmer of less than 20 years (SIP units have a lifespan of approximately 20 years). But the payback period to the farmer is calculated on only 10% of the full cost of the system. Payback periods for the full system cost were likely to be closer to 30 years on the low end. For systems not in use, the calculation of payback period is not even possible. In addition, many wealthy farmers will not benefit from an SIP unit because they also have access to three-phase electricity. With the BREDA subsidy, farmers pay a small portion of the cost of the SIP unit. Therefore, they have little incentive to maximize the value of the asset by ensuring that it is used at maximum capacity. I saw this even in the case of the OBC farmer with only 3 acres of his own land who calculated that he would recoup a return on his own investment in three to four years. This farmer was satisfied with the three to four-year timeframe and happy that he could expand his cropping calendar and switch to more vegetable crops. He saw no reason to expend additional effort as a water seller in order to recoup his investment more quickly.

In the final analysis of the data, the poorest farmers do not have access to SIPs in Bihar, and the farmers that have adopted SIP receive few if any benefits from the technology. Despite the very poor performance of the BREDA SIP scheme in terms of its benefits to the poorest farmers (as well as benefits to users), other SIPs have performed better both in terms of the benefits realized by adopters and to some extent in terms of benefits realized by the poorest farmers in small-scale pilot programs in Bihar. For example, in a study of the community managed pilot program in Nalanda district, Kishore *et al*. (2017)

found that the pilot program had resulted in a 9-10% increase in productivity in rice and wheat. More importantly, it allowed farmers in the SIP command area to continue to grow paddy during a drought when almost half of other land in the area was left fallow. The analysis of this pilot demonstrates that SIP can have positive benefits in Bihar by increasing crop productivity and lowering the cost of irrigation.

There are a number of institutional experiments currently underway in the state and elsewhere, to see if the SIP innovation system can be reoriented to ensure the poorest farmers capture more of the benefits from this technology.

For example, GIZ has a project in the Vaishali district in north Bihar which is a community based pay per-use model. The GIZ demonstration consists of two 2hp pumps that service a total of 147 farmers on 60 acres of land (which means the average farmer served by the project has 0.4 acres – placing them amongst the poorest by landholding classification). Farmers pay between 50 and 60 *rupees* per hour of irrigation. In addition, while there is limited data available on cost recovery for the project, the goal of the GIZ project was never about cost recovery as much as demonstration that the poorest farmers in Bihar can benefit from SIP technology. The project is also focused on efforts to promote SIP in Bihar more broadly. GIZ regularly bring in farmers from across north Bihar to visit the SIP units and engage in capacity building activities. They also build awareness about SIP technology for loan officers at banks and other actors in Bihar's agricultural system who will be needed in the future to support *widespread use* of SIP technology (ICIMOD, 2015).

In addition to the GIZ pilot in Vaishali district, the NGO I work with in Gaya district, PRAN, developed a model for SIPs where marginal farmers pay a fixed seasonal cost for the SIP system. While the model does not cover the initial capital cost of the system, the fixed cost is collected in a bank account that will cover the cost of a replacement unit in 10 years, making the project potentially sustainable after the initial up-front investment by donors or the government. Under this program design, the NGO selects farmers they have already been working with, with landholdings in very remote areas where government officials rarely visit. These farmers are unlikely to receive grid connections for some time, and the SIP system for them is a significantly better option than diesel pumps. In theory, the community model creates an incentive structure that encourages farmers to use their SIP system at full capacity. This incentive structure is critical to ensuring a decent return on investment. In practice, the NGO reports that significant work is required during the first year or more of the project to build collective norms around the use of the SIP system to both ensure that all farmers have paid for the use of the system and that all farmers who have paid the seasonal fixed cost, receive timely access to water.[63]

While NGOs strongly support the community managed approach, many scholars are concerned about the drawbacks of community ownership. Community ownership often decreases incentives for long-term maintenance, as well as incentives to maximize the value of the asset through full utilization. A different institutional approach that relies more heavily on private ownership and entrepreneurship has been proposed by scholars from IWMI-Tata Water Policy Program in a working paper published in 2016. In this paper, Durga *et al*. propose an alternative institutional design for the SIP subsidy scheme in Bihar, which they argue would improve the performance of SIPs on both criteria of interest: higher benefits to users and more benefits for the poorest farmers. Their scheme is based on the idea that SIP owners could transform their main business from agriculture to water provision by becoming "irrigation service providers" or "ISPs" (Durga *et al.*, 2016). In the ISP model, the SIP owner would receive the SIP for a 40% subsidy, 20% down payment and 40% loan on an 8hp SIP unit capable of irrigating 1 acre per day (provided there is sufficient solar radiation). The loan repayment cost would then act as a flat-rate tariff which would incentivize the SIP owners to maximize the quantity of water they sold in a year as profit. If several SIP owners are clustered in a given area creating market competition, they calculate that this

[63] The first experiment in this project began in 2012 with funding from JAIN irrigation. While it was an initial success, a three-phase transformer was installed in the village the next year, making the expensive SIP unit redundant. A second larger experiment is currently underway in a much more remote village with three SIP units of 2.5hp each.

model would halve the cost of irrigation for all farmers within the command area of the SIP unit (when compared to the costs of diesel irrigation).

The IWMI-Tata model estimates that a single 8hp SIP unit could serve between 60-70 farmers. Statistically speaking, many of these farmers are likely to be marginal farmers in terms of landholding (simply because the vast majority of Bihar's landowners fall into the marginal category). Even if the ISP owner is not amongst the poorest farmers, this institutional design would help the poorest farmers realize benefits from ISP by significantly decreasing the price of water they incur and by allowing them to increase their cropping intensity.

While the IWMI-Tata institutional design remains on paper, it is a clear example of the type of thinking needed to reorient the SIP innovations system to better serve the needs of the poorest farmers in Bihar. It is also not unlike the proposed NABARD subsidy model, yet the IWMI-Tata model would be more likely to benefit the poorest farmers because of the clustered-nature of the program design where private competition would reduce the cost of irrigation water facing water buyers.

Lessons for orienting the SIP innovation system to meet the needs of the poorest farmers can also be taken from outside Bihar. For example, one of the failures of Bihar's SIP program is when units are installed where there is already or likely to be three-phase electricity in the near future. To address this challenge, a successful SIP program in Bangladesh worked with the government to identify those areas least likely to be served by the grid and targeted those regions for SIP programs (ICIMOD, 2015). Targeting SIPs for remote areas would mean that agricultural officers and the private sector companies that install SIPs will have to travel to Bihar's hinterlands. Often these areas are challenging for government officers to visit due to an ongoing Naxalite movement in Bihar. Partnering with NGOs who have pre-existing relationships in remote communities could help overcome this challenge.

In summary, while SIPs in the BREDA scheme currently perform poorly on both criteria of interest: benefits to the poorest farmers and benefits to adopters, both of these failures could be overcome through changes to the institutional design of the subsidy program. Whether SIPs in Bihar will live up to their potential is a question of overcoming barriers in both the institutional and physical dimensions of the technology in Bihar. While both the institutional design of the subsidy program, as well as the physical design of the SIP units currently in use limits the benefits the poorest farmers realize from the technology, there are examples from both inside and outside Bihar of ways in which the sociotechnical barriers preventing the poorest farmers from benefiting from SIPs can be reoriented. The next sub-section looks systematically at which STCMs are the most important drivers of variance in the benefits the poorest farmers realize from SIP technology as it currently exists at scale in Bihar under the BREDA scheme.

2.6.1.2: STCMS as Barriers for the Poorest: SIPs

The STCMs that played the largest role preventing the poorest farmers from benefiting from SIP were *lack of financial assets* (STCM 1), *lack of access to credit* (STCM 4), *misaligned incentive structures* (STCM 10) and *corruption* (STCM 11).

Under the BREDA subsidy scheme, farmers must pay approximately 450 USD (10% of the cost). This sum is far outside the scope of what the poorest farmers can afford, in a state where marginal farmers earn on average 250 USD annually (STCM 1). The barriers created by *lack of financial assets* are exacerbated by *lack of access to credit* for poor farmers (STCM 4). Interviews with credit union lenders and private sector banks showed that taking out a loan for a SIP is difficult no matter the size of the farmer's land, as most bank loan officers are unfamiliar with the technology and reticent to make a loan. It is even more challenging for the poorest farmers who are unlikely to have a relationship with a banker, a strong credit history or even sufficient collateral to apply for the loan.

The incentive structure embedded in the BREDA subsidy program (STCM 10) also skews benefits towards the largest farmers in the data set. This is partly due to the requirement to own one acre of land, which would immediately disqualify more than half of the farmers in the 12-village survey. While this requirement may seem logical in order that the SIP units will be used, marginal farmers with less than an acre of land, could easily become SIP-entrepreneurs (akin to the IWMI-Tata ISP model, albeit at a smaller scale) selling more water than they personally consume. From a technical perspective, what matters is the total area that the SIP unit can irrigate. If the command area around an SIP unit is large enough, then even a farmer with a fraction of an acre who uses his entire landholding to install the SIP unit, could become a water-entrepreneur selling water to neighbors in the command area. This argument has been made by multiple groundwater experts, who argue that the high upfront capital cost combined with low marginal cost of SIP systems, can mimic the high flat-rate electricity regimes that have catalyzed groundwater markets in other states in India (Mukherji, 2007; Raitha, Verma and Durga, 2014; Durga *et al.*, 2016).[64]

A second way in which *misaligned* incentives (STCM 10) drive variance in the extent to which the poorest farmers benefit from the BREDA subsidy program, is the way in which the subsidy program is advertised to farmers in newspapers, which means that wealthier farmers are significantly more likely to know about it in the first place.

Finally, corruption (STCM 11) plays an important role in preventing the poorest farmers from benefiting from the subsidy program. This is because the government actors responsible for deciding who should get the subsidy program have responded to both overt corruption in the form of bribes and more latent corruption in the form of simply making sure the most influential elites get the BREDA subsidy, irrespective of their eligibility (i.e. landholding of more than five acres).

Other STCM that prevent the poorest farmers in the sample from benefiting from SIPs include *inappropriate technology design* (STCM 2), *missing infrastructure* (STCM 5), *ineffective extension services* (STCM 6), *lack of individual farmer capacity* (STCM 7), *weak capacity for collective action* (STCM 8), and *structure of land tenure regimes* (STCM 9).

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[64] Groundwater markets are discussed at greater length in the EMP case study in Section 6.4.

The design of the SIP units in use, restricts farmers from using a diesel engine in conjunction with the SIP on a single borewell (STCM 2). This is problematic when farmers need access to more water than the SIP can provide either due to atmospheric conditions, nightfall or the constraints of a 2hp SIP which is not as powerful as the diesel engines in use in Bihar. This STCM is a bigger barrier for the poorest farmers who are the least likely to own one let alone two borewells. The current design physical dimensions of SIPs in Bihar that limit the ability of farmers to easily switch between SIP and diesel engines, is not integral to the design of the technology. Alternative designs exist that would allow farmers more flexibility to switch between SIP units and diesel engines.

Missing infrastructure (STCM 5) also creates a barrier for the poorest farmers who are least likely to own their own borewell – an eligibility requirement of the BREDA program. For a SIP subsidy program to better target the poorest farmers, including the cost of borewell construction within the subsidy package, would help ensure the poorest farmers benefit.

With respect to *ineffective extension services* (STCM 6), it is difficult to disentangle the difference between this STCM and *corruption* (STCM 11). The very fact that despite the efforts of the BREDA subsidy scheme to target small and marginal farmers with less than five acres of land, the actual recipients of the scheme appear to be almost exclusively larger landholders from UC and OBC castes. This indicates that the institutional norms in Bihar's extension services are not oriented towards the needs of the poorest farmers.

Multiple NGOs (including Green Peace, GIZ and PRAN) that are working to design more effective financial mechanisms for providing access to SIPs on the part of farmers, report that building the capacity for collective action (STCM 8) is essential to project success. Many of the failures in a Green Peace solar village were due to intra-tola tensions. In Gaya district, a novel pilot program run by PRAN to recoup the maintenance and replacement cost of the SIP system, required extensive handholding by PRAN staff to ensure the community purpose of the project was met.

Finally, the poorest farmers are less likely to have a title for their land (STCM 9), a requirement of the SIP subsidy program. In the 12-village survey, while 96% and 93% of UC and OBC farmers have land titles respectively, only 83% of SC/ST farmers have land titles.[65] This discrepancy in land titles between the poorest farmers and their wealthier neighbors however is not excessively large. In reality, it drives very little of the actual variance in benefits. So many other STCMs get in the way of the poorest farmers benefiting before STCM 9 becomes a factor, that the 11% of SC/ST households without documentation of their land title would likely never have had access anyway.

Only one STCM plays absolutely no role in preventing the poorest farmers from realizing greater benefits from SIP: *missing market linkages* (STCM 3). There is some concern that if this technology scales in certain pockets of Bihar (especially if the IWMI-Tata scheme is implemented) there will be gluts in vegetable production which would require greater cold storage capacity. For the time being though, this is not a factor and is not a driving variance in the benefits the poorest farmers realize from the current incarnation of SIP in Bihar.

2.6.2 System of Rice Intensification (SRI)

The System of Rice Intensification (SRI) is a practice-based technology for improving rice yields and decreasing seed and water inputs. SRI consists of a set of practices including earlier transplanting from nursery to field, line sowing, using fewer individual plants per mound when transplanting from nursery to the main field, increased spacing between plants, soil aeration often with mechanical weeders, and, perhaps most striking to the outside observer, keeping the rice field moist but not flooded throughout the season (Uphoff, 2003; H. De Laulanié, 2011).[66] The technology has an unconventional "bottom-up"

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[65] This excludes landless households.

[66] SRI methods are often described by as a "package of practices" from which farmers in different biophysical and sociotechnical situations can choose depending on the opportunities and constraints they face. Professor Uphoff maintains a website out of Cornell University which summarizes the principles of SRI in detail: http://sri.cals.cornell.edu/aboutsri/methods/index.html

history. It was developed in Madagascar in the 1980s by a French Jesuit priest working in close collaboration with local NGOs and farmers (De Laulanié, 1993; H. De Laulanié, 2011). The technology spread from Madagascar to other countries via multiple pathways but most notably through the work of Norman Uphoff, a tenured political scientist at Cornell University who traveled to Madagascar in the mid-1990s for research and while there heard about SRI. After participating in three years of on-farm evaluations, Uphoff began to promote SRI as a promising technology for improving rice yields for small farmers (Uphoff, 1999; Dominic Glover, 2011).

Initially, SRI met with significant pushback from the established rice research community, who called the practice "agronomic UFOs," or "unconfirmed field observations" amongst other more nuanced critiques (Dobermann, 2004; Sheehy *et al.*, 2004; Sinclair, 2004; Sheehy, Sinclair and Cassman, 2005). In spite of these critiques, SRI eventually gained support from many prominent organizations including the World Bank, The International Fund for Agriculture Development (IFAD), a specialized agency under the United Nations, and Oxfam – a major international NGO focused on poverty alleviation.[67] In addition to the interest of these global actors and organizations in SRI, Professor Uphoff fostered a global network of academics and civil-society partners who promote the technology (Dominic Glover, 2011). Because SRI is viewed as a technology that both increases yields while decreasing input costs, actors looking for "pro-poor" agricultural technologies identified SRI as a particularly promising approach to benefit resource poor farmers (Stoop, Uphoff and Kassam, 2002; Africare, Oxfam America and WWF-ICRISAT, 2010).

In India, SRI first took hold in the state of Tamil Nadu at the turn of the century (Prasad, 2006). By 2009, the technology had garnered attention and praise across India and Robert Zoellick, then president of the World Bank, published an article in a leading Indian newspaper, *The Hindustan Times*, citing the

[67] In 2017, SRI was featured in an editorial in *Nature Plants* as a strategy for meeting the United Nation's Sustainable Development goals (Nature Plants, 2017).

experience with SRI in Tamil Nadu, in which he championed the potential of SRI to increase rice yields 30% to 80% while decreasing water use (Zoellick, 2009).

SRI was first introduced in Bihar in 2007, when Anil Verma, an agronomist who worked for a national rural livelihoods NGO, Pradan, moved back to Bihar to open a satellite Pradan office in Gaya district. Mr. Verma introduced SRI in a single village in 2007 (Verma, 2013).[68] After observing the results in the initial year, Mr. Verma was so convinced by the potential of SRI to transform livelihoods for poor farmers in Gaya district that he later split off from Pradan, which focused on supporting self-help groups more broadly, in order to focus exclusively on the promotion of SRI through a new NGO that he called PRAN (Preservation and Proliferation of Rural Resources and Nature).[69] By 2009, Anil Verma's work with SRI had caught the attention of local policy makers who he invited to meet with farmers and observe their yield cuttings in the villages where Anil was working. Having heard about SRI from his deputies, Nitish Kumar, the Chief Minister of Bihar, hoped that there was promise in the technology and had rice planted using SRI methods on his own land in 2010.

By 2011, SRI had captured so much enthusiasm that Nitish Kumar declared 2011 an official year for SRI in the state. Launching an "*SRI Kranti*" or "SRI Revolution", Kumar declared his intention to promote SRI in order to make Bihar a "rice basket" for India and he allocated substantial funding to the promotion of SRI in 2011-2012. By the end of 2012, the Bihari government estimated that SRI had been

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[68] I have also seen references to field experiments with SRI on agricultural field stations in Bihar dating back to 2002, but I have not been able to find original documentation nor any evidence of the field trials beyond their citation in other journals. At any rate, Anil's work was likely the first time that SRI was taught to Bihari farmers. See (Thiyagarajan and Gujja, 2012).

[69] Over the course of my fieldwork, I became close to Anil Verma and the staff of PRAN. Eventually I was invited to join PRAN's board as a special invitee board member (special invitee because only Indian citizens can be legally responsible for domestic NGOs). While I attended multiple board meetings for PRAN and engaged with both the organizations staff and board, I do not think this impacted my ability to evaluate the benefits of SRI in a useful and critical way. While I care deeply about the future of PRAN, the opportunity to see the inside functioning of an Indian NGO at such proximity also gave me useful ethnographic material to work with. I also don't believe that PRAN's success is nearly as much about the physical technology of SRI itself as it is about their dedicated efforts to work with poor farmers. Nonetheless, even PRAN (as will be discussed further in this case study) often falls short of their aspirations to work with the poorest farmers.

adopted on almost three hundred and fifty thousand hectares of land in Bihar (Verma, 2013). In this same year, a small farmer in Nalanda district, Sumant Kumar, reportedly harvested 22.4 metric tons of paddy from a single hectare of land, breaking a world yield record held by a farmer in China (Ahmad, 2013).[70] Fueled by competitive geopolitics, Sumant's agricultural achievements garnered domestic and international attention. His yield record was reinterpreted as a triumph for Bihar's chief minister and for the country as a whole (Krishnan, 2013; The Times of India, 2013; Vidal, 2013; Times of India, 2014). For his achievements Sumant was awarded a prize in New Delhi by the Union Minister of Agriculture (Nadimi, 2012).

Following on these successes, the government emphasized SRI in its second Agriculture Road Map (Government of Bihar, 2012). The 2012-2017 Agriculture Road Map allocated substantial funding to promote SRI amongst Bihar's farmers. The extent of the funding was surprising for a technology that remained both relatively under-studied and controversial among many agriculture scientists both in India and internationally. The total budget for SRI promotion was 144 million dollars, which was approximately 8% of the total budget allocation in the 2012-2017 Agriculture Road Map of 1.8 billion dollars (see Table 2.12).

[70] It's worth noting that China disputes Sumant Kumar's yield record. Yuan Longping, known as the father of hybrid rice in China has claimed that the yield record in Bihar is "120 percent fake" (Krishnan, 2013). Nonetheless, Sumant has been inundated with domestic and international visitors (including delegations from China) to learn more about how a poor Bihar farmer achieved such high yields.

Table 2.12: SRI as portion of total budget in 2012-2017 Agriculture Road Map.
In total, 144 million dollars or 7.9% of the 1.8-billion-dollar budget is allocated for SRI related activities over the five-year plan.

Spending Category	2012 - 13	2013 - 14	2014 - 15	2015 - 16	2016 - 17	2012-2017
System of Rice Intensification subsidies and extension	9.6%	8.9%	7.9%	6.9%	6.3%	7.6%
Conoweeder or weeder technology	0.5%	0.3%	0.2%	0.2%	0.1%	0.2%
Budgetary spending on System of Rice Intensification as a proportion of total agricultural budget	10.1%	9.2%	8.1%	7.1%	6.4%	**7.9%**

Since establishing SRI as a cornerstone of Bihar's agriculture strategy, the government has claimed substantial success, linking the adoption of SRI in Bihar directly to overall increases in paddy yield in the state (Times of India 2013). In 2013, Bihar's agriculture production commissioner, Alok Kumar Sinha, said that SRI "requires less water and gives 2-3 times the yield compared to traditional cultivation of rice" and "is set to change the face of paddy cultivation in the state as thousands of farmers have been adopting it following encouraging results" (Business Standard, 2013). A report published by the Government of Bihar's Finance Department in 2015, directly credited the adoption and widespread use of SRI as the causal driver behind increased paddy yields since 2011. It stated that "because of the use of new 'SRI' technique and new agricultural implements, there was an enormous rise in rice production" (Government of Bihar, 2015, p.xxv).

According to the Government of Bihar, in addition to SRI's benefits in terms of increased yields, the technology also has a second important physical dimension in the drought-prone state – it requires less water. According to the government not only does SRI save water in general, but it can also help farmers withstand drought. During a year where droughts affected many of Bihar's districts, the Principal

Secretary of Agriculture for Bihar, A. K. Sinha credited SRI with helping farmers overcome the drought, saying in the Times of India that farmers planting with SRI methods would not be affected by the drought because SRI requires less water for irrigation (Dayal, 2011).

Yet despite the claims about SRI's success in the state, high quality adoption data is limited.[71] It is likely however that the government's data on adoption is problematic. While my questions about the government's SRI adoption figures were never convincingly answered by officials in the state, the indication I got from the lower-level department of agriculture employees was that the government used the quantity of subsidy packages allocated as a proxy for adoption of SRI. If this is true, then Bihar's adoption figures are only as good as the agricultural extension system linking farmers with the subsidy program. It is however unlikely that the entire allocation of funding reaches farmers. Leakage of funds due to corruption is almost inevitable. Supporting my own suspicion about the quality of SRI adoption figures, some agricultural scientists in the Bihar also question the government's adoption data. A group of agronomists at RAU told me that they believe the SRI adoption figures published by the government are exaggerated by as much as 75%.

There is substantial incentive for Nitish's government to tout (and even exaggerate) the benefits of SRI. In a capital-constrained state with many competing demands on available finances, the 144 million dollars allocated to the technology is substantial. Nitish Kumar invested in SRI despite concerns on the part of many agronomists and agricultural scientists in and outside Bihar about its efficacy. But for Nitish, the "pro-poor" narrative behind SRI and specifically the idea that it can increase the yields of the poorest farmers without requiring them to invest in expensive inputs meant that the technology could also

[71] Jamal Latif Poverty Action Lab (JPAL) was in the midst of a study evaluating some aspects of SRI when I was in Bihar, but despite repeated requests, I have not been able to see preliminary results of their evaluations and to date nothing has been published. Moreover, the evaluation was not of SRI per se, as much as a digital technology platform for promoting SRI run by the NGO Digital Green.

accomplish important political ends. Nitish tapped into the “pro-poor” narrative around SRI to show that his agenda is focused on the needs of this large voter block.[72]

In addition to including SRI in the 2012 Road Map, Nitish further capitalized on the symbolism of SRI by bringing onto his 2010 election ticket a female SC farmer who was an early adopter of SRI, Jyoti Devi (Jha, 2011). Jyoti Devi came from a particularly disadvantaged scheduled caste known as the Musahars who are infamous amongst Bihar’s higher castes for eating rats as part of their diet. In fact, an article that ran in the times of India about Jyoti’s election was even titled “Beyond the Rat Race” (Times of India, 2010).[73] Jyoti Devi won her seat in the 2010 election and remains a member of Bihar’s Legislative Assembly (MLA) in the lower house. For Nitish, his support of Jyoti Devi served as a reminder of his commitment to female empowerment and the needs of the rural poor. It also highlighted the fact that so much of the funding in Bihar’s Agriculture Road Map was allocated for the “pro-poor” technology she pioneered. Whatever the actual impact of SRI has been on Bihar’s poorest farmers, the narrative has been carefully constructed. Not only has Nitish selected a technology that beat China’s yield record in rice, but it's a technology that is specifically beneficial to poorest farmers like Joyti Devi.

Despite its “pro-poor” symbolism, the extent to which the evidence supports the rapid success of SRI in increasing yields and helping the poorest farmers overcome drought is limited. This case study, like the other five, focuses on the extent to which the poorest farmers realize benefits from a technology. What is unique about this case is that unlike the other five cases, it is the only technology that was specifically selected because of its “pro-poor” characteristics.

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[72] In Bihar, the majority of the population are poor rural farmers and as it turns out, this group votes at higher rates than people in Bihar’s urban centers.

[73] This article is particularly revealing in the way it describes how Jyoti became part of Nitish’s election ticket in 2010. From Jyoti’s description, she was essentially plucked out of thin air to be on the ticket, making it clear that Nitish had sought out her candidacy for the things she symbolized – lower caste empowerment, female empowerment and the potential of SRI to transform the well-being of the poorest farmers (Times of India, 2010).

2.6.2.1: Sociotechnical Analysis of SRI in Bihar

My 12-village survey found that 88% of respondents had heard of SRI and that 18% of households had adopted SRI. On the surface, these are quite extraordinary statistics for a technology that is complex to adopt and was only introduced at scale in Bihar in 2011. In contrast, only 15% of farmers have heard of MIS (drip irrigation) and less than 1% of the farmers in the 12-village survey had adopted the technology, despite the fact that the technology has been highly subsidized since 2006 (see section 2.6.3)

Despite perceptions of SRI's widespread success in Bihar fueled both by the media and the government, a more detailed analysis of the data is less supportive of the government's narrative of SRI as a "pro-poor" technology. The results of the 12-village survey show that the majority of adopters of SRI are from OBC castes (14% of UC farmers, 24% of OBC farmers, and 8% of SC/ST farmers had adopted SRI). The factor by which an SC/ST farmer in Bihar is less likely to adopt SRI than a UC/OBC farmer is 0.34. This is the lowest likelihood factor of any of the technologies for which I was able to calculate this factor. Moreover, out of the 55 farmers with more than a hectare of land (2.5 acres), 42% practiced SRI. In contrast, out of the 283 farmers surveyed with less than one hectare of land only 13% practiced SRI.

Ethnographic findings from Bathani village mirror the results of the larger survey and shed some light on the reasons for the adoption trends seen in the survey. In Bathani village, the benefits of SRI accrued exclusively to farmers in Surka *tola*.[74] Farmers in the other two *tolas* while aware that farmers in Surka were using SRI, were generally unenthusiastic about their own prospects for benefiting from the

[74] Though one household in Erki reported that they had been paid 25% more as hired labor to plant using SRI methods on a farmer's land in Surka, thereby indicating that there may be some positive spillover effects on wages from SRI. Though pursing this line of inquiry led me to little additional evidence of this trend.

technology. In Surka, farmers had been practicing SRI since 2014 and now cultivate not only rice, but wheat and multiple vegetable crops using SRI-like methodologies.[75]

Amongst the three families in the ethnographic account, no family has adopted SRI, but for very different reasons. Family A helped another household in Surka plant their paddy field using SRI methods and observed the benefits the SRI brought in the 2015 monsoon season to many households in Surka. However, Family A has not been able to use SRI yet because their land, unlike the land of most households in Surka, did not have assured irrigation until recently when they invested in a new borewell and electric motor pump. They hope to use SRI in the future as they have seen the success of their neighbors with the technology, but do not plan to do it in the upcoming monsoon season because the husband will likely be away in Kolkata and they worry it will require more labor. In contrast, Family B in Rajapur had never heard of SRI and did not know that the farmers in Surka had been planting with SRI for two monsoon seasons. Finally, Family C in Erki knew about SRI from farmers in Surka and had seen their fields, but no one has approached this family to offer training. Moreover, they have heard mixed reviews of the technology from other farmers in Roh and so they were ambivalent about trying it themselves. Mostly, Family C simply had not had the time to investigate the technology and without the support of an NGO or government extension officers, they were unlikely to pursue the SRI on their own.

The reason for the heterogeneity in adoption of SRI between *tolas* in Bathani has both institutional and physical dimensions. By far the biggest reason is that the NGO PRAN began working with some of the female farmers in Surka *tola* to promote SRI at the start of 2014, but not in the other two *tolas*. When I asked the staff member, Sanjay, responsible for promoting SRI in the region of Gaya where Bathani is

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[75] SRI methods have expanded in Bihar to encompass a wide number of crops including wheat and multiple vegetable crops. SRI advocates have re-branded the technology alternatively as “system of root intensification” or “SCI” “system of crop intensification”. The expansion of management practices under the SRI umbrella could offer the empirical case work for an entire dissertation in science and technology studies. Suffice it to say here, that while the Bihar government has officially supported the System of Wheat Intensification in addition to SRI, this chapter focuses primarily on the system of rice intensification as the first and most highly funded version of SRI.

located, why he had chosen to concentrate his efforts on Surka, his response was not that different from a public-sector extension officer – the farmers in Surka are simply better prepared to successfully adopt SRI for two reasons. First and foremost, the farmers in Surka have better access to water than farmers in Erki or Rajapur, which he said would facilitate their ability to use SRI. Second, Surka's farmers were already more focused on agriculture than those in Erki, which he felt meant that they would be more amenable to devote the time and effort required to adopt SRI. Rajapur *tola*, he said was out of the question as a place to promote SRI. While he knew that Anil, the director of PRAN and his boss probably would have wanted him to focus on Rajapur, low individual farmer capacity and water scarcity in Rajapur made promotion of SRI a herculean task. He hoped that perhaps in a few years, success in Surka would induce farmers in the other two tolas to practice SRI; but given the constraints on his time (he already worked more than 12 hour days six days per week), choosing farmers who could more easily adopt SRI made his job just a little bit easier. The end result of Sanjay's decision was that despite the reported "pro-poor" characteristics of SRI as a technology, and despite an NGO, focused specifically on helping the poorest, promoting the technology in Bathani, the benefits of SRI were still concentrated amongst the wealthiest farmers in Bathani.

Sanjay's primary reason for working in Surka – that farmers need water to practice SRI – was recurrent across the 12-village data set, as well as in every other interaction I had in Bihar with farmers who had adopted, disadopted or heard about SRI and decided not to adopt the technology. They all agreed that practicing SRI requires not only access to water but also control over access, including frequency of irrigation. Farmers in the 12-village survey cited multiple barriers to the adoption of SRI, but the most common barrier was lack of water availability and water control. In the 12-village survey, when farmers who had heard of SRI but had decided not to adopt the technology were asked for their main reason for not adopting it, 62% cited lack of water availability. Of the farmers who had adopted SRI but did not plan to use SRI in the future, 46% cited water availability constraints as their primary reason for disadoption of the technology.

That water is the biggest barrier to adoption of SRI in Bihar is on the surface a surprising finding. For a technology that claims decreased water requirements for rice cultivation, it is counterintuitive that farmers would raise concerns about water as a barrier to using SRI. Yet qualitative interviews with farmers in multiple villages with varying experience with the technology, demonstrate a clear link between assured water availability and their ability to adopt SRI. First, farmers who are dependent on either monsoon rains or on purchasing water from other farmers, face uncertainty with respect to the future availability of water. Under such circumstances, if they have access to water on one day, but are uncertain when they will access water again (either due to lack of rain or the inability to negotiate a water purchase from a borewell owner whose well and or pump may be in limited supply) the farmer will choose to irrigate more today and flood their field instead of following SRI recommendations for irrigation. Assured access to irrigation in Bihar's drought-prone climate is limited, especially for the poorest farmers who are much less likely to own their own well, and often face higher transaction costs ensuring timely access to irrigation, in addition to the financial costs of purchasing irrigation.

Another physical dimension of SRI that is impacted by lack of assured irrigation, is the younger age at which seedlings are transplanted from the nursery to the main fields under SRI methods. The younger seedlings are more vulnerable to dry conditions and if water access is not guaranteed in the field, farmers face the risk of losing their entire crop after the seedlings have been transplanted and before they have a chance to grow deep enough roots to withstand drought. For this reason, if the monsoon is delayed, farmers without assured irrigation access will delay transplanting their crop from the nursery to the field beyond the recommended 10-12 days under SRI and wait up to 30 days or more using traditional practices.[76] These findings undercut the government's narrative that SRI helps Bihari farmers because it requires less water and helps farmers overcome drought conditions.

A second causal mechanism that limits benefits to the poorest farmers is the design and implementation of the SRI subsidy program. Across the 12-village survey, only 8% of farmers reported receiving the subsidy to practice SRI. Wealthier households received the SRI subsidy with 14% of UC households, 12% of OBC and 3% of SC/ST households receiving the subsidy package. The subsidy package for SRI provided by the government consists of 5kg of seeds, 3kg of fertilizer and in some cases *conoweeders,* which are a large hand-held tool for weeding the paddy field between rows of plants. Under the subsidy program, the rule for which farmers received a *conoweeder* was never entirely clear and while the government claimed that all recipients of the subsidy received *conoweeders*, in fact many farmers who got the subsidy claimed to have only gotten seeds and fertilizer.

The SRI subsidy program disproportionately helps wealthier farmers. In addition, in focus groups with female farmers who have used SRI methods for more than three years and report high satisfaction with SRI, many express consternation with the design of the government's subsidy policy. The main point these women farmers make is that for a technology that requires fewer seeds, it makes little sense for the government to incentivize adoption of the technology by giving farmers seeds and fertilizer. Instead, these farmers repeatedly suggested that the government could more effectively support SRI adoption by improving access to irrigation for poor farmers and by hiring more and better extension agents to teach SRI to farmers in their fields. The only inputs the government should subsidize according to many SRI farmers are the *conoweeders* which are unique to the practice of SRI, but can be shared within a village community so that only one weeder per 15-20 households is needed. Unfortunately, while the 2012-2017 Agriculture Road Map earmarks 144 million dollars for SRI, only 0.2% if this budget is

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[76] The finding that water availability constrains SRI adoption is consistent with other emerging literature on the challenges facing resource poor farmers in adoption of SRI (Truong *et al.*, 2017).

allocated to providing *conoweeders* to farmers. In addition, it remains difficult for farmers to purchase *conoweeders* independently on the private market in Bihar. Farmers only access to the technology is through the limited supply from NGOs and the government subsidy program.

Skepticism over the government's SRI subsidy program was echoed by the staff of the NGO PRAN. They told me that when they are trying to expand SRI into new villages, they look for villages where government extension staff have not already promoted SRI. This is not in an effort to spread resources, but because as Sanjay said "the farmers in villages where the government has already worked expect the subsidy and often do not actually want to follow the practices of SRI." Indeed, more than one UC farmer I interviewed admitted that they had taken the SRI subsidy without following through and adopting the SRI methods. After all, free seeds and fertilizer are always nice to have. In fact, even my own translator's family, a wealthier family that operates multiple small businesses on the outskirts of Gaya, received the SRI subsidy. While they had used the seeds and fertilizer, they decided to plant their fields with traditional methods. When asked why, they said they could not find hired labor willing to plant their fields with SRI methods and they were unwilling to do the labor themselves. In a second example, a UC farmer I had tea with in a village near Bathani, also admitted a similar story. When I asked if he had practiced SRI, he said yes, but that he thought the technology had few advantages and did not increase yields. When I asked him if he had received the SRI subsidy, he said he had received it twice. Later in the conversation however it became clear that he had not actually used SRI methods beyond transplanting fewer seeds per mound from the nursery to the main field.[77] In order to cover his tracks that he had not actually followed the SRI practices, but still received the SRI subsidy not once but twice, he dismissed any benefits from SRI.

[77] Indeed, many farmers in Bihar are transplanting fewer seedlings per mound from the paddy nursery to the field irrespective of whether they practice SRI or not. Many farmers attributed this change to higher quality seeds available on the market so that fewer seedlings were likely to fail.

My suspicion is that many respondents in the 12-village survey were not unlike these two examples. They received the SRI subsidy, so when asked if they practice SRI they said yes, even if they had only used the free seeds and fertilizer from the subsidy package with traditional management practices. More frequently, these farmers would adopt one of two of the recommendations such as fewer seeds transplanted per mound, and then claim to have both practiced SRI and seen little benefit from the technology. If other farmers in the dataset who received the SRI subsidy are like these two families, it is likely that the number of SRI adopters in the survey is higher than the real value. At the same time, if non-adopting subsidy recipients are inclined to report minimal benefits from practicing SRI, then reported benefits from adopters may be lower than the true value.

Interestingly, while survey results indicate that only 8% of farmers have received an SRI subsidy package, 18% reported practicing SRI. On the surface, the data suggests that farmers are adopting SRI without the support of the government. While this is likely true in some cases, in many cases the discrepancy is largely driven by NGO support for SRI (NGOs promote SRI without the use of the subsidy incentive). While overall adoption rates for SRI in the survey data were only 18%, in villages supported by NGOs the adoption of SRI is higher at 35%.[78] There are multiple reasons for this including the long-term knowledge support provided by PRAN and their model for training and incentivizing local village resource persons to help other farmers learn about SRI. They also facilitate community building around SRI which enables farmers to mitigate risks with respect to timely water access.

Outside of the 12-village survey, I visited many villages with PRAN in the Gaya district where every farmer in the village practices SRI: at the height of monsoons season, the straight rows of SRI-

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[78] Out of the 12-villages I surveyed, three had primary extension work done by NGOs. In the first village, Bathani, PRAN had worked with one of the three *tolas,* which only began a few months before my own fieldwork started. In one of the other villages in Gaya district, PRAN had worked in the village from 2010-2014, but had stopped their extension activities as part of a designed phase-out process. In the third village, in Madubhani district, JEEVika, an organization that functions like an NGO but is funded by the Bihari government, had done most of the extension work.

paddy are visually striking to observe. Long-term practitioners of SRI report very high benefits from SRI. Focus groups with farmers who have practiced SRI for more than three years regularly highlight the increased yields as well as the reduced input costs as the two main benefits of SRI, yet even these focus groups bemoan the high cost of water as the biggest barrier to practicing SRI. Due to a delayed monsoon onset in 2012, many farmers I interviewed who had been planning on using SRI management practices were forced to switch to traditional management practices, after they were unable to transplant the seedlings from the nursery to the main field until the seedlings were more than 25 days old.

As further evidence that some farmers in Bihar are excited about SRI, on more than one occasion, I was approached by farmers in Bihar in a local market who wanted to tell me about SRI. I do not believe these farmers knew I was specifically interested in SRI, rather they just wanted to share something they were excited about. In fact, SRI for many farms has deep symbolism. The technology in Hindi is called *sri-vidhee* which means respected method. And in many ways in Bihar, the farmers who adopt SRI treat the practice as something between farming and religion.

In summary, SRI is a technology that has significant benefits for many adopters of the technology. However, the poorest farmers in Bihar are not realizing benefits from SRI compared to their wealthier peers. The ability of the poorest farmers to benefit from SRI is hampered by both physical and economic water scarcity and by limited capacity of extension agents (whether employed by NGOs or the government) to support the poorest farmers in adopting the technology. This finding stands in stark contrast to the statements of government figures who say that SRI is not only “pro-poor” but helps farmers successfully plant rice even under drought conditions.

2.6.2.2: STCMS as Barriers for the Poorest: SRI

The STCMs that played the largest role preventing the poorest farmers from benefiting from SRI were *missing infrastructure* (STCM 5), *ineffective extension services* (STCM 6) and *misaligned incentives* (STCM 10).

Missing infrastructure (STCM 5) plays by far the biggest role in driving variance in benefits of SRI of all of the STCMs. The uncertainty surrounding the onset of the monsoon, combined limited and expensive access to groundwater, especially for the poorest farmers, has resulted in the benefits of SRI in Bihar being largely captured by wealthier farmers (STCM 5).

In addition to *missing infrastructure*, *ineffective extension services* (STCM 6) play a major role in the variance in benefits of SRI. Block level agriculture officers who are largely responsible for promoting the governments SRI scheme at the village level, are far more likely to engage with wealthier farmers than with the poorest farmers who are often hard to reach. The orientation of the extension services to wealthier farmers is underscored by the 3% of SC/ST farmers who list their local agricultural officer as their most trusted source of information, as compared to 11% of OBC farmers and 14% of UC farmers. A bias towards wealthier farmers on the part of extension agents is almost universally acknowledged by field level extension agents themselves. In discussions with extension agents they cite several reasons for working with wealthier farmers including the belief that wealthier farmers can serve as "demonstration" farmers in the trickle down of new technological advances. They also cite the challenge of working with the poorest farmers who are often in more remote areas and require greater effort in terms of demonstration and training (according to the extension officers) to master a new practiced based approach. Extension agents are also significantly more likely to provide training to farmers who live closer to larger roads. In the 12-village survey, five of the 12 villages were located within 20 minutes of paved roads (by car or motorcycle). Farmers in the villages within 20 minutes of a paved road reported having heard about SRI from block level extension officers at three times the rate that farmers in the other six villages that were harder to access.

Finally, *misaligned incentives* (STCM 10) embedded in the subsidy program play an important role in driving variance in benefits of the program. With SRI comprising a large part of the mandate of the block level extension officers (over 15% of the total extension budget was earmarked for SRI between

2012 and 2017), extension officers are under intense pressure to meet SRI targets and ensure adoption. This pressure combined with underwhelming overall extension performance means that many extension officers take the path of least resistance and provide SRI assistance to farmers that approach them or whom they already know well – these farmers tend to be larger farmers. In addition, some extension officers themselves are poorly trained in SRI methodology and prefer to work with larger farmers who require less hand-holding while mastering the technique. Nevertheless, these challenges also apply to almost any agriculture technology adoption scenario where behavioral change on the part of the farmer is required. The *misaligned incentives* in the SRI subsidy program extend beyond these challenges to the terms of the subsidy arrangement which include free seeds, fertilizers and *conoweeders* for farmers who receive the SRI subsidy. These are valuable inputs but many of them are valuable whether or not you practice SRI and they offer no additional incentive to practice SRI. The design of the subsidy program leads both to wealthier farmers capturing more of the benefits from the subsidy, as well as a false reporting about SRI adoption. The terms of the subsidy program are even more obtuse when viewed through the eyes of poor farmers in villages where SRI has taken off and where NGOs have supported farmers in achieving substantial benefits from SRI without the subsidy program.

Other STCMs that prevent the poorest farmers in the sample from benefiting from SRI include *lack of individual farmer capacity* (STCM 7), *weak capacity for collective action* (STCM 8) and *structure of land tenure regimes* (STCM 9).

Limited educational attainment on the part of many poor farmers skews the benefits of SRI to wealthier farmers (STCM 7). This is in part because SRI is a difficult technology to master and also because the design of the SRI outreach programs that the government runs are not well-targeted at the poorest farmers. For example, much of the SRI extension material from the government is distributed in printed formats, which is unhelpful to the poorest farmers who are much more likely to be unable to read the material. While almost all the farmers I interviewed, who have used SRI for more than two seasons, reported either decreased or equal labor requirements to their former management practices, substantial behavioral changes were required including mastery of new skills in transplanting and weeding. Developing these skills takes time and often assistance. I saw no indication that the poorest farmers with no formal education could not master the skills required for SRI, but substantial handholding is required on the part of NGOs who work with the poorest farmers. Unfortunately, unlike the NGO programs, the far larger government extension program is not well-targeted at the poorest farmers.

Weak capacity for collective action (STCM 8) limits the benefits of SRI for the poorest farmers. This is because farmers practicing SRI can achieve substantial efficiencies through collective management of nurseries and sharing *conoweeders,* which are necessary for weeding and aerating the soil. In Bathani village, the close-knit *Yadavs* in Surka regularly supported each other with the more complex tasks involved in SRI and worked out systems for sharing in both tasks and tools. In Rajapur and Erki, farmers in contrast rarely supported agricultural activities outside their own nuclear family. In many villages in Gaya district where SRI is practiced by almost all farmers in the village, caring for nurseries, transplanting crops from nursery to field and sharing *conoweeders* is a village-wide endeavor.

Structure of land tenure regimes (STCM 9) also play some role in limiting the benefits of SRI to the poorest households. The mechanisms through which this STCM operates are similar to almost any technology investment (perhaps with the exception of rubber-*walla* pipes discussed in Section 6.5). The frequent use of sharecropping arrangements means that the benefits from any investments in technology are split between landowners and sharecroppers. While the extent to which SRI actually requires increased labor is debated, the costs in the first year in terms of learning and skill development are substantial. Moreover, the overall structure of the power arrangement also prevents sharecroppers from feeling empowered to try a new approach to agriculture if they fear the landowner may be suspicious of the technology (many farmers are initially skeptical of SRI because the visual impression of an SRI-planted field in the first weeks is substantially less-dense that a field planted under conventional management practices).

The STCMs that play no role in preventing the poorest farmers from realizing greater benefits from SRI include *lack of financial assets* (STCM 1), *inappropriate technology design* (STCM 2), *missing market linkages* (STCM 3), *lack of access to credit* (STCM 4), and *corruption and security* (STCM 11).

2.6.3 Drip Irrigation (MIS)

Drip irrigation, a subset of micro irrigation systems (MIS), distributes water through a network of pipes, tubes and emitters directly to plants near their roots. MIS improves the water use efficiency of many crops at the field level, though the extent of water savings especially when measured at basin rather than field level, is still under debate (Ibragimov *et al.*, 2007; Van der Kooij *et al.*, 2013). What is less uncertain is that MIS technology can benefit the farmers who adopt the technology. MIS can improve yields and decrease labor requirements, raising incomes for farmers (Hussain and Hanjra, 2004). In addition, for farmers who pay high marginal costs for water, MIS can result in substantial additional savings. Many farmers in India, recover their investments in MIS through increased yields and decreased labor costs in as little as two to three seasons. Well-maintained MIS technology can last for eight to 10 years (Liebrand, 2017).

India as a whole has achieved remarkable success in adoption and widespread use of MIS. In January 2006, the Government of India launched the Centrally Sponsored Scheme on Micro Irrigation (first introduced in 2006 and updated in 2010 and renamed the National Mission on Micro Irrigation or NMMI) (Government of India, 2010). By 2010, India had the single largest area under MIS globally, though the fraction of MIS compared to total irrigated area was still quite low at 3.12% of total irrigated land (Palanisami *et al.*, 2011; ICID, 2012). The rapid success of MIS in India has also been very lucrative for India's private sector MIS companies. JAIN Irrigation Systems Ltd is now one of the largest MIS companies globally.

The Centrally Sponsored Scheme on Micro Irrigation introduced by the central government in 2006, provided a 40% subsidy for MIS technologies. Individual states were given the responsibility of subsidy delivery, which led to variation in institutional policies as well as the percentage of subsidy offered to farmers as many states chose to inject additional funds into the program. This resulted in subsidies for micro irrigation ranging from 50% in some states to 90%. The subsidy program also offered additional 10% subsidy for small and marginal farmers. In Bihar, for most of the period between 2006 and 2015, the MIS subsidy was 90% with 40% given by the central government and additional 50% by the state. For SC/ST farmers, the subsidy was at times as much as 100% when additional subsidy incentives to target vulnerable farmers were added to the scheme by Bihar's government.

While the MIS subsidy program in India has led to rapid adoption of the technology in multiple states, Bihar has in general seen far less success in terms of adoption and widespread use of the technology. A 2011 study found that despite the 90% subsidy on MIS, only 0.02% of the potentially irrigable agricultural land area in Bihar had been converted to MIS. This figure stood in stark contrast to other states such as Andhra Pradesh, where 50% of the potential area is covered by MIS (Palanisami *et al.*, 2011).

2.6.3.1: Sociotechnical Analysis of MIS in Bihar

The use of MIS in Bihar has not followed the same rapid uptake seen in other states in India. The 12-village survey conducted for this project found only one household that had adopted MIS. The lone farmer who adopted MIS in the 12-village survey, is a UC landowner in Jehanabad district with 14 acres of land on which he grows multiple crops including high value timber, wheat and maize. He recently developed a fish-farming business after the introduction of electricity to his village, which allows him to pump groundwater to fill his ponds. He owns four separate wells and sells excess water to neighbors in his village. In 2009, he received a 90% subsidy on two separate MIS systems – a drip system which he uses to irrigate teak and mahogany trees, and a sprinkler system which he uses to irrigate winter wheat and maize. He first heard of the subsidy program from his block agriculture officer who visited his home to tell him about the opportunity. He had already seen JAIN Irrigation technology at an agricultural fair and said he immediately jumped on the opportunity to purchase the technology with a substantial subsidy. He was able to apply for two separate subsidy packages under his own name and the name of his father-in-law. He said he was extremely pleased with the results of the MIS systems he received through the subsidy program. For the mahogany trees, impacts on yield are hard to estimate, but he has achieved substantial labor savings and a reduction in the cost of irrigation. In addition, the sprinkler system he uses for winter maize and wheat has increased his yields and reduced labor, but because he irrigates these plots with electricity rather than diesel, the savings on the cost of irrigation were minimal.

Due to the lack of MIS technology in the 12-village survey results, I followed a research protocol similar to the protocol followed for SIP. I obtained a list of drip irrigation adopters from officials responsible for administering the subsidy policy. I then conducted field visits to a randomly selected group of six MIS adopters in Vaishali district to understand more about the dynamics of who was benefiting from drip irrigation in Bihar (see Table 2.13). In addition to the six farmers surveyed in the Vaishali district, two additional farmers are included in Table 2.9 – the first is the farmer who was sampled in the 12-village survey and the second is a farmer who was interviewed because he had received a subsidy for SIP in the Nalanda district (see section 2.6.1.1) and also happened to have a subsidized MIS system as well. To better understand the sociotechnical mechanisms structuring access to MIS across socioeconomic groups, I also interviewed government officials responsible for implementing the MIS subsidy, private sector company officials, equipment dealers and professors at Bihar's Rajendra Agriculture University (RAU) responsible for extension and outreach for MIS.

Table 2.13: Summary MIS fieldwork interviews

Interviews conducted in 3 districts: Vaishali; Jehanabad and Nalanda. The first six interviews in the table were conducted using a random sample from a list of subsidy recipients in Vaishali district. The last two interviews were interviews of opportunity in the course of other fieldwork.

Ca-ste	Land hold-ing (Ac)	Subs-idy (Y/N)	MIS in Use? (Y/N)	Description of Benefits from MIS to Farmer	Approximate Payback Period	
					Farmer Invest-ment	Full System Cost
UC	45	Yes	Yes	Farmer received MIS subsidy in 2013 for 5 ha of land. He received a second subsidy for additional 5 ha in his brother's name in 2015. Both systems are still in use. The first irrigates bananas and the second irrigates guava. He first learned about MIS from his agriculture cooperative. He worked with a private sector MIS dealer to apply for the subsidy, which he said was a straightforward process and the dealer did most of the paperwork. He is considering expanding his area under MIS and wishes the area covered by the subsidy program would be expanded.	less than 1 year	3-4 years
UC	17	Yes	Yes	Farmer received subsidy in 2014. He uses it on 5 ha of bananas. He heard about the subsidy from a family member who works for the block agriculture office. He said he had been very pleased with the training he had received from JAIN Irrigation dealer about operation and maintenance of MIS system. Yields have increased and he used less water which was very helpful as his land was too far from a three-phase transmission line.	less than 1 year	3-4 years
UC	37	Yes	Yes	Received subsidy in 2013 for 4 acres (on plot nearest his house). He heard about it at an agricultural fair from a MIS dealer. He said the system had raised his yields of the vegetable crops he had grown with it. He intends to continue to use the system, but said he was not focused as much on agriculture these days because his sons are professionals in Patna and the land is mainly an investment, which he gives out on a sharecropping basis.	A little more than a year	5-6 years
OBC	10	Yes	Yes	Received subsidy in 2014. He saw MIS system of neighbor and approached block agricultural office who helped him begin the application process. Farmer uses MIS on his largest plot which is 3.5 acres. Because he does not own his own well near his other plots of land which are quite far away, he says he would not be able to use MIS on them, but the 3.5 acre plot is near to a well he shares with his brother giving him enough water control to use MIS. He uses MIS to grow vegetables including onion and tomatoes.	A little more than a year	5-6 years

Table 2.13 (Continued)

Ca-ste	Land hold-ing (Ac)	Subs-idy (Y/N)	MIS in Use? (Y/N)	Description of Benefits from MIS to Farmer	Approximate Payback Period	
					Farmer Invest-ment	Full System Cost
UC	8.5	Yes	No	MIS system was purchased with subsidy in 2013. Due to illness in family, unable to properly use MIS system after first season.	NA	NA
UC	43	Yes	Yes	Farmer very focused on growing his business. He grows mainly bananas and guavas. He first heard of MIS at a famer training run by the Agriculture University (RAU) in 2011. He purchased his first MIS system in 2011 through the subsidy program and was so impressed with the benefits that in 2012 he had his brother (who lives and works in Patna) apply for the subsidy in his name. His nephew also received a subsidy in 2013. He now has MIS on 15 ha of his banana plantation.	One to two seasons	less than 3 years
UC	14	Yes	Yes	This farmer was surveyed as part of the 12-vilage survey. He has had MIS since 2009. The survey enumerator noted that not only did the farmer know that his MIS system was made by JAIN Irrigation Ltd, he also knew they were based out of Maharashtra and concluded that they "make high quality machines". He compared his own MIS system to a neighbors' made by a different company which he said had many failures. He uses a drip system on teak and mahogany trees. And sprinkler system on winter maize and wheat. He received a subsidy for both drip and sprinkler systems.	A little more than a year	3-4 years
UC	7.4	Yes	Yes	This farmer was interviewed as part of the interviews for SIP project, but he happened to also have MIS on 1.5 ha of land. He is also a dealer for JAIN Irrigation Systems Ltd. He received 90% subsidy on his drip system and used it in a large enclosed area on multiple vegetable crops including eggplant, peppers and potatoes.	Less than 1 year.	3-4 years

The MIS fieldwork covered eight MIS adopters. Except for two of the informants, all were randomly selected from a list of farmers who had received the subsidy provided by the horticulture department[79] for Vaishali district. The two additional MIS adopters were also subsidy recipients. Interviews with private sector officials indicated that the vast majority of drip irrigation purchases in Bihar are through the state sponsored subsidy program, so methodologically the subsidy recipient list is representative of all drip irrigation users in the state. Two separate private sector companies estimated that the "cash and carry" portion of their business (where subsidies are not involved) accounted in one case for less than 10% of their MIS sales in Bihar. A third company said they had no cash and carry business and all of their sales were under the subsidy program. The few MIS sales outside the subsidy system were to institutional clients such as university research programs, large businesses in and around Patna who use MIS for landscaping and local NGOs ineligible for the subsidy.

The results of the survey of MIS adopters demonstrated the overwhelming degree to which the benefits of the technology are skewed toward wealthier farmers. Of the eight farmers surveyed, three were semi-medium farmers, two were medium farmers, and three were large farmers. In addition, all but one farmer who adopted MIS came from a UC background. The MIS adopters mostly grew high-value crops including high-value timber products, bananas and vegetables. Almost all respondents (seven of eight) reported high benefits from their investment. Respondents also said they were able to recoup their investment in drip irrigation (10% of the cost of the system) in as little as a single season and at most three seasons.

As further evidence of the degree to which the benefits of the MIS subsidy program are skewed towards wealthier farmers, three of the households interviewed received the subsidy package in the name of more than one family member. The subsidy package was intended to cover only five hectares of land

[79] The horticulture department is the responsible implementing agency for the MIS subsidy scheme in Bihar.

under the terms of the subsidy scheme (12.4 acres), yet these households were able to cover significantly more area at a 90% subsidy. One household had three members of the household apply for and receive the subsidy, which now covers 37 acres of their banana and guava plantation. The head of this household estimated that he recouped his private investment in the MIS systems in one to two seasons. He is considering covering more of his land with MIS, but hopes to find a way to get this technology at a subsidized rate.

Many of the households that received the subsidized MIS heard about the availability of the subsidy program directly from block or district agriculture officers with whom they were in regular contact. One of the MIS adopters reported visiting his district agriculture officer for tea on a regular basis to discuss local trends and new government initiatives. This stood in stark contrast to the responses I received when I asked about MIS in Bathani village where not a single farmer had heard of MIS technology. In one particularly revealing moment, I had the chance to speak with one of the MIS adopters I interviewed in Vaishali district months earlier a second time, when we were both staying at the same guest house and invited to attend an important annual research conference at RAU. This farmer had been asked by the head of the University to speak at the annual meeting of all faculty and research staff, where research programs shared their results across departments in an effort break down disciplinary silos. The farmer I had already met in Vaishali was given the third speaking position on the opening agenda (a place of high honor directly after the two most senior officials in the room). The speech by this farmer was meant to underscore to all in attendance the importance of listening to the needs of farmers in designing research programs at RAU. In some ways, the moment was gratifying – the effects of the farmers' first movement (Chambers, Pacey and Thrupp, 1989) had impacted the design of agricultural research programs even at a government run facility in one of India's poorest states. Yet at the same time, this farmer's central place on the day's agenda begged the question: Which farmers and whose needs were being listened to by the RAU's research community?

Overall, the findings from my fieldwork demonstrated that MIS is a technology with clear and unambiguous benefits to users, but the benefits in Bihar are concentrated among the elite farmers of the state. The findings from my field interviews were confirmed by interviews with MIS equipment dealers. One dealer told me that over 85-90% of the MIS technology he sold under the government subsidy program was to large farmers with over 25 acres of land (a massive landholding by Bihar's standards). He said that except for a few programs run by NGOs, he was unaware of any marginal farmers (less than one hectare or 2.5 acres) who had received MIS through the subsidy program. In perhaps his frankest remarks, he made it clear that his company had little incentive to market to small and marginal farmers. He stated that the small profits received per farmer were not worth the time investment on the part of his employees to go through the steps necessary to design and install an MIS system, as well as conduct the necessary training to ensure small farmers were able to properly use and care for the drip irrigation technology over multiple seasons. In fact, he said that it would take his employees more time to sell MIS to a small farmer than a large farmer, because the time investment required to first convince a farmer to buy the system and then to train a farmer on how to use and maintain it (even though it is largely fixed irrespective of the size of the land area covered), was likely higher for poorer farmers who lacked the education to read instructions.

Another barrier to adoption by the poorest farmers is that the cost per unit area of MIS does not scale linearly with size. Instead, there are fixed costs which decrease as a percentage of the overall price as plot size expands. This physical dimension of the MIS technology means that both small farmers, as well as farmers with fragmented landholdings will pay more per square foot than larger farmers for the same MIS system. My own calculations based on cost data provided by JAIN Irrigation Systems Ltd in Gujarat indicates that marginal farmers with plot sizes less than 2.5 acres will pay approximately 20% more per unit area than larger farmers. However, the increased costs to poor farmers while significant, do not appear to be the primary barrier to adoption in Bihar. Rather, despite a robust subsidy program, the technology is rarely advertised to small farmers by the private sector companies and equipment dealers who have largely taken on the responsibility for farmer outreach and promotion of MIS technology in India (see Chapter 4).

An interview with a government employee involved with the administration of the subsidy program at the district level in Gaya also demonstrated why the program had seen little success across his district. He explained that the design of the drip irrigation technology available through the subsidy program is not well-suited for small farmers who would benefit most from smaller "low-tech" drip irrigation systems specifically designed for kitchen gardens to increase vegetable production at the household level. Moreover, he pointed out that because the subsidy program did not include these low-cost, low-tech systems, the private sector largely failed to market these systems in Bihar. Rather he believed that for low-cost drip irrigation to be successful, the government would need to re-design the MIS subsidy program and probably work not only through private sector companies, but also include the input of NGOs in their strategy for engaging with small farmers.

What this district agriculture official may or may not have known is that the central government under the subsidy guidelines specifies technology standards for design specifications eligible under the subsidy program. These guidelines were originally intended to ensure product quality, as well as prevent private sector companies from over-charging for the equipment. However, these standards exclude low cost MIS systems from the subsidy program. By excluding low cost MIS from the subsidy program, the guidelines have essentially removed low cost MIS products from the market as the private sector has concentrated most of their resources on the lucrative subsidy market.[80]

[80] This may be changing as JAIN Irrigation Systems Ltd. recently purchased one of the leading low-cost MIS companies, DripTech. Moreover, the barriers to low-cost MIS technology erected by the design of the subsidy program were raised by researchers including myself in India, and several high-level reports have recommended changes to MIS subsidy policy to include technology better suited to the needs of the poorest farmers (GGGI, 2015).

In summary, there are two primary mechanisms preventing the poorest farmers from benefiting from MIS both of which are rooted in the design of the national subsidy program. First, the institutional dimensions of the subsidy scheme leave the private sector actors who are most responsible for implementing the scheme with little incentive to work with the poorest farmers. Second, the physical dimensions of the technology selected by the Centrally Sponsored Scheme on Micro Irrigation are not well-suited to the needs and purchasing power of the poorest farmers.

2.6.3.2: STCMS as Barriers for the Poorest: MIS

The STCMs that played the largest role in preventing the poorest farmers from benefiting from MIS were *inappropriate technology design* (STCM 2), *missing infrastructure* (STCM 5) and *misaligned incentives* (STCM 10).

Out of these three STCMS, *inappropriate technology design* and *misaligned incentives* both result from the design of the centrally sponsored subsidy program. While there are specific provisions in the design of the subsidy program to support access by the poorest farmers, these provisions have proven ineffective in Bihar in aligning incentives to meet the needs of the poorest farmers. Instead, the poorest farmers are specifically excluded from MIS because the main actors responsible for implementing the policy have little incentive to work with the poorest farmers. At the same time, the standards set by the subsidy program select for a technology design that is *inappropriate* to the needs of the poorest farmers. While low-cost MIS systems exist that are appropriate for poor farmers, (particularly those designed to support small-scale kitchen gardens and increased vegetable consumption) these technologies are not included in the technology standards outlined. Without a subsidy incentive, private sector companies and dealers have shown little interest in marketing these products. The end result is that the combination of SCTM 2 (*inappropriate technology design)* and SCTM 10 (*misaligned incentives*) prevent the poorest farmers in Bihar from benefiting from MIS, despite the high priority given to the subsidy program by the central and state governments.

In addition to *misaligned incentives* and *inappropriate technology design*, *missing infrastructure* (STCM 5) also creates disproportionate barriers for the poorest farmers. However, this barrier is latent in Bihar due to the strength of STCM 2 and STCM 10, which limits observable instances of poorest farmers using or even attempting to use drip irrigation in the first place. However, like with SRI, MIS cannot be used unless farmers can control their access to irrigation.[81] The need for assured irrigation with MIS like in the SRI case, is counter-intuitive because MIS decreases the amount of water used for irrigation overall. However, just as with SRI, all precision irrigation technologies require increased control over irrigation schedules. This is because if farmers choose only to provide a small amount of water one day, they need to be certain water will be available in a few days' time when they need to irrigate again to prevent their crops from drying. Thus, farmers will only choose to irrigate less today if they can be reasonably assured that they will have access to water when their crops need water again. If the timing of water access is uncertain, farmers will decrease their risk by giving excess water to the crop when they have access to water, so that they have more flexibility in timing the next irrigation as crops can survive off the residual moisture in the field. Thus, water scarcity caused by missing infrastructure in Bihar makes effective use of MIS difficult for many of the poorest farmers.

Projects run by NGOs that support small and marginal farmer adoption of MIS, pair the MIS system with interventions to assure access to irrigation such as solar pumps or large reservoirs. As demonstrated in Bathani village and in the larger 12-village survey, water is almost always distributed inequitably between farmers. This means that the poorest farmers are at a disadvantage not only because they have to pay other farmers to use their wells and pumping equipment, but also because water-buyers often have considerable uncertainty as to when they will be given the opportunity to draw water from another farmers' well. Under these conditions, even if the subsidy scheme were better targeted at the

[81] Additional fieldwork on MIS I conducted in Gujarat also showed that for farmers who buy water and therefore lack control over their irrigation schedules face substantial barriers in adopting MIS technology.

poorest farmers, MIS technology systems would likely remain inappropriate for the poorest farmers due to *missing infrastructure* in the form of assured irrigation access.

Other STCMs that prevent the poorest farmers in the sample from benefiting from MIS include *lack of financial assets* (STCM 1), *missing market linkages* (STCM 3), *lack of access to credit* (STCM 4); *ineffective extension services* (STCM 6), *lack of individual farmer capacity* (STCM 7) and *structure of land tenure regimes* (STCM 9). Uncertainty of MIS dealers over whether farmers will have available financial assets or access to credit (STCMS 1 and 4), make them less likely to even approach the poorest farmers with information about MIS technology. Even extension programs run by government extension agents or agronomists at the RAU focus their efforts on wealthier farmers when promoting MIS because of a belief that it is a technology that is beyond the capacity of the poorest farmers to effectively use (STCM 6 and 7). Their assumption is not unfounded. The design of MIS technology currently funded by the subsidy program is more expensive per unit area for smaller fields and requires extensive maintenance. This includes cleaning routines that require flushing the system with water – an additional expense and challenge under conditions of severe water scarcity and where farmers have minimal education to understand complex maintenance operations and maintenance instructions for a new technology. MIS is also a technology best suited for high-value and vegetable crops. To the extent that *market linkages* (STCM 3) are weaker for the poorest farmers who often accept a smaller price for crops in order to reduce transaction costs by selling their crops at a smaller (but usually closer) market, return on investment in MIS technology per unit crop produced will also decline, further decreasing the benefits the poorest farmers might realize from investments in MIS. The *structure of land tenure regimes* also plays a role in limiting access of the poorest farmers to MIS (STCM 9). Because of the failure of land redistribution in Bihar, the many farmers who lease or sharecrop land are ineligible for the MIS subsidy program.

The STCMs that play no role in preventing the poorest farmers from benefiting from MIS include *weak capacity for collective action* (STCM8), and *corruption* (STCM 11).

2.6.4 Electric Motor Pumps (EMPs)

Electric motor pumps (EMPs) are tools for extracting groundwater for the purposes of irrigation. EMPs can be used to lift ground water from ponds or rivers, but in South Asia they are most commonly used to lift groundwater from wells including both open wells and deeper borewells. EMPs are not the only tool for extracting ground water. Diesel engines are also extensively used throughout South Asia's groundwater economy. Both EMPs and diesel engine pumps serve the same purpose in the irrigation sector – lifting water. The only difference between EMPs or diesel engines from the perspective of lifting water for irrigation is the mode of energy generation. Nevertheless, from the perspective of farmers, there are vast differences between the two technologies.

Diesel pumps are in almost every way an inferior alternative to EMPs. A new diesel pump set is almost a third more expensive than a new EMP; the maintenance cost of a diesel pump is five times the maintenance cost of an electric pump; and the efficiency of an electric pump is 30% higher (Purohit and Michaelowa, 2008). However, all of this is not what makes diesel pumps a hugely inferior option for farmers in most of India. Rather, the cost of irrigation with diesel is significantly higher than with electricity. Rising diesel prices in India have led to what scholars have called an "energy squeeze" on India's smallholder farmers. During the period 1990 through 2007, farmers faced an eightfold increase in the nominal price of diesel. At the same time, the nominal price of rice rose by less than 50% (Shah, 2007). In the end, the only reason that farmers choose diesel pumps over EMPs is when EMPs are not an option because their water source is either not served by the electric grid or because of intermittency issues that make assured and timely irrigation with EMPs impossible.

Since the 1990s, there has been a burgeoning literature on India's groundwater economy. Much of this research has been led by Tushaar Shah, a leading Indian economist and former director of the Institute for Rural Management (IRMA) in Gujarat. Shah and his students have not only developed extensive in-depth understanding of the impacts of the political-economy of groundwater across states, but also influenced state policy. They have also focused specifically on the poverty and inequality dimensions of different sociotechnical groundwater systems in India. So, unlike many of the other technology case studies discussed in this chapter, the questions surrounding the impact of these technologies on the poorest farmers is not new. That being said, because of the rapidly evolving sociotechnical regime in Bihar's groundwater sector, the question of how the poorest farmers will benefit from EMPs is worth asking. This is not only because of the degree to which water is the number one constraint almost all farmers in the survey cited to improving their agricultural productivity, but also because improved water access and control is often also the key to adoption of additional technologies such as MIS or SRI. Fortunately, while many questions remain about the implications for the poorest of Bihar's rapidly evolving groundwater regime, the extensive research by Shah and his co-authors allow for highly informed speculation grounded in the developments in Bathani and the 12-village survey. This case study thus draws extensively on their work and situates the quickly evolving role of EMPs in Bihar today within this broader literature.

In the introduction to his book "Taming the Anarchy? Groundwater Governance in South Asia" (Shah, 2009), Tushaar Shah explores the history of South Asia's groundwater economy. Irrigation he argues "has always been central to life and society in the plains of South Asia" (p. 5). In 1890, the region had 12 million hectares of irrigated land compared with three million hectares in the United States, two million hectares in Egypt. Since the 1970s, growth in irrigated area in India has expanded rapidly. The explosive growth in irrigation was driven by a shift in the physical dimensions of irrigation technology. Up until the late 1960s, irrigation was mainly supplied through extensive surface irrigation networks, which fell under the jurisdiction of village communities or the state to build and maintain. Beginning in the 1970s, India experienced a groundwater boom in the form of individually owned groundwater wells which are powered either by EMPs or diesel pumps. (A small but growing number are also powered by solar energy as discussed in Section 6.1).

One well-known challenge created by India's rapid shift to groundwater is rapid depletion of groundwater in the northern and western states of India including Punjab, Haryana, Gujarat, Karnataka and Tamil Nadu (Rodell, Velicogna and Famiglietti, 2009). While this is a significant concern, it turns out that in Bihar and other parts of eastern India including Orissa and West Bengal, groundwater depletion is a minor concern. This is because the state sits on top of the Ganga-Meghna-Brahmaputra (GMB) aquifer system that is abundantly recharged (Shah and Ballabh, 1997). According to a study published in Nature in 2009, Bihar was only withdrawing 30-40% of annual groundwater recharge (Rodell, Velicogna and Famiglietti, 2009). In other words, Bihar could increase the well-being of its people by using more groundwater without negatively impacting its natural capital base.

Despite Bihar's abundance of groundwater, farmers in the state face substantial water scarcity as evidenced by the low cropping intensity and their own evaluations of the biggest barrier to improved productivity. The water scarcity they face is economic rather than physical – the water is there, it is just too expensive to access it. The energy squeeze, caused by the rising price of diesel, has impacted Bihari farmers perhaps more than farmers in any other part of India. This is because at least until recently, Bihar had one of the worst electrification rates in India and the lowest per capita consumption of electricity (Oda and Tsujita, 2011). Based on data gathered in 2008-2009, Oda and Tsujita estimated that only 60% of villages in Bihar were electrified. From the perspective of agriculture, the number of villages with sufficient power capacity not only to bring electricity to fields and wells, but also to run the higher capacity motors required for lifting groundwater, was significantly below 60%.

Bihar's electricity situation in the 1990s and early 2000s actually got worse rather than better. According to the Bihar State Electricity Board, 18,000 out of the 47,000 electrified villages in Bihar were "de-electrified" (Kishore, 2014). My own experience confirms this figure. On a visit to a remote village to see a newly installed solar powered irrigation pump, I learnt that while the village had not had electricity for many years, back in 1979 the older villagers recall the day electricity was extended to their village. Elders remember a five to ten-year period where the village received intermittent electricity, but since the 1990s they have not had a day of electricity and the infrastructure has now decayed.

Due to the limited electricity infrastructure, almost all groundwater extraction mechanisms (WEMs) run on diesel pumps rather than EMPs (Kishore, Sharma and Joshi, 2014). Despite the fact that between 1977 and 1992 West Bengal and Bihar have witnessed the largest percentage increase in total number of groundwater extraction mechanisms (including both diesel and electric pump sets) in the entire country, Bihar actually experienced an absolute decline in the number of EMPs – a result no doubt of de-electrification (Mukherji, 2005). In other words, adoption of groundwater irrigation technologies boomed in Bihar in the 1970s and 1980s, but this boom was almost entirely a result of diesel pumps. When the price of diesel in India rose, the costs hit Bihari farmers especially hard. Indeed, their cost of cultivation, especially when compared to their peers in states like Punjab and Gujarat with free or nearly free flat-rate electricity, became non-competitive for many crops.

A unique feature of South Asia's groundwater boom is that it also produced indigenous institutional dimensions to the technology – specifically groundwater markets, whereby owners of borewells would sell water to their neighbors (Mukherji, 2005). The growth of water markets in India developed at a rapid pace in conjunction with the growth in the groundwater sector. A study looking at data between 1976-77 and 1997-98, shows that in 1976-77, only 4.9% of net area irrigated was irrigated through water markets (where water buyers purchased water from another well owner) (Mukherji, 2005). By 1997-98, that number had risen to 31%. In a 20-year period, India witnessed a 20-fold increase in the size of its groundwater market. Mukherji (2005) calculated the value of agricultural output generated through groundwater markets in the 1990s was almost 150 billion *rupees* (1990-93 constant prices). Careful economic analysis of groundwater markets in India show that the institution can be “pro-poor” in that the groundwater markets allow the poorest farmers to access water for irrigation they might not have been able to, in the absence of these markets (Shah, 2007). However, the actual benefits realized by the poorest farmers through groundwater markets depends on the local institutional dimensions of these markets, which are strongly influenced by government policies (Shah and Ballabh, 1997; Kishore and Mishra, 2005; Prakash, 2005; Mukherji, 2006; Kishore, 2014).

While early growth in groundwater markets in Bihar was high, later price hikes in diesel and the absence of electricity hampered the continued growth of groundwater markets and made access to irrigation exorbitantly expensive for farmers throughout Bihar (Shah and Ballabh, 1997).

When Nitish Kumar came to power in 2005, he emphasized the need to improve rural electricity infrastructure in the state. And indeed, rural electrification has proceeded at a rapid rate, with Nitish announcing in the final days of 2017 that all villages in Bihar were now connected to the grid. However, this only means that at least one household in a village has electricity. As Nitish announced the 2017 accomplishment, he set another goal of having every household connected to the electric grid by the end of 2018 (Pti, 2017). Whether or not this ambitious goal is accomplished, it may not solve the agricultural problem because many of the connections are single phase rather than three-phase – insufficient capacity to power EMPs – and getting electricity from transformers in the center of villages to the fields and wells where they are needed is an additional challenge.

That said, increasing electrification is driving increasing adoption of EMPs in both Bathani and the larger 12-village data set. The rest of this case study will reflect on this data in conversation with the larger literature on groundwater economies in India. It looks at the ways in which the changing sociotechnical regime impacts the realization of the benefits for the poorest farmers.

2.6.4.1: Sociotechnical Analysis of EMPs in Bihar

Of the households surveyed for this project, only 4% have thus far adopted electric motors for pumping groundwater. The first household to adopt electric motors was in 2008, and the peak year of adoption was 2015, making electric motors a very new technology within the context of Bihar. Across the entire dataset, 10% of UC farmers had adopted electric pump sets, whereas 4% of OBC and 3% SC/ST farmers had adopted electric pumps. Even so, electric pump sets are seen both by the few farmers who own them and the farmers who do not as one of, if not the most, desirable agricultural technologies in Bihar. In the 12-village survey, when asked what technology households would invest in if they had sufficient capital, borewells combined with EMPs were the clear favorite. 92% of households said they would invest in some combination of borewell and EMP package (what they wanted depended of course on whether they already had a borewell).

In Bathani, three phase electricity (single phase electricity was already available, but is insufficient to power an electric motor) reached the village in the summer of 2015. The transformer was located on the main road between the wealthier hamlet of Surka and poorer hamlet of Rajapur. By the winter of 2015, farmers began to switch to electric pump sets to power borewells, but switching costs were high so only wealthier farmers could afford to make the switch. At the time of my fieldwork, two electric motors had been installed in Bathani – one in Surka near to the river, and one on the agricultural land adjacent to Rajapur, but on land owned by a very industrious household from Surka (discussed in Section 2.5.3 as Family A). In addition, Family C was in the process of building a borewell on the outskirts of Erki which they planned to power with an EMP from a newly installed transformer in an adjacent village. All households who had invested in the electric pump sets came from the Yadav caste. The Yadav caste in Surka, while traditionally known for livestock husbandry, also led the village in landholding size, well ownership, and overall technology adoption.

Water markets based on diesel engines are already a part of Bathani's agricultural system. Farmers in Bathani pay 70-80 *rupees* per hour (just over one dollar) to buy water from another farmer. Farmers are most likely to buy water during the winter season and least likely to buy water in the summer when many households simply forgo a crop due to the high cost of water (see Table 2.14). In every season, OBC farmers are more likely to purchase water than SC/ST farmers. This is not because SC/ST farmers have access to water without purchasing it, but because SC/ST farmers due to the high cost of irrigation often chose to forgo crops during winter and summer seasons (see discussion of cropping intensity in section 2.5.2) or to practice deficit irrigation which decreases yields, but reduces the cost of irrigation.

Table 2.14: Water purchasing by caste and tola in Bathani.

Season and Caste	Surka	Rajapur	Erki	Total
Monsoon				
OBC	70%	50%	33%	**57%**
SC/ST	50%	25%	28%	**34%**
Winter				
OBC	70%	50%	48%	**62%**
SC/ST	54%	25%	56%	**50%**
Summer				
OBC	45%	0%	0%	**29%**
SC/ST	0%	0%	0%	**0%**

Over the course of my fieldwork, I was particularly interested in how the introduction of electric pump sets in Bathani would impact the availability and cost of water not only for EMP owners, but for water buyers. Larger farmers who have the land and capital to construct borewells, sell water to neighboring farmers. Research on EMPs in West Bengal demonstrated significant benefits to small farmers from the introduction of electric motors with flat rate electricity (Mukherji, 2007). The flat fee creates high incentives for electric pump set owners to sell their excess groundwater to neighboring farmers. Competition between water sellers drives down the cost of water for other farmers, significantly decreasing the cost of water access.

In Bathani, connections for electric motors cost a monthly flat rate fee of 220 *rupees* (roughly 3.40 USD). In Bathani, the price of purchasing water from another farmer using a diesel pump set ranged from 70-80 *rupees* per hour (just over one dollar). Profit margins to borewell owners using diesel pump sets were not large (perhaps 10-15% profit), but if after switching to electric motors the price per hour of water on the water market remained the same, the electric pump set owners would essentially pocket the entire hourly fee as pure-revenue after their fixed monthly electricity payment.

In discussions with new electric pump owners, it was clear that for the time being, the switch to electric pump sets would not change the price they charged hourly for water. Of course, competition in theory between electric pump set owners should drive down the cost. However, in Bathani, groundwater tables are very variable (see discussion in Section 2.5.2). Building a new borewell is expensive. It is likely that only wealthier farmers will construct new borewells and other households who adopt EMPs will already own their own well or borewell. As discussed in Section 2.5.2, most well-owners in Bathani are in Surka *tola* and come from OBC castes. This is particularly true for the higher quality open wells and all of the borewells.

Because of inequality in well ownership in Bathani, the only way to bring benefits of electric motors to the poorest farmers is to ensure that they have borewells with a high daily capacity. Until now, no household in Rajapur has sufficient assets to invest in borewell construction, and based on my observations of limited collective action activity between residents of Rajapur, the likelihood that Rajapur's farmers will pool their money to construct a borewell is low. In this context, government intervention in this type of infrastructure would seem the only way to ensure that the poorest farmers in Bathani have access both to borewells, but more importantly to the significant potential decrease in the price per unit of water provided by the new availability of EMPs.

In Bathani, the monthly cost of an electric motor connection to the grid was not yet widely known, but as this information becomes available, water buyers will likely balk at the exorbitant profit margins of water sellers. In fact, in Surka hamlet, the close familial and caste-based connections caused Family A to decide to give water away (at least for the time being) from their new borewell and EMP. In contrast, Family C in Erki where family and caste-based networks are less important, planned to sell water from their new EMP at the same rate as they currently sell water from their diesel powered borewells. The husband from Family C said that "as long as I have invested in these borewells and the pumps, why should I not charge as much as I can for the water?" Whether or not increasing adoption of EMPs in Erki will induce market competition and force Family C to lower prices is an open question. However, for the time being, families in Bathani who live closer to the newly installed transformers and who can afford to invest in the electric wires, borewells and EMPs required to realize benefits from the newly installed transformers, will reap the benefits from EMPs.

While electric motors are clearly a new technology in Bihar, the certainty that more equitable water markets will develop as they have in West Bengal should be called into question, especially in regions with complex hydrology and high failure rates for borewells. The inequity is exacerbated by the fact that wealthier farmers tend to already own the highest quality land, close to rivers and in low lying areas where borewell construction is less risky in the first place. While electric motors are an aspirational goal for farmers across Bihar, the likelihood is that at least in the near future, they will continue to bring greater benefits to wealthier farmers. Yet from a public policy perspective, this is not the only potential outcome. Government programs focused on building borewells for the poorest farmers combined with the growing availability of electricity across Bihar, could dramatically decrease the cost of cultivation for small farmers. In addition, fairness norms could force electric pump set owners to decrease the price they charge for water over time.

2.6.4.2: STCMS as Barriers for the Poorest: EMPs

The STCM that played the largest role preventing the poorest farmers from benefiting from EMPs in Bihar was *missing infrastructure* (STCM 5). The lack of three-phase electricity in Bihar is high, but evidence from Bathani also shows that when three-phase electricity is installed, it often benefits relatively wealthier farmers simply because of where the transformers are placed in the village (closest to the wealthiest households). A second major challenge preventing the poorest farmers from benefiting from EMPs even when three-phase transformers are installed, is that the government leaves the infrastructure investments necessary to transmit electricity from the village transformer to farmer's fields to the farmers themselves. While wealthier farmers can afford to invest in the wires and electrical poles to do this, the poorest farmers often cannot.

Other STCMs that prevent the poorest farmers in the sample from benefiting from EMPs include *lack of financial assets (*STCM 1), *lack of access to credit* (STCM 4), *weak capacity for collective action* (STCM 8), *structure of land tenure regimes* (STCM 9*), misaligned incentives* (STCM 10), and *corruption* (STCM 11).

*Lack of financial assets (*STCM 1), is probably the next greatest barrier after *missing infrastructure* preventing the poorest farmers from benefiting from EMPs. This is not due to the price of EMPs themselves, but due to the cost of investing in borewells and electricity wiring required as co-investments with EMPs. *Similarly,* the fact that the poorest farmers in Bihar both cannot access credit (STCM 4) and often say they would not want it even if it were available, hampers the poorest from making investments in EMPs, borewells and wiring through loans.

The structure of land tenure regimes also plays some role in preventing the poorest farmers from benefiting from EMPs. Failure of land reforms in Bihar has led not only to unequal distribution of land, but unequal distribution in quality of land, particularly with respect to water access. In Bathani, the wealthier farmers own land with high groundwater tables whereas the poorest farmers who received government wasteland (like Family B), have land with poor water access.

*Misaligned incentives (*STCM 10) and *corruption* (STCM 11) both probably also play some role in preventing the poorest farmers from benefiting from EMPs. This is because transformers are so often installed next to the home of the wealthiest households in the wealthiest *tola.* Whether this happens due to overt corruption or simply because the engineers responsible for constructing the transformers have not been given instructions to install transformers close to the poorer corners of the village, is a question I was unable to answer. Still, if the Bihari government wants their infrastructure investments to be "pro-poor", they should ensure that transformers are installed closest to the land of the poorest farmers.

The STCMs that play no role in preventing the poorest farmers from benefiting from EMPs include *inappropriate technology design* (SCTM 2); *missing market linkages* (STCM 3); *ineffective extension services* (STCM 6) and *lack of individual farmer capacity* (STCM 7).

2.6.5 Rubber-Walla Pipes (RWPs)

Rubber-*Walla* Pipes are actually plastic pipes made from a transparent plastic that are about 10-inches in diameter and semi-flexible. The pipes are known locally in Bihar as rubber-*walla* pipes (RWPs). The first mention of RWPs that I can find in academic scholarship on Bihar is in a 1997 article by the groundwater economist Tushaar Shah who recommended that subsidizing RWPs would make local groundwater markets more competitive (Shah and Ballabh, 1997). Apart from this article, there is very little published literature on the use of RWPs in agriculture in Bihar or elsewhere in India.

Judging by the paucity of research on RWPS, they are not traditionally thought of as an interesting agricultural technology. However, in the context of Bihar, from the perspective of farmers this could not be farther from the case. The value of RWPs is that it transports water from water sources to farmers' fields with substantially less labor than the earthen channels that farmers constructed and maintained prior to the introduction of RWPs.

While there is little information on the origin of the RWP, the private sector in India has been promoting the value of increased plastics use in agriculture since the 1980s, when the National Committee on Plasticulture Applications in Horticulture (NCPAH) began to promote the use of plastics in agriculture around the country. NCPAH has close ties with the private sector who are the primary suppliers of all plastics in agriculture. NCPAH focuses their efforts on funding research and promotion of plastics in agriculture and more recently on subsiding drip irrigation (see Section 2.6.3). Whatever role NCPAH played in promotion of RWPs, nowhere on their website or promotional material do they mention the technology.

RWPs appear to have become available on the market in Bihar the early to mid-1990s and by the early 2000s the technology had come into widespread use (see Section 2.5.1). Based on information I gathered in interviews with store owners and extension officials, I do not think RWPs have ever been subsidized by the government, but the relatively low cost of RWPs, the ease of use and the fact that it helps farmers decrease backbreaking labor investments, has led to rapid uptake of the technology.

2.6.5.1: Sociotechnical Analysis of RWPs

Despite the relative scarcity of information on RWPs in the literature or in government documents, across the entire data set RWPs are the most used technology by all socioeconomic groups of farmers, with 87% of all farmers using this technology. The factor by which lower caste farmers are less likely to use RWPs is also relatively high at 0.89, meaning that under the revealed preference assumption that use equates to benefits, RWP is a technology that both the poorest and wealthier farmers both benefit from – a "raise all boats" technology. Actual benefits to the poorest farmers are likely higher than the likelihood factor suggests because the poorest farmers benefit from RWPs in ways that wealthier farmers may not, which I will discuss below.

In Bathani, the use of RWPs is also high, but differentiated by *tola*. While in Surka, 92% of households use RWPs, in Rajapur the number of households who use RWPs is far lower at 27%. In Erki, 80% of farmers use RWPs. The low level of RWP use in Rajapur is directly related to water access. Farmers like Family B whose land is too far from a groundwater source to reliably transport water even with an RWP, do not use the technology. Family B, despite its large landholding, is uphill from almost every water source making use of RWPs impractical and limiting Family B to a rainfed production system.[82]

Farmers in Bathani reported that RWPs, depending on care and use, need to be replaced every three to five years. I was curious about the purchasing habits across the dataset about RWPs. Across the 12-village dataset, 29% of households bought RWPs in the last year (some for the first time, but mostly as replacements for RWPs that had been damaged). Across castes, 45% of UC farmers, 39% of OBC farmers and 18% of SC/ST farmers purchased RWPs in the past year. But this data does not show the full extent to which the poorest farmers benefit from RWPs.

In Bathani, water buyers said that the introduction of RWPs had enabled them to begin to purchase water from farmers who were reluctant to sell them water before the introduction of the technology. Farmers across the data set began using RWPs when they came on the market in the 1990s. By 2000, there was a substantial spike in adoption of RWPs. The spike was led by OBC farmers but quickly

[82] Note: I am very curious to return to Bathani and see how the growth in the water market may have impacted farmers like the Family B. My suspicion is that Family A's borewell could easily service family B's land. But for the time that I was in Bathani, Family A was just getting used to their borewell and had not really developed a water selling strategy. The farmers Family A did give water to, were members of their own extended family. The social distance between Family A and Family B meant that neither farmer even considered an economic relationship between the two households despite the fact that Family A's land well was ideally located to service Family B's large landholding with the help of RWP. As water markets grow in Bathani with the expansion of the electrical grid, I am curious about the inter-caste dynamics.

followed by other socioeconomic groups. RWPs solved a substantial problem for water buyers: it allowed them to transport water across other farmer's fields without building labor intensive water channels for the water to flow through. This not only decreased labor, but also decreased farmer conflict as the RWP was a temporary structure that did not take up space or require water buyers to spend substantial time on other farmer's fields. The SC/ST farmers in Surka said that RWPs had been particularly helpful for them. Before the introduction of RWPs, the close-knit *Yadavs* in Surka would support each other in the constructing of irrigation channels and generally coordinated irrigation schedules. SC/ST farmers were often left out of the process of deciding where and when the earthen channels would be built, substantially decreasing their certainty over if and when they would even be allowed to purchase water from well owners. With the introduction of the RWP, the transaction costs for selling water decreased substantially and SC/ST farmers felt that they were more easily able to purchase water from their well-owning neighbors.

RWP is often included in the overall cost of water buying. While water sellers usually claimed that they provided use of RWPs free of cost, water buyers said that they pay approximately 10 *rupees* an hour on top of the other costs to use the water-sellers' RWPs. Water buyers in Bathani also felt that it was prudent to own some of their own RWPs, to ensure that lack of RWPs was not a barrier for timely access to irrigation when they needed it. Whatever the truth (and there is almost always a gap in the data between water buyers and water sellers in their assessments of costs) all farmers in Bathani agreed that RWPs had lubricated the water market in ways that were beneficial across socioeconomic groups.

Overall, farmers felt that RWPs were a very important technology in their 'technology portfolio'. However, for wealthier famers, they considered RWPs to be an improved substitute for the old-fashioned earthen channels which were more labor intensive but served the same purpose. For this reason, wealthier farmers and well-owners tended to rank RWPs as nice to have, but non-essential technology. At the same time, the poorest farmers ranked RWPs very highly in terms of importance (just behind borewells and

EMPs and even ahead of improved seed varieties discussed in the next section). This is because RWPs benefited many of the poorest farmers more than any other group because whether or not they personally owned RWP, it often substantially improved their access to irrigation water.

In many ways, RWP shares physical dimensions similar to drip irrigation (MIS). It is made from flexible plastic, it transports water, decreasing labor costs and increasing yields. But unlike MIS which has not caught on in Bihar despite substantial subsidies, RWPs have reached widespread use in the innovation system without support by the government. Instead, the physical dimensions of the technology met specific needs that all farmers in Bihar had and the cost was low enough that it allowed the poorest farmers to also invest in the technology. Moreover, the social dimensions of the technology lubricated the groundwater market, which brought the poorest farmers relatively more benefits.

2.6.5.2: STCMS as Barriers for the Poorest: RWPs

While wealthier farmers use RWPs at slightly higher rates than the poorest farmers, the benefits accrued from RWPs may actually skew towards the poorest farmers. This is due to RWPs easing the constraints of the transaction costs in water markets. There are therefore few barriers preventing the poorest farmers from realizing greater benefits from RWPs.

The only SCTM that created a moderate barrier for the poorest farmers was *missing infrastructure* (STCM 5). For example, in Bathani, farmers in Rajapur *tola* had little incentive to invest in RWPs because for many of them, like Family B, even the flexibility afforded by RWPs did not put the family close enough to irrigation infrastructure to make RWPs useful.

2.6.6 Improved Seed Varieties (ISVs)

High yielding seed varieties or (HYVs) first came to India during the late 1960s and early 1970s, heralding what William S. Gaud, the administrator for USAID, coined a "Green Revolution." These seeds came from Mexico (wheat) and the Philippines (rice), developed by Rockefeller Foundation funded scientists with a mission to improve global agricultural yields and forestall a Malthusian famine (Stakman, Bradfield and Mangelsdorf, 1967). After the introduction of the high yielding varieties (HYVs) in India, wheat production skyrocketed from 11 million tons in 1961 to 23.2 million tons in 1971 and 46 million tons in 1984 (Chopra, 1985). While contested interpretations of the legacy of the Green Revolution abound, the packages of seeds and fertilizer in conjunction with government interventions to stabilize market prices and ensure access to irrigation, undoubtedly had significant impact on both yields and economic growth in the states where the technology took off (Edwards, 1974; Parayil, 1992; Pingali, 2012).

The benefits of the Green Revolution were not distributed evenly across the country. The concentration of Green Revolution technology adoption in the west and northwest and especially in Punjab, helped Punjab become one of the most developed states in India. Punjab maintained the highest per capita GDP of any state in India through the mid-1990s when it was overtaken by the IT boom concentrated in the south (Abbi and Singh, 1997). In contrast, many of the eastern states including Bihar, failed to benefit from the Green Revolution technologies at least until the late 1980s and early 1990s (Bhalla and Singh, 2001; Singh, 2010).

The success of the Green Revolution in Punjab and other western states was the product of both very effective new technology (the physical dimensions of the HYVs) combined with institutional interventions on the part of government actors. These actors developed supportive economic incentives hand-in-hand with the necessary infrastructure to support widespread adoption of the high yielding seed varieties (Chopra, 1985; Pingali, 2012). In contrast, in Bihar and other eastern states, the Green

Revolution failed to have a significant impact on agricultural systems. There are many reasons for Bihar's failure to benefit from the Green Revolution, but perhaps the most important reason at least under the leadership of Lalu Prasad, was a lack of availability of improved seeds in the state.

After his election in 2005, Nitish asked the Ministry of Agriculture to identify barriers to improved agricultural productivity in the state. The minister identified low adoption and use of improved seed varieties in Bihar as one of the key problems facing the agricultural sector. By 2005, several different types of seed technologies were available in India, including both the high yielding varieties (HYVs) of the Green Revolution and more recent hybrid seed varieties. Hybrid varieties rely on a different biological mechanism than the Green Revolution's HYVs which are inbred rather than hybrid. Hybrid rice was introduced in Bihar in the early 2000s and was unavailable before that. One key difference with hybrid rice is that its quality degrades much more quickly between generations so that farmers ideally must buy new seeds each year when using hybrids. The tradeoff is that yields are higher. Note that hybrid technology is separate from GMO technology which is not permitted in India except in the case of cotton (a non-food crop). Because both high yielding and hybrid crops are relatively new to Bihar and farmers often do not differentiate between the two, the research focused on sociotechnical causal mechanisms affecting adoption of both high yielding varieties and hybrids, which I collectively call improved seed varieties (ISV).

The Ministry of Agriculture focused on improving Bihar's low seed replacement rate. The seed replacement rate is the most common metric used to evaluate the performance of a seed system. The seed replacement rate is defined as the measure of an overall cropped area that is planted with ISVs or certified seeds as opposed to farmer-saved seeds. Generally, a seed replacement rate of 100% is not the target, rather targets are set specific to the biology of the crop. A report commission by the Ministry of Agriculture, found that the seed replacement rate for paddy increased from 6.8% in 2003-04 to 10% in 2004-05, but this was still well below the target of 30-35% for a self-pollinating crop (BAMETI, 2007).

The Ministry further noted that the key barrier to improved seed replacement rates was overall unavailability of ISVs in the state. The reasons for the unavailability of ISVs in Bihar included a depleted seed production capacity in the public sector, failure of the state to participate in central government schemes to strengthen seed infrastructure, and lack of private sector activity in the state (S. Maho, Director of Agriculture Gaya District, personal interview, December 19, 2015).

The 2008 Agriculture Road Map allocated 44.1 million USD over five years (8.3% of the 532-million-dollar budget) to a new seed plan program in order to increase seed replacement rates in the state. While money was allocated for improved breeding programs, the majority of the budget allocation (58%) went to the seed distribution program, which offered ISVs including wheat, paddy, hybrid paddy, pulses, oilseeds and maize to farmers at significantly subsidized rates (Government of Bihar, 2008). The 2012 Road Map increased funding for the seed program to 137 million USD (7% of the 1.8 billion budget).[83]

The rest of this case study shows that the use of ISVs by farmers in Bihar has risen substantially across socioeconomic groups. It also demonstrates that the story of increasing adoption of ISVs in Bihar is not a story of direct government subsidy support for the technology leading to increased adoption (despite the hundreds of millions of dollars allocated to the subsidy program). Rather, overall improvements in governance and security (STCM 11) has led to increased private sector participation from the multi-national to the village scale. This in turn has improved access to ISVs on the part of all farmers in Bihar.

2.6.6.1: Sociotechnical Analysis of Improved Seed Varieties in Bihar (ISVs)

In the 12-village survey, 82% of respondents said they used ISVs in the past 20 years. Moreover, the gap between the poorest and wealthier farmers was also relatively small. While 86% of UC farmers

[83] It is worth noting that this is less than the amount allocated in the 2012 Road Map for SRI, which was 144-million dollars.

use ISVs, 85% of OBC and 77% of SC/ST farmers use ISVs. The factor by which a lower caste farmer is less likely to use ISVs is 0.93, making ISVs in Bihar a technology that "raises all boats."

In Bathani, overall 65% of households use ISVs – significantly lower than the larger dataset. The difference in use of ISVs was starkest by *tola*. In Surka *tola,* 78% of households used improved seeds whereas in Rajapur only 18% of households used improved seeds. Across Bathani, all farmers with more than 2 acres of land used ISVs. The foremost barrier to use of ISVs in Bathani is access to water. If farmers cannot afford to water their crops or are concerned about timely access to water, they will not invest in ISVs.

There is a sharp difference in use of ISVs in Bathani between those farmers who can purchase water in the event of late onset of the monsoon and those who cannot. The barrier is not as much financial as infrastructural. In Rajapur for example, farmers whose land was close enough to a well to purchase limited water in the event of drought or late onset monsoon, would invest in paddy ISVs. But if farmers felt that in the event of a drought, finding assured access to irrigation would not be possible, they chose to forgo ISVs due to the potential risk of loss. This was the case for Family B where the male head of the household refused to invest in ISV paddy despite his wife's belief that their yields would be better. He was too worried that the crop would fail and they would lose their investment. As a compromise, he purchased seeds from a neighbor. These seeds were one third the cost of buying ISVs at the market, but they would likely yield better than the seeds he had been saving at home for multiple seasons.

Family C who owns two wells and has assured irrigation access on all their land, use the most expensive ISVs (hybrid paddy). Family C said that after they began using hybrid ISVs that their paddy yields more than doubled. Moreover, because they own their own wells, there is very little risk of crop failure.

Finally, Family A also invested in ISVs, but not the most expensive hybrid ISVs as at least until this year, the potential for loss without their own irrigation source was too great. Instead, they used more economical ISVs from West Bengal, which are cheaper than the ISVs from what they called the "big companies" which in Bihar include Syngenta, Monsanto, and DuPont. However, they are considering investing in higher quality ISVs in the future, now that their borewell assures timely access to irrigation.

Another farmer in Rajapur did not use ISVs on his own 0.3 acres of land because he feared that he would not be able to secure timely irrigation for his crop in the event of a drought. However, he did use ISVs on another 0.5 acres of land he sharecropped on the land of a farmer from Surka. The sharecropper and landowner negotiated that they would split the cost of the short duration ISVs for paddy, as well as the cost of irrigation which they would buy from a third household who owned a nearby well to the 0.5-acre plot. They were confident that they would receive timely irrigation because the landowner was also related to the well-owner. This was an arrangement that was mutually beneficial to both the sharecropper and the landowner because in addition to the improved yields they observed with the ISVs, using a shorter duration variety allowed them to plant their winter wheat crop sooner, which would improve their wheat yield as well.[84]

This institutional arrangement between the sharecropper and the landowner was only possible because of a longstanding relationship between the sharecropper and the landowner (at least 10 years). Over many years, they had developed mutual trust which gave both parties a greater sense of confidence to make a joint investment in ISVs. The sharecropper and the landowner went together to buy the ISVs in Roh to ensure that they both knew the cost of the seeds. More importantly perhaps, because the landowner still lived in Surka, he was able to observe the management practices of the sharecropper to ensure his investment was well cared for. Had there not been a level of trust between the two parties, or

[84] In Bihar, late planting of wheat is a major constraint on yields Singh et al 2001. The recommended sowing time for wheat in Bihar is November 19-25, when monsoon paddy is still in the field in much of the state because the paddy is often delayed as farmers wait for delayed monsoons and try to avoid paying for irrigation. The delayed planting of paddy, which in turn delays the planting of wheat has significant implications for the wheat yield. A one-month delay in sowing of wheat can reduce productivity by more than 50% (Hoda, Rajkhowa and Gulati, 2017).

had the landowner been an absentee landowner, they would not have been able to co-invest in expensive inputs for the sharecropped land. They would also not have made this investment had the plot of land not been near a borewell owned by a farmer that would assure timely irrigation access.

ISVs were one of the most important technologies from the farmers' perspective. When asked to rank technologies by their importance, ISVs consistently ranked directly behind water access technologies (electric motor pumps and rubber-*walla* pipes) in their importance to farmers. Short-duration ISVs, or seeds that have been bred to grow more quickly, are particularly useful in Bihar where water is expensive. This is because the short-duration paddy ISV, shortens the length of time for the paddy crop to mature, which decreases water requirements over the season, allowing the farmers to rely to a greater extent on the monsoon rains with fewer purchased irrigation.

Clearly, IVS have benefited farmers across the socioeconomic spectrum in Bihar. While wealthier farmers use ISVs at slightly higher rates, the poorest farmers are not far behind. Increased use of ISVs coincided with the election of Nitish Kumar as Chief Minister and his emphasis on improving the seed replacement rate in the 2008 Agriculture Road Map. For example, no farmer in the dataset said they had begun using improved seeds prior to 2000.[85] And while OBC farmers were the first farmers to report adopting ISVs at scale around 2005, SC/ST farmers started using them soon after. The rate of ISV adoption increased around 2005, with additional smaller spikes in 2008 and 2009 followed by a substantial increase in 2010.

[85] Other sources show that HYVs were in higher use in Bihar prior to 2000 than my data suggests. I am not sure what accounts for the discrepancy between my data and data from Indiastat.com as cited by Kishore *et al*. (2014) which shows that HYVs for rice covered 24.7 percent of all cropped area in 1981/1982 and 73.9% in 2001/2003. I suspect that the differences in the data have come from two sources. First, farmers who adopted HYVs sometime in the 1990s were likely to report the year 2000 in the 12-village survey. Second, the 12-village survey captures a realistic socioeconomic sample of households thereby including many marginal farmers who account for a small ratio of the overall landholdings. The data from Indiastat.com focused on percent of overall area where numbers are likely to be driven up by higher adoption amongst medium farmers. Finally, there is some chance that HYVs were in more widespread use prior to the Lalu era and then were disadopted due to both unavailability of HYVs caused by a breakdown in supply chains due to corruption and security (STCM 11) and higher costs of diesel making investments in agriculture less attractive for many farmers.

In order to understand which STCMs were preventing farmers from adopting ISVs in the 1990s and early 2000s, and why ISVs were both quickly adopted between 2005 and 2015, with benefits distributed relatively evenly across socioeconomic groups, I relied on qualitative data from my fieldwork in Bathani as well as interviews with owners of seed stores in the nearby market town of Roh. What I found was that while Nitish's government should certainly be credited with the increased use of ISVs in the state, the reasons for this success are less straightforward than simply effective implementation of the 2008 and 2012 Agriculture Road Maps. The seed program under both Road Maps was heavily biased towards government subsidized seeds as a method for increasing the use of ISVs in Bihar. In contrast to the emphasis placed on the subsidy program by the government, the vast majority of farmers surveyed reported buying their seeds from private sector input dealers rather than government seed banks. Indeed 89% of farmers in the 12-village survey who reported using ISVs said they used private sector shops in nearby villages, rather than government seed banks to purchase new seeds.

The extent to which the subsidy program benefited any farmers, was biased towards wealthier farmers. While overall only 3.4% of farmers reported receiving a subsidy for ISVs, 4.1% of UC farmers, 3.4% of OBC farmers and 2.8% of SC/ST farmers reported receiving an ISV subsidy. In Bathani, I spent a great deal of time trying to understand the reasons that more farmers did not take advantage of the ISV subsidy program. The biggest reason was high transaction costs associated with the subsidy program. While transaction costs were not onerous (indeed the government needs some kind of verification program to administer a subsidy program) farmers nonetheless had to travel to the block headquarters (20-30 minutes by bicycle) to get subsidized seeds rather than the local market town of Roh (10 minutes by bicycle). Moreover, farmers make regular trips to Roh for everything from selling vegetables to buying any type of household goods, so the time investment to purchase ISVs could easily be "co-invested" with other necessary business. Apart from the time involved in going to the government seed bank, farmers expressed skepticism about the quality of government subsidized seeds, believing that seeds from government sources are more likely to be "fake ISVs" or seeds that had been swapped out by corrupt government officials for an inferior product. In contrast, farmers tended to trust the seeds sold by private sector seed stores. Indeed, they believed that the owners of seed stores lived in their communities and would face greater social consequences for selling counterfeit product than the more distant government officials. This preference for seeds from private sector suppliers is buttressed by results from the 12-village survey that show that private sector seed dealers are (apart from other farmers) the most trusted source of information for farmers across all caste categories, far outperforming government extension officers and even NGOs (see Appendix 2).

Another problem with the government seed program was the fixed quantity available through the subsidy program. While it was often difficult to get consistent numbers from either farmers or extension officers, it seemed seed banks sold seed in quantities that far exceeded the needs of the poorest farmers. For example, a 30kg bag of ISV paddy was available from the government at the block headquarters for 700 *rupees*. This worked out to about 23 *rupees* per kg (or 0.3 USD). In contrast, ISV from the local seed store is around 200 *rupees* per kg (3 USD). However, many of the poorest farmers with only a small fraction of an acre do not need more than a single kg of seeds to plant their field. Therefore, investing in a 30kg bag even at substantial savings, requires spending more than twice as much money up front and then finding a way to sell the seeds to neighbors which can also be difficult especially if the bag has already been opened. The large quantity of seeds sold through the government program combined with the additional transaction costs of travel, has led to a situation where for most farmers, it is better just to buy ISVs from trusted seed stores than to go to the government seed banks.

Finally, what seems to be either uneven implementation of subsidy program rules or confusion over the rules themselves, has left farmers in Bathani under the impression that unless they have at least one 2.5 acres (1 hectare) of land and their land title records, they were ineligible to receive the seed subsidy. While district officials confirmed the land records requirement, they said there was no minimum land requirement and that the smallest farmers were welcome to apply for subsidized seeds. Indeed, in a speech organized by Oxfam in Patna focusing specifically on the poorest farmers, Vijoy Prakash, the Principle Secretary in the Department of Rural Development, said that all government seed programs were explicitly targeted at the poorest farmers, with a 2-acre ceiling on farmers eligible to apply for the seed subsidy program (V. Prakash, public speech, June 25 2015, Patliputra Hotel, Patna). Whatever the truth of the matter, from the perspective of benefits derived by farmers from the seed subsidy program (as measured by access), benefits were limited across all socioeconomic groups, but particularly limited for the poorest farmers.

If the government's seed subsidy program did not catalyze the rapid uptake of ISVs in the state, then what were the underlying causal mechanisms responsible for the rapid increase in adoption around 2010? In Bathani, farmers believed that increased use of ISVs was directly related to increased availability of ISVs in the market. Like the rest of Bihar, Roh's economy has also changed since the election of Nitish Kumar. The number of seed stores operating in Roh rose from one before 2005 to five in 2015. In addition, a sixth seed store opened in Erki *tola* in 2013, putting access to ISVs at Bathani farmers' doorsteps. With competition in input supply stores, farmers receive access to more varied sources of information about seed varieties and benefit from price competition. Farmers in Bathani also believe that the quality of seeds available from the private sector has improved and that market competition and the ability of farmers to change which seed stores they patronize, ensures that the owners of the seed stores will not sell them sub-par products.

Interviews with private seed sellers in Roh revealed that a major driver of improved access to ISVs for all farmers was the improvement in law and order in the state that was a direct result of the election of Nitish Kumar. Each of the seed vendors interviewed in Roh (n=4) confirmed that business conditions had improved markedly since the election of Nitish Kumar, which gave them increased confidence to open a business. In addition to the local seed vendors, larger private sector seed companies were increasingly interested in working with distributors in Bihar. Interviews at higher levels in the seed supply chain confirmed that just as international NGOs flocked back to Bihar after the election of Nitish Kumar, multi-national companies also observed the improving governance in the state and began to see opportunities for growth. Larger private sector companies also felt that the process for seed certification was now more standardized, less corrupt and easier to get through, which also made them more confident to invest in growth in Bihar (Aanand Shrikar, Monsanto India, personal interview, August 8, 2015). Even domestic seed companies based out of neighboring West Bengal began targeting Bihar as a new opportunity for growth and developing business relationships with local seed sellers. In open-ended questions about ISVs in the 12-village survey, respondents repeatedly mentioned the improved access to seeds from West Bengal (with similar agro-ecological conditions) as a major benefit of the improved seed system in Bihar. These ISVs are often cheaper than those from major multi-national companies, but still improve yields over traditional seed varieties.

In summary, the story of increasing adoption of ISVs in Bihar is not a story of direct government subsidy support for the technology leading to increased adoption (despite the hundreds of millions of dollars allocated to the subsidy program). Rather overall improvements in governance and security (STCM 11) has led to increased private sector participation from the multi-national to the village scale. This in turn has improved access to ISVs on the part of all farmers in Bihar.

This is not to say the government of Bihar has not played an important role in the rapid adoption of ISVs, but their role as a "last mile" actor has not been successful. Instead, in addition to improvements in law and order, the government has played two critical roles unlocking access to ISVs for Bihari farmers. First, by improving the quality of breeding programs, they have worked hand-in-hand with private sector companies and international organizations such as the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT) to increase the overall availability of quality ISVs. Second, through improving the regulatory process for seed certification, as well as more strictly enforcing punishments for selling counterfeit seeds, the business environment has also improved. This has led to increased private sector participation, as well as increased farmer confidence in the seed program. This does not mean that there are no longer fraudulent seeds in the state, but Nitish's government has pursued cases of fraudulent seed sales very publicly in an effort to signal both to farmers and to seed sellers that the seed supply chain is well-regulated (e.g. Ahuja, 2017).

2.6.6.2: STCMs as Barriers for the Poorest: ISVs

Overall, the poorest farmers realize benefits from ISVs at roughly similar rates to their wealthier peers. Therefore, for the ISV case study, I did not identify STCMs that strongly prevented the poorest farmers from benefiting from this technology.

While benefits are distributed relatively evenly, wealthier farmers are still benefiting more than the poorest. This was especially clear in Bathani, where adoption of ISVs in Rajapur *tola* was only 18%. The differences in benefits realized by farmers in Rajapur compared to Surka is driven by the poor physical access to water in the *tola*. This makes investments in ISVs in Rajapur particularly risky for farmers, and demonstrates that ISVs require some minimum level of infrastructure (STCM 5). Because the poorest farmers are the least likely to own their own well, and often face high transaction costs and overt discrimination buying water from farmers in "higher" castes, the need for a minimum level of infrastructure to realize benefits from ISVs limits the benefits the poorest farmers realize from this technology.

In addition to *missing infrastructure* (STCM 5), the *structure of land tenure regimes* (STCM 9) also played some role in explaining variance in benefits of ISVs. This is especially true for sharecroppers who are the least likely to use ISVs (12%). Interviews in Bathani showed that in situations with long-term relationships between sharecroppers and landlords, landlords are more likely to encourage investment in ISVs and other inputs. This can happen where there is an element of trust between sharecroppers and landowners. However, where the social distance between the sharecropper and the landlord is larger, landlords are usually unwilling to invest financial capital in yield enhancing technologies. At the same time sharecroppers, knowing they will give half their production to the landlord, lack substantial incentive to invest in yield enhancing technologies on their own.

Finally, *misaligned incentives* (STCM 10) also seems to play some role in driving variance in the benefits the poorest farmers realize from ISVs. The governments subsidy program is fairly ineffective across the socioeconomic groups, but especially so for the poorest farmers because the design of the subsidy program sells seeds in quantities that are much larger than the poorest farmers need.

The STCMs that played little to no role in explaining variance in benefits included *lack of financial assets* (STCM 1); *inappropriate technology design* (STCM 2); *missing market linkages* (STCM 3); *lack of access to credit* (STCM 4); *ineffective extension services* (STCM 6); *lack of individual farmer capacity* (STCM 7); *weak capacity for collective action* (STCM 8) and *corruption and security* (STCM 11).

While *lack of financial assets* (STCM 1) may have played some role in driving variance, conversations with the poorest farmers in Bathani led me to believe that it was rarely the ISVs themselves they could not afford. Rather, like the case with Family B discussed above, the concern was less about the cost of the ISVs, but about the chance of losing their investment if they were unable to access or afford the necessary irrigation to keep their crop alive. Family B, for example, felt that they were unable to access or afford irrigation for their paddy crop, then if the drought came they risked also losing their investment in ISVs which led them to forgo use of ISVs in the first place. For this reason, I do not include STCM 1 as a driver of variance in benefits for ISVs as it appears that *missing infrastructure* and the high cost of water are significantly more important barriers for the poorest farmers in Bihar.

Finally, one might expect that given the overall importance of improved *corruption and security* (STCM 11) in improving the ISV innovation system in Bihar, that this STCM should be listed amongst the drivers of variance in benefits realized from ISVs by the poorest farmers. However, the improvements in this STCM in Bihar while critical to the overall adoption of ISVs, do not appear to drive variance in benefits across socioeconomic groups. The improvements in *corruption and security* benefited farmers across socioeconomic groups and gave them all access to ISVs. In fact, given the greater reliance of the poorest farmers on advice from seed sellers, the increased number of seed sellers due (at least in part) to improvements in *corruption and security* likely benefited the poorest farmers more than other groups (see Appendix 2 for data on who farmers trust for agricultural information).

2.7 Findings

This section draws on the findings from the six case studies to examine the extent to which each of the 11 STCMs prevent the poorest farmers from benefiting from agricultural technology in Bihar. In this section, I first discuss some of the more surprising findings from the analysis, then move onto a discussion of each individual STCM, drawing insights from across the six case studies as well as other insights from my fieldwork in Bihar that are relevant to a particular STCM.

Table 2.11 is a color coded visual representation of the extent to which each of the 11 STCMs prevent the poorest farmers from benefiting from technology across the six case studies. Recall that none of the technologies are specifically “pro-poor”, in that no technology benefited the poorest farmers more than wealthier farmers. Instead, all technologies evaluated in this study (based on the likelihood factor that the poorest farmers will use a technology compared to wealthier farmers calculated in Section 2.6), are either technologies that “raise all boats” or technologies “for the rich”. Because there are no technologies that are “pro-poor” among the six technologies evaluated in the case studies, Table 2.11 was constructed to show the extent to which different STCMs play a role in preventing the poorest farmers from benefiting from each of the six technologies. In Table 2.15, I rank STCMs as high if they played a large role in a specific case study in preventing the poorest farmers from benefiting from the technology; medium if they played a moderate role; and low if they played little to no role.

Table 2.15: Importance of each STCM across cases.
This table summarizes the extent to which each of the 11 STCMs prevent the poorest farmers from benefiting from technology across the six case studies. High means that the SCTM is a large barrier limiting the poorest farmers from realizing benefits from the technology; Medium means that the STCM plays a moderate role in preventing the poorest farmers from benefiting from the technology; Low means that the STCM plays little to no role in preventing the poorest farmers from benefiting from the technology.

Technology / **Sociotechnical Causal Mechanisms**	**Solar Irrigation Pumps**	**System of Rice Intensification**	**Drip Irrigation**	**Electric Motor Pumps**	**Rubber-*Walla* Pipes**	**Improved Seeds Varieties**
(STCM)	(SIP)	(SRI)	(MIS)	(EMP)	(RWP)	(ISV)
Lack of financial assets	High	Low	Medium	Medium	Low	Low
Inappropriate technology design	Medium	Low	High	Low	Low	Low
Missing market linkages	Low	Low	Medium	Low	Low	Low
Lack of access to credit	High	Low	Medium	Medium	Low	Low
Missing infrastructure	Medium	High	High	High	Medium	Medium
Ineffective extension services	Medium	High	Medium	Low	Low	Low
Lack of individual farmer capacity	Medium	Medium	Medium	Low	Low	Low
Weak capacity for collective action	Medium	Medium	Low	Medium	Low	Low
Structure of land tenure regimes	Medium	Medium	Medium	Medium	Low	Medium
Misaligned incentives	High	High	High	Medium	Low	Medium
Corruption and security	High	Low	Low	Medium	Low	Low

Recall that the six case studies were purposively selected along two dimensions of variance – benefits to the poorest farmers (where sustained use is used as a proxy for benefits), and the amount of benefits realized by technology users. The six case studies thus represent a wide-range of technologies that vary in the extent to which they benefit the poorest farmers. The six case studies are also a sample of technologies available to farmers in Bihar including technologies that are widely available to the poorest (e.g. rubber-*walla* pipes, improved seed varieties) and technologies that the poorest farmers appear all but excluded from benefiting from (e.g. solar irrigation pumps and drip irrigation). The goal is that by studying the barriers preventing the poorest farmers from benefiting from each of these technologies, the average barriers when assessed across the six case studies is representative of the overall importance of each of the 11 STCMs in preventing the poorest farmers from benefitting from technologies in general in Bihar.

In this section I assume that the STCMs identified as high, medium and low barriers preventing the poorest farmers from realizing greater benefits from technology in the six individual case studies, are representative of the relationship between STCMs and barriers for the entire set of modern agricultural technologies available in Bihar.[86] Based on this assumption, I use the findings from the six case studies (summarized in Table 2.11) to rank the STCMs by the extent to which each STCM matters in preventing the poorest farmers from realizing benefits from technology in Bihar.

I assign five points to STCMs that play a high role in preventing the poorest farmers from realizing benefits from technology in an individual case study, two points to STMCs that play a medium role in an individual case study, and zero points to STCMs that play little or no role in an individual case. I chose this weighting-scheme because in my analysis, the importance of "high" values in preventing the poorest farmers from benefiting from technology is significantly greater than the "medium" values. I then summed the score for each STCM, and divided each sum by the modal score of all STCMs to develop a ranked order of STCMs in terms of their importance in preventing the poorest farmers from benefiting from agricultural technologies. In the weighted score, STCMs with a score greater than one, play a greater than average role in preventing the poorest farmers from realizing benefits from technology. Likewise,

[86] This is of course an assumption and by including more technologies in the analysis (or performing the analysis again with a different set of technologies) one could confirm (or reject) the findings here. Nonetheless, by using a purposive selection method, I argue that six case studies are sufficient to accurately capture a representative sample of the barriers preventing the poorest farmers from benefiting from technology in Bihar.

STCMS with a score less than one, play a below average role in preventing the poorest farmers from realizing benefits from technology. The results ranked from most important to least are summarized in Table 2.16 below.

Table 2.16: Ranked order of STCMs by importance.

I calculated raw scores by summing points across the six case studies, assigning five points to STCMs when they played a high role in preventing the poorest farmers from benefiting from a specific technology; 2 points when the STCM played a medium role in preventing the poorest farmers from benefiting from a specific technology; and zero points when the STCM played little to no role. The weighted score was calculated by dividing each raw score by the modal raw score for all STCMs (in this case 9). The scale runs from 0.2 to 2.3.

STCM	Raw Score	Weighted Score
Missing infrastructure	21	2.3
Misaligned incentives	19	2.1
Structure of land tenure regimes	10	1.1
Lack of financial assets	9	1
Lack of access to credit	9	1
Ineffective extension services	9	1
Corruption and security	7	0.8
Inappropriate technology design	7	0.8
Lack of individual farmer capacity	6	0.7
Weak capacity for collective action	6	0.7
Missing market linkages	2	0.2

The extent to which each of the STCMs is a barrier preventing the poorest farmers realizing the benefits of technology is the main analytic outcome from this chapter. It is worth reiterating here that the analysis ranks the STCMs in terms of the extent to which they prevent the poorest farmers from realizing benefits from technology in Bihar. The analysis does not evaluate the extent to which the STCMs are responsible for low aggregate yields or low contribution of agriculture to GSDP. For example, it is highly likely that improving market linkages by building cold storage capacity and processing facilities in Bihar would raise agricultural GSDP (lychee farmers would certainly benefit). This however was not the point of the analysis. Rather, the study is specifically focused on the STCMs that prevent the poorest farmers from realizing the benefits of technology.

These results are based on the results of six purposely selected case studies. They are thus compelling, but not necessarily conclusive. Adding more case studies to the analysis would add more certainty to the findings. Nevertheless, based on the six case studies, some interesting and unexpected findings and hypotheses can be articulated.

Missing infrastructure is the biggest barrier preventing the poorest farmers from realizing greater benefits from technology. The fact that *missing infrastructure* is a problem in Bihar's agricultural system will not be surprising to those already familiar with agriculture in Bihar. For example, Avinash Kishore, an agricultural economist with IFPRI, former HKS PhD student, and native of Bihar, has noted on multiple occasions that improving infrastructure and in particular electricity access is vital to unlocking Bihar's agricultural potential (Kishore, 2014; Kishore, Joshi and Pandey, 2015). This analysis confirms his findings, but also goes beyond his findings and demonstrates that not only is infrastructure important for overall productivity growth in the state, but it is also important for "inclusive growth". In other words, *missing infrastructure* (STCM 5) is also the most important barrier to the poorest farmers benefiting from agricultural technologies. From a policy perspective, this finding supports investments in infrastructure not only as a tool for growth in the agricultural sector, but also as a tool for inclusive growth.

Perhaps more surprising is the large role of *misaligned incentives* (STCM 10) in preventing the poorest farmers from benefiting from technology across case studies. *Misaligned incentives* played a high role in preventing the poorest farmers from benefiting from solar irrigation pumps (SIP), the system of rice intensification (SRI) and drip irrigation (MIS). *Misaligned incentives* also played a medium role in the electric motor pump (EMP) and improved seed variety (ISV) cases. The only case where *misaligned incentives* was not a barrier for the poorest farmers was the case of rubber-*walla* pipes (RWP). In the SIP case, this STCM played out through two separate institutional mechanisms. First, the BREDA scheme was advertised to farmers through newspapers and interactions with extension officers who were more likely to offer the limited number of subsidized SIP units to wealthier farmers. Second, the requirement under the BREDA subsidy scheme that recipients own at least one acre of land, automatically excluded the poorest farmers. Likewise, in the SRI case the design of the subsidy which incentivizes farmers to use SRI by giving them seeds, even though the physical dimensions of the technology requires fewer seeds, raised questions about the institutional structure of the subsidy program among the poorest farmers who practice SRI without the benefits of the subsidy. Instead, these farmers argued that the subsidy should be re-designed to offer more intensive extension support in the field and to ensure farmers had the physical weeders which are the only expensive input in the practice of SRI. Even in the case of ISVs, the poorest farmers were limited in their ability to benefit from the subsidy program because of the quantity of seeds provided under the subsidy program. This could easily be re-designed so that the ISV subsidy targets seeds in the quantities most appropriate to the poorest farmers (one to two kg).

The importance of *misaligned incentives* in the ranking of STCMs (see Table 2.12 above) suggests that in Bihar, re-designing the institutional components of agricultural policies is one of the most important interventions for ensuring that the poorest farmers realize greater benefits from technology. In other words, after investments in infrastructure, the key strategy for ensuring the poorest farmers benefit from agricultural technology, is improved institutional design. This should be done in order to re-structure the incentives of actors across Bihar's agricultural system to better meet the needs of the poorest farmers.

Misaligned incentives and the importance of institutional design is an STCM that to date has had limited discussion in the agricultural systems and development literatures. For example, even the papers I draw on in Section 2 in order to demonstrate the relevance of misaligned incentives (STCM 10), usually do not explicitly identify the STCM by name, rather the misalignment of incentive structures is latent in their findings and discussion. However, the findings from this chapter, as well as the other two chapters in this dissertation, underscore the value of institutional design in improving the functioning of the innovation system to meet the needs of the poorest farmers.

Improving institutional design to meet the needs of the poorest farmers will require taking into account the complex sociotechnical circumstances facing the poorest. This is not an easy feat. Nevertheless, in a state like Bihar it may in fact be a more manageable task for policy makers than fixing the *structure of land tenure regimes* (STCM 9), another STCM which plays an important role preventing the poorest farmers from realizing greater benefits from technology – but one that for political reasons may not be easily soluble.[87]

Finally, the role of *lack of capital assets* as an important STCM is unsurprising given that it is also the feature that defines the population of interest in the study: the poorest farmers. What is surprising is that it is not the most important STCM and that investments in infrastructure (especially if there are rules and safeguards in place to target this infrastructure at the poorest), as well as improved alignment of incentives in the innovation system, can benefit the poorest even under highly capital constrained conditions.

2.7.1 STCM 1: Lack of Financial Assets (Score 1)

Lack of financial assets, with a score of 1 (the modal score), played an average role in blocking benefits to the poorest across the six case studies. STCM 1 was a high barrier in one case – SIP. In the MIS and EMP cases, STCM 1 was a moderate barrier. However, in three of the six cases, *lack of financial assets* was not a barrier.

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[87] Recall that after his election Nitish Kumar commissioned a report on land reform, but then essentially tabled it because it was not politically tenable (Bandyopadhyay, 2009). Even Lalu Yadav, the champion of lower caste empowerment was unable to enact real land reform in the State. This is not to say that land reform would not be highly beneficial to the poorest farmers, but as my former advisor John Briscoe always said: “Do not let the best become the enemy of the good.”

In the SIP, MIS and EMP cases, the mechanism through which this STCM operates is largely straightforward – lack of capacity to afford the upfront cost of investment in the technology. In the EMP case, the high capital costs also include the borewell and the electrical wiring which is usually required as a co-investment with the EMP. While the EMP itself is not particularly expensive, the borewell and wiring make the EMP outside the financial reach of the poorest farmers.

In contrast to the SIP, MIS and EMP cases, *lack of financial assets* operates different in the RWP case. In the RWP case, the poorest farmers likely benefit more from RWP relative to their wealthier neighbors even when they lack the financial assets to invest in the technology at the same rates as their wealthier neighbors. This is due to the way in which RWP reduces transaction costs in groundwater markets, making it easier for the poorest farmers to benefit from these markets. The physical dimensions of the RWP technology actually help to overcome *lack of financial assets* (STCM 1).

In contrast, the physical dimensions of a technology like SIP will almost certainly be beyond the *financial capacity* of the poorest farmers. However, institutional experiments including ones being conducted in Bangladesh, show how the institutional dimensions of a capital intensive technology like SIP, can be re-designed to benefit the poorest farmers (ICIMOD, 2015).

By definition, the poorest farmers *lack financial assets* to invest in agricultural production, and are therefore likely to be more risk adverse (Yesuf and Bluffstone, 2009; Dercon and Christiaensen, 2011). The important insight about STCM 1 from these case studies is that while *lack of financial assets* defines the poorest farmers and certainly limits their ability to benefit from technology, there are both specific physical characteristics of technology (e.g. rubber pipes) and specific institutional characteristics (e.g. NGO led SIP program design) that overcome this STCM. Moreover, at least three other STCMS play an even larger role in preventing the poorest farmers from benefiting from technology, offering some insights into the multiple pathways available to increase the well-being of the poorest farmers in Bihar.

2.7.2 STCM 2: Inappropriate Technology Design (Score 0.8)

Inappropriate technology design, with a score of 0.8, played a below average (modal) role as a barrier limiting benefits to the poorest farmers across the six case studies. The only case in which STCM 2 played a high role was the MIS case. In the SIP case, STCM 2 played an intermediate role. In all other cases STCM 2 played no significant role.

In both the MIS and SIP cases, specific selection decisions about technology make the physical dimensions of these two technologies as incarnated in Bihar, inappropriate for the poorest farmers. The sociotechnical approach demonstrates that the technology design in each of these cases is not intrinsic to the general concept of the technologies, but rather is a product of inappropriate design standards selected by actors at the selection stage of the innovation process. Both SIP and MIS technology have the potential to be re-designed so that their physical dimensions better meet the needs of the poorest farmers in Bihar. The barrier to doing this is not in the physical attributes of the technology itself, but in the requirements that farmers, government policy makers and other actors demand from the engineers and private sector businesses who design the physical specifications of these two technologies.[88]

Overall, it is perhaps surprising that *inappropriate technology design* did not play a greater role in limiting benefits to the poorest farmers across the six case studies. This finding calls into question some of the key messages of the appropriate technology and even the local innovation literatures. Indeed, effective technologies for wealthier farmers (at least in the context of Bihar) tend to be effective technologies for the poorest farmers as well.

[88] Note that a similar story could be told for the direct-wheat seeding machines currently subsidized by the Bihari government. The machines are far too large for the average landholding. Yet this is nothing more than a design choice. Models of similar machines exist that are more appropriate for the poorest farmers, but these are not the ones subsidized by the government.

2.7.3 STCM 3: Missing Market Linkages (Score 0.2)

Missing market linkages, with a score of 0.2, was the least important barrier preventing the poorest farmers from realizing greater benefits from technology out of the 11 STCMs identified in this Chapter. The only case study in which STCM 3 played an intermediate role was the case of MIS. In all other cases, STCM 3 played no significant role.

In the MIS case, *missing market linkages* played an intermediate role in limiting benefits of this technology to the poorest farmers. The reason that *missing market linkages matter* in the case of drip irrigation is because for poor farmers, this technology is used with vegetable or horticultural crops. Both of these crops are perishable and when grown at scale, require market linkages to sell the crops without creating market gluts that decrease the price farmers receive for their crop on the market. However, because there is limited observable instances of poor farmers using MIS in Bihar, evidence of this STCM was limited to a few NGO pilot programs that supported farmers in adopting MIS. These NGO-led programs found they needed to link poor farmers with markets to sell their crops in order for their drip irrigation pilots to be successful. If only one farmer in a village has MIS, the impact of MIS on vegetable yields would likely not be enough for this to matter, but in villages where the NGO has linked multiple farmers with drip irrigation, access to markets become an issue.

Apart from the small role *missing market linkages* played in the MIS case, this STCM was not an important barrier in limiting benefits to the poorest farmers. At the same time, *missing market linkages* likely depresses overall yields and agricultural GSDP in Bihar. However, investments in market linkages on the part of the government or other actors may actually result in negative consequences for the poorest farmers. There are two reasons for this. First, the poorest farmers consume privately a significantly higher proportion of their production. Therefore, only a fraction of their overall production enters the supply chain and any public-sector investment in market linkages would bypass the poorest farmers. Second, in Bihar where widespread caste and wealth based discrimination is still deeply entrenched, wealthier farmers actively work to exclude the poorest farmers from the benefits of the government procurement programs that do exist. Local elites responsible for administering government procurement programs at the block level were transparent in interviews that they ensure their family and friends benefit from limited procurement programs over and above other farmers in the region.

While investments in market linkages and government procurement may raise the overall incentive of Bihar's farmers to invest in yield improving technologies, the benefits would likely accrue disproportionately to the wealthier farmers. While it may be an important investment strategy for the state, it should not be confused with a strategy that will benefit the poorest farmers and indeed may drive even greater wedges in intra-village and intra-regional inequality.

2.7.4 STCM 4: Lack of Access to Credit (Score 1)

Overall, *lack of access to credit,* with a score of 1, played an average (modal) role as a barrier preventing the poorest farmers from realizing benefits from technology. STCM 4 played a high role in the SIP case and a moderate role in the MIS and EMP cases.

In the SIP case, while there are multiple reasons that the poorest farmers are unable to benefit from this technology in Bihar, one reason is certainly *lack of access to credit.* I saw direct evidence of this while observing a workshop led by NABARD (National Bank for Agriculture and Rural Development) officials who had flown in from Delhi and local bank lending officers. The NABARD staff came to Patna to try to encourage local bank officials to extend loans to farmers for their new SIP scheme and were holding the workshop to educate bankers about SIP systems to improve the likelihood that they would provide loans for SIP investments. The NABARD officials described an elaborate program to ensure that farmers with small landholdings could also benefit from the subsidy program (including waiving the need for collateral when several small farmers formed a joint liability group). Despite NABARDS effort to come up with an institutional design suitable to the needs of the poorest farmers, the bankers all expressed reluctance to lend to poor farmers. Their reasons included not only the lack of credit history or collateral, which were both significant factors, but also the logistical challenge of banks sending staff to visit poor farmers in remote areas to verify details of the loan.

Similarly, in the MIS case, the MIS distributers cited concerns that poor farmers would not be eligible for bank loans nor could they afford to pay for the technology in cash, as reasons for not marketing their technology to the poorest farmers (recall in the case of MIS much of the outreach and extension is done by the private sector equipment dealers). However, this is likely only a minor reason why the poorest farmers are not adopting MIS in Bihar. Multiple other STCMs are a greater barrier.

Similar mechanisms played out in the EMP case, where the capital restrictive investment for the poorest farmers was the borewell necessary to use their own EMP. What connects the three cases – SIP, MIS and EMP – is of course high up-front investments that are beyond the capacity of the poorest farmers to afford without financial support. However, I believe that despite the modal score of this STCM, improving access to credit would not overcome as many barriers as fixing other STCMs that also scored 1 (e.g. ineffective extension services). This is because farmers in Bihar tend to be credit-adverse. I was amazed by the number of times Bihari farmers told me cautionary tales from other states about the dangers of farmer indebtedness. The concerns about farmer suicides in Maharashtra and other states that permeate left-wing development organizations were mirrored in the concerns of Bihari farmers. A general trend amongst Bihar's farmers was an unwillingness to go into debt.

The general aversion to loans on the part of farmers in Bihar, suggests that improving *access to credit* in Bihar would help wealthier farmers, but may do little for the poorest farmers. This is both because lending officers are reluctant to lend money where collateral and credit history is unavailable, but also because poor farmers are unlikely to seek out loans in the first place.

2.7.5 STCM 5: Missing Infrastructure (Score 2.3)

Missing infrastructure, with a score of 2.3, was the biggest barrier preventing Bihar's poorest farmers from benefiting from technology in Bihar. As discussed in the introduction to this section, for observers of Bihar's agricultural system, the fact that *missing infrastructure* is hampering agricultural growth is not a new finding. What is new is that *missing infrastructure* is also the biggest driver of variance in benefits realized from technology between wealthier and poorer farmers.

Missing infrastructure was a high barrier in three out of the six case studies and an intermediate barrier in the other three. There was no case where *missing infrastructure* played no role. The primary way in which *missing infrastructure* impacts the poorest farmers is through access to water which mediates their ability to adopt multiple potentially beneficial technologies. This is because the poorest farmers are least likely to own their own wells; are the least likely to own or sharecrop high quality land near streams or canals; are the least likely to live near transformers that allow them to adopt relatively low-cost electric motor pumps as opposed to irrigating with diesel engines; bear greater social transaction costs when buying water from farmers of wealthier socioeconomic backgrounds/castes; and have the least available financial capital to purchase water from their neighbors or buy diesel to run their own groundwater pumps.

There are some technologies that can help the poorest farmers overcome *missing infrastructure* such as the physical dimensions of SIP and RWP. SIPs provide access to groundwater irrigation without the need for an electrical grid. RWPs help farmers transport water longer distances with less labor. However, the details of both of these case studies demonstrate how the physical dimensions of the technology must align with both the institutional dimensions of the technology and the physical characteristics of the local landscape in order for these technologies to be beneficial to the poorest farmers. Too often this is not the case. In the SIP case, the institutional dimensions of the subsidy program are biased towards wealthier farmers who are more likely to have the ability to provide their own borewell which they are willing to devote exclusively to a SIP unit. The poorest farmers are unlikely to own their own borewell which is a prerequisite to qualify for the subsidy program. This means that the benefits of the generous SIP subsidy program are further skewed toward wealthier farmers.

The RWP case study shows that despite the significant benefits the technology has brought to the poorest farmers by lubricating groundwater markets, this technology only goes so far. When infrastructure is completely lacking as it is in Rajapur *tola*, the technology alone cannot overcome missing infrastructure challenges.

Missing infrastructure, as the biggest barrier preventing the poorest farmers from benefiting from technology in Bihar, is the barrier that should be addressed first by policy makers and other actors concerned with improving well-being of the poorest farmers in the state. However, this STCM must be addressed in ways that actually benefit the poorest farmers. As shown in Bathani, simply building a transformer in a village is not enough to ensure the poorest farmers in the village realize benefits from technology. Rather, the government should ensure that the transformer is located closer to poorer households, so it is the wealthier households who pay a higher cost to purchase sufficient electrical wiring to connect their own wells to the transformer. Alternatively, when a new transformer is built, the government could subsidize the necessary electrical wiring to connect the transformer to the wells of farmers with less than 1 acre of land or who belong to SC/ST households.

2.7.6 STCM 6: Ineffective Extension Services (Score 1)

Ineffective extension services, with a score of 1, played an average role in blocking benefits to the poorest across the six case studies. SCTM 6 played a high role in the SRI case, and an intermediate role in the SIP and MIS cases. It played no role in the other three cases.

The main way that this STCM acts as a barrier preventing the poorest farmers from benefiting from technology, is through a general bias towards wealthier farmers by the extension agents. This is both because extension agents show a greater level of respect towards wealthier farmers and because extension agents recognize that their jobs will be easier if they work with wealthier farmers. Their implicit hope is that if wealthier farmers in a community demonstrate a new technology, that this will generate 'trickle down' adoption. As we saw in Bathani, while technologies do trickle within castes or even between castes within a single *tola,* they do not trickle to the poorest farmers in a village who often live in separate *tolas* and belong to the lowest castes.

When asked about their experience with different sources of information, farmers across socioeconomic groups ranked state extension services very low as a trusted source of information (see Appendix 2). This was especially true for the poorest farmers. The limited relationship between the poorest farmers and the extension services is an important barrier preventing the poorest farmers from realizing greater benefits from technology in Bihar. This is especially true for programs that include subsidy support (including SIP, SRI and MIS) as these programs are much more likely to be targeted at wealthier farmers. In the other three cases (EMP, RWP and ISV), *ineffective extension services* were not an important driver of variance, largely because the private sector and other farmers are the main actors responsible for "last-mile" delivery of these technologies. The poorest farmers feel comfortable approaching local input suppliers for information and are happy that the growing number of input supply businesses in Bihar means that competition is increasing the quality of information and technology available in the market.

For many technologies, the private sector is able to fill the void left by *ineffective extension services.* In the SIP, SRI and MIS cases this is not the case, but for different reasons. In the SIP case, extension services played an overtly biased role, using the SIP subsidy program as a way to generate rents for local officials through bribes and the social connections that come with connecting local elite farmers with a flashy piece of technology. In contrast, in the SRI case, the degree of overt corruption was less. Rather, extension officers are under pressure to stimulate adoption of the technology given the high-stakes of Bihar's 144-million-dollar investment into SRI. At the same time, supporting farmers to adopt the technology is time intensive. Extension agents thus rationally target their efforts at wealthier farmers who they believe have the capacity, including access to water and education to adopt the new practices more easily. For this reason, wealthier farmers are significantly more likely to receive both the subsidy, as well as training visits from extension agents. In the MIS case, *ineffective extension services* played a relatively minor role as most of the extension is done by the private sector. However, in Bihar (unlike in other states with more robust drip irrigation subsidy programs (see Chapter 4)) some extension is still done by state extension officers and programs run through RAU which are financed by the government. Observing a MIS training visit by university agronomists from RAU in North Bihar, I watched as they selected the wealthiest farmer in a village to host a demonstration plot (for which he received the MIS equipment at no cost). Then the agronomists proceeded to discuss the design of the MIS system only with other wealthy farmers in the village, as less wealthy farmers walked by on a nearby road without being invited to the conversation.

2.7.7 STCM 7: Lack of Individual Farmer Capacity (Score 0.7)

Lack of individual farmer capacity, with a score of 0.7, played a below average role as a barrier preventing the poorest farmers from realizing greater benefits from technology across the six case studies. STCM 7 was a moderate barrier in the SIP, SRI and MIS cases. It was not a barrier in the EMP, RWP and ISV cases.

Lack of individual farmer capacity (STCM 7) often plays out through unexpected mechanisms. In the MIS case for example, the mechanism preventing the poorest farmers benefiting from the technology was the lack of willingness of private sector dealers to engage with the poorest farmers. This is in part due to *the lack of individual capacity* of the poorest farmers which results in increased time investment required to train them to use complex MIS systems (regular maintenance of MIS equipment, especially higher cost MIS equipment, is essential and leads to technology disadoption if farmers are not properly trained, which often requires follow-up visits by dealers even for highly skilled and educated farmers). However, this is a secondary concern for the dealers, whose primary aversion to working with the poorest farmers is their smaller landholding size, which means their commission per unit and time investment in selling the technology is significantly lower.

In the case of SIPs, it is not the lack of capacity on the part of poorest farmers to operate the technology where this STCM plays a role (in fact this technology once installed is simple to operate for all farmers). Rather, it is that the poorest farmers are significantly less likely to read the newspaper and feel empowered to directly approach agricultural extension officers to apply for the subsidy.

In the case of SRI, the mechanism through which STCM 7 operates is more straightforward. SRI is a complex set of practices to adopt and requires support from NGOs or state extension officers to help farmers master the new practices. State-run extension programs have published most of the material that promotes SRI in written documents, which are less helpful to the poorest farmers who also tend to lack the capacity necessary to decipher the material. NGOs have been more successful teaching farmers SRI through hands-on field training. Digital Green, a larger NGO based in New Delhi, has even developed video-based training material available through smart phones, as well as small portable projectors that extension agents can carry.

Overall, what is important about STCM 7, is that it does have a meaningful effect preventing the poorest farmers from realizing benefits from technology, but the pathways through which it operates are complex and often have interaction effects with other STCMs. Overall, the physical dimensions of most technologies are not intrinsically too difficult for farmers with limited education to use effectively. Instead, the institutional dimensions supporting widespread use of the technology exclude the farmers with limited capacity.

2.7.8 SCTM 8: Weak Capacity for Collective Action (Score 0.7)

Overall, with a score of 0.7, *weak capacity for collective action* (STCM 8) played a below average role as a barrier preventing the poorest farmers from realizing greater benefits from technology across the six case studies. STCM 8 played a moderate role in SIP, SRI and EMP cases. It played no role in the MIS, RWP and ISV cases.

The clearest example of *lack of capacity for collective action* as a barrier preventing the poorest farmers from realizing greater benefits from technology comes from an EMP example in Surka *tola.* Soon after the three-phase transformer was installed in Surka, many of the male heads of households in Surka met to discuss how to jointly fund the necessary capital investment to bring electrical wiring from the transformer to the center of Surka's agricultural lands. This type of collective action would have been unlikely to develop in Erki and next to unfathomable in Rajapur. It also meant that the benefits from the electricity in the form of the ability to quickly adopt EMPs, were quickly concentrated in Surka *tola* and not where the poorest farmers lived in Rajapur.

In the case of SRI, *collective action* is a barrier preventing the poorest farmers from benefiting from the technology because inter-village coordination benefits all farmers practicing SRI. Under SRI methods, sharing labor and equipment is important. Stronger capacity for collective action in a community is helpful because it allows for coordination in sharing of *conoweeders* and organizing shared labor. It is for this reason that PRAN, the NGO that has been so successful in promoting SRI in Gaya district, emphasizes collective action in the design of its training and support programs. In Surka, farmers practicing SRI were very involved with their neighbor's agricultural processes and coordinated their schedules around one another. Similar collective action dynamics would be much less likely to arise in Rajapur and Erki where networks between households are loose.

Overall, *weak capacity for collective action* is not a higher order priority barrier to overcome in order to support the poorest farmers in realizing greater benefits from technology. This is interesting because it is a barrier that has received significant treatment in the agricultural systems literature after the spotlight put on collective action for positive sustainable development outcomes, by the Nobel Prize winning economist Elinor Ostrom (Ostrom, 1990; Schlager and Ostrom, 1992; Markelova *et al.*, 2009; Hellin, 2012). What this analysis shows is that at some point, investments in collective action programs are likely to have positive impacts on the ability of the poorest farmers to benefit from technology, but until the higher order barriers such as *missing market infrastructure* and *misaligned incentives* are addressed, investments on the part of donors and NGOs in collective action are likely to result in limited overall benefits.

2.7.9 STCM 9: Structure of Land Tenure Regimes (Score 1.1)

Structure of land tenure regimes, with a score of 1.1, played a slightly above average role in preventing the poorest farmers from realizing greater benefits from technology. While this STCM did not play a role in blocking the poorest farmers from realizing greater benefits from technology in any single case, it played an intermediate role in driving variance in five out of the six cases. The sole exception was the RWP case.

The mechanism through which STCM 9 operates in Bihar is limitations on access and incentives to adopt technology for landless farmers who grow crops on a sharecropping basis (occasionally, farmers also lease land but sharecropping is more common). Sharecroppers lack title over the land they cultivate and are therefore ineligible for most government subsidy programs. This applies to the SIP, MIS, SRI and ISV cases.

One example of creative policy design to realign incentives and mediate the impact of the current *structure of the land tenure regime* on the poorest farmers' ability to benefit from technology, came from a government official in the Gaya district. In this example, the newly appointed District Agricultural Officer, Mr. Mahatto, told me that instead of requiring formal proof of land tenure to receive a diesel subsidy in drought years, the agricultural officer decided to offer the subsidy to sharecroppers and other farmers without official land titles (S. Mahatto, Director of Agriculture Gaya District, personal interview, December 23, 2013).[89] To do this, he created his own set of rules for eligibility for the drought-induced cash transfer including requiring that two neighbors, in addition to a local agricultural officer, sign their name on the back of the diesel receipt, affirming that the diesel was used for irrigation. This is an example of local institutional experimentation to better meet the needs of the poorest farmers. Unfortunately, it was impossible for me to verify whether this extension official had made the story up for my benefit (knowing my interest in poverty) or if this program had been effectively implemented. At any rate, it is an example of the type of creativity that is required to design programs and policies that do not inadvertently exclude the poorest farmers. This may be especially important for overcoming the barriers created by the *structure of the land tenure regime* in a state where direct land redistribution is unlikely.

As discussed in the introduction to this section, the finding that the structure of Bihar's land tenure regimes prevents the poorest farmers from realizing greater benefits from technology is not surprising. A large literature details the negative impacts on investments and conservation of poorly designed and enforced land tenure regimes (Meinzen-Dick and Gregorio, 2004; Meinzen-Dick, 2011). What is perhaps useful from this analysis is that while *structure of land tenure regimes* matters, it may not matter as much for improving the benefits the poorest farmers realize from technology, as improving infrastructure and re-designing policies to better target the poorest farmers. This is helpful in a state like Bihar, where land reform is the third rail of politics and unlikely to proceed.

[89] The official requirement in the state-wide diesel subsidy, designed to go into effect when drought was officially declared at the district level, required proof of land tenure (see discussion in Kishore *et al*., 2015 for more on the design of the conditional cash transfer program).

2.7.10 STCM 10: Misaligned Incentives (Score 2.1)

Misaligned incentives, with a score of 2.1, was the second most important barrier preventing the poorest farmers from realizing greater benefits from technology in Bihar. STCM 10 played a high role in the SIP, SRI, MIS cases, and an intermediate role in the EMP and ISV cases.

In the SIP case, this STCM played out through two separate institutional mechanisms. First, the BREDA scheme was advertised to farmers through newspapers and interactions with extension officers who were more likely to offer the limited number of subsidized SIP units to wealthier farmers. Second, the requirement under the BREDA subsidy scheme that recipients own at least 1 acre of land, automatically excludes the poorest farmers.

In the SRI case, the design of the subsidy program which is intended to incentive farmers to use SRI, is flawed. This is because the physical dimensions of SRI require fewer seeds than traditional management practices. This "institutional flaw" was raised by focus groups of SC/ST female farmers who practice SRI without benefits of the subsidy. These farmers argued that the subsidy program should be re-designed to offer more intensive hands-on training in the field specifically targeted at poor farmers, and to ensure the poorest farmers had the physical weeders (*conoweeders)* which are the only expensive input in the practice of SRI. As further evidence of *misaligned incentives* under this SRI subsidy program, only a small fraction of the 144-million-dollar budget was devoted to *conoweeders*, whereas most of the budget was earmarked for the ineffective subsidy packages comprised of seeds and fertilizer.

In the MIS case, the design of the subsidy program attempts to add greater incentives for the poorest farmers by giving small and marginal farmers an additional 10% subsidy. However, the 10% incentive is targeted at the poorest farmers rather than the equipment dealers who are responsible for "last mile" technology delivery. Because equipment dealers prefer to work with wealthier farmers where their profits are higher, the poorest farmers never learn about MIS in the first place. In order for the poorest farmers to realize greater benefits from MIS, equipment dealers would need to be offered their own incentives for working with the poorest farmers.

In the EMP case, the mechanism through which *misaligned incentives* manifests is somewhat speculative on my part. In my travels through Bihar, there seemed to be a clear pattern of transformers being built closest to the wealthiest neighborhoods in villages when the grid was extended. This increases the costs for the poorest farmers in extending wires from the transformer to their land, which they must pay for themselves. If the Bihari government were to direct engineers to install site transformers closest to the poorest *tola*, it could significantly change the distribution of benefits from increased use of EMPs in Bihar.

In the ISV case, the poorest farmers were limited in their ability to benefit from the subsidy program because of the size of the bag of seeds provided under the program. This could easily be re-designed so that the ISV subsidy targeted seeds in the quantities most appropriate to the poorest farmers (one to two kg).

In summary, what I mean by *misaligned incentives,* are cases where the institutional rules or norms undergirding institutional dimensions of a technology are biased towards wealthier farmers. In these cases, slight changes in institutional design has the potential to realign incentives for different actors in the sociotechnical regime, decreasing the barriers that prevent the poorest farmers from benefiting from the technology.

2.7.11 STCM 11: Corruption and Security (Score 0.8)

Corruption and security, with a score of 0.8, played a below average role in preventing the poorest farmers from realizing greater benefits from technology. STCM 11 played a high role in the SIP case and an intermediate role in the EMP case.

In the two cases where *corruption and security* (STCM 11) prevents the poorest farmers from benefiting from technology, the mechanism through which the STCM operates is low-level corruption on the part of government staff. Despite substantial overall improvements in *corruption and security* in Bihar since the election of Nitish Kumar, petty corruption remains widespread, especially at lower bureaucratic and political levels. This corruption limits access for the poorest farmers to state provided subsidies and other incentive schemes (e.g. SIPs). Similarly, as seen in the case of EMPs, the apparent ability of wealthier farmers to influence the location of transformers within villages, also limits the benefits of technology to the poorest farmers.

On the other hand, improvements in law and order in Bihar have improved the availability of ISVs in the state, by encouraging private investment and competition. This has led to farmers across the socioeconomic spectrum realizing increased benefits from ISVs. Improvements in law and order have impacted wealthy and poor farmers' access to ISVs in similar ways.

2.7.12 Summary: Policy Implications of STCM Approach

The analysis in Section 2.6 and 2.7 looked at a set of 11 STCMs as potential causal factors preventing the poorest farmers from accruing greater benefits from agricultural technologies. By ranking the STCMs in terms of their importance as barriers, the analysis identified both the higher and lower order barriers that prevent the poorest farmers from benefiting more from agricultural technologies in Bihar.

The policy implication from this analysis, is that it makes little sense for policy makers and other actors interested in improving the well-being of the poorest farmers to address lower order barriers such as *missing market linkages* (score 0.2), before addressing higher order barriers such as *missing infrastructure* (score 2.3) and *misaligned incentives* (score 2.1). In other words, as long as infrastructure is a major barrier preventing the poorest farmers from realizing greater benefits from agricultural technologies, improving the quality of state extension services or spending heavily on programs to improve collective action capacity amongst the poorest farmers, will not have the intended outcome. While such programs may result in some positive outcomes, they are not addressing the limiting barriers preventing the poorest farmers from benefiting from agricultural technologies. Some seemingly useful interventions such as investing in market improved market linkages may even have the unintended consequence of benefiting those farmers who already have access to affordable irrigation, over those that do not.

Once the biggest barriers have been addressed, many of the intermediate barriers including *structure of land tenure regime, lack of financial assets, lack of access to credit,* and *ineffective extension services* are closely clumped as barriers preventing the poorest farmers from benefiting from technology. When STCMs are more closely clumped as barriers, there are several ways to think about strategically managing these "clumped" barriers. First, it probably makes most sense to address barriers that are clumped in terms of the cost or feasibility of addressing them. For example, in Bihar, despite many attempts, reforming the land tenure system has proven politically impossible whether for populist leaders like Lalu Prasad or technocratic leaders like Nitish Kumar. While *structure or land tenure regimes*, with a score of 1.1, is the third most important STCM, it is also closely clumped with *lack of financial assets, lack of access to credit,* and *ineffective extension services*, all of which scored 1 and all of which may be easier to begin to address than the issue of land tenure in Bihar.

A second way to think about addressing closely clumped barriers is by looking for barriers that are the most ubiquitous across cases. While the most ubiquitous barriers might not create the largest overall barriers, they create some barriers across many cases and are therefore worth addressing. From a feasibility standpoint unfortunately, after *missing infrastructure*, *structure of land tenure regimes* is the most ubiquitous barrier, which I already discussed is one that has proven difficult to address. However, in other contexts, it may be useful for policy analysist to think about the implications of not only addressing the largest average barriers, but also the most ubiquitous.

The chapter concludes in Section 2.8 with a discussion of the contribution of this chapter to innovation studies and the utility of the methodological approach used in this chapter to pursuit of the Sustainable Development Goals.

2.8 Discussion

In this chapter, by developing a methodology for analyzing the barriers that prevent the poorest farmers from realizing greater benefits from technology, I aimed to bring greater conceptual clarity to the discussion of technology and poverty in the development literature. The global development agenda as articulated by the UN Sustainable Development Goals (SDGs) encompasses 17 goals, almost all of which will require the application of science and technology to achieve. While this dissertation focused specifically on poverty rural agrarian settings, the methodology developed in this chapter is broadly applicable to the challenge of making greater use of science and technology to analyze the distributional outcomes of policies and programs aimed at meeting most, if not all of the SDGs. The methodology could be used in other contexts such as reducing poverty in urban settings (the list of STCMs would of course be different). It could also be used to look at the distributional implications of potential interventions in other sectors, such as improving access to quality education (SDG 4).

Methods, like the one I developed in this chapter, for ensuring that scholarship and policy focus specifically on the needs of the poorest in the context of the sustainable development goals are lacking. As demonstrated in the literature review in Chapter 1, too frequently scholarship on technology and innovation black boxes the issue of distributional impacts of both the physical dimensions of technology, but especially the distributional impacts of the institutional dimensions of technology. I hope that the approach presented in this chapter will spur scholars and policy makers to think more systematically about the impact of technology policy, not only on aggregate benefits (measured in yield gains, income, reduced drudgery of labor) but also on differential impact on the well-being of the poorest.

Substantively, this chapter identified the most important sociotechnical causal mechanisms (STCMs) preventing the poorest farmers from realizing greater benefits from technology in Bihar. These were discussed at length in Section 2.7. The ranking of STCMs in Bihar can be used by policy makers and other actors interested in addressing rural poverty in Bihar. The methodological approach can also be used in other contexts in order to study the distributional impacts of policies and interventions meant to overcome barriers to technology adoption in the agricultural sector.

The sociotechnical approach introduced in this chapter combines a concern with who benefits from technology, with a perspective on technology that includes both the physical and institutional dimensions of technology "necessary to apply it on significant scale" (Brooks, 1980, p. 65). This approach allows the explanations for the barriers preventing the poorest farmers from benefiting from technology, to include a wide range of causal mechanisms that are more complex than many approaches which either focus on physical (e.g. improved seed varieties, better tractors) or specific institutional barriers (e.g. land tenure, market access).

By combining the analysis of STCMs with a sociotechnical approach that takes into account both the institutional and physical dimensions of technology, the methodological approach used in this chapter reveals the mechanisms behind the failure of the poorest to seize benefits latent in technology. What is particularly interesting is that one of the two most important STCMS in the context of Bihar is *misaligned incentives* (STCM 10). This STCM basically shows that many barriers facing the poorest farmers have to do with the institutional design of incentives in a given innovation system. This STCM in many ways encompasses the institutional dimensions of technology discussed in the sociotechnical approach and shows the degree to which institutional concerns are a cornerstone enabling the poorest farmers to realize greater benefits from technology. This may have implications for larger theory about technology adoption and diffusion scholarship.

From a policy perspective, the STCM approach, by untangling the mechanisms behind the failure of technology to benefit the poorest farmers, gives policy makers an opportunity to not only address the most important barriers preventing the poorest farmers from realizing greater benefits from technology, but also to intervene intelligently in a system where the mechanisms behind the specific barriers are also more clearly understood.

In addition to the ranking of STCMs, there were two additional empirical findings from Bihar in this chapter that are worth highlighting because they have broader relevance to the study of technology and poverty.

First: In this study, I was unable to identify a technology that is explicitly "pro-poor" in that it helps the poorest farmers more than other groups of farmers. There are several potential reasons why these "pro-poor" technologies are missing in Bihar and potentially more broadly from the technology space. The first and perhaps most obvious is that there is a demand-pull problem in the broader innovation system: technologies that may be specifically "pro-poor" are simply not being *invited* and not being *selected*. If this is the case, then designing demand generation mechanisms such as prize money to incentivize actors at the *invention* and *selection* stages of agricultural innovation systems to focus on explicitly "pro-poor" technologies, would be one policy solution. Another would be to prioritize the work of actors like Anil Gupta and the Honey Bee Network (also discussed in Chapter 1) and search out local innovations that the poor have created for themselves and help scale these technologies. In all likelihood, both of these activities would increase the pool of "pro-poor" technologies available to farmers to some degree. However, a second reason for the missing "pro-poor" technologies could be that the category of "pro-poor" technologies is intrinsically empty. In other words, it may be that the poorest benefit most from technologies that benefit all groups and that what is really required is not "pro-poor" technologies per se, but rather institutional structures that help the poor access technologies which are generally beneficial to all farmers. The case of SRI in Bihar helps illustrate this point. While SRI has the physical characteristics of "pro-poor" technology, in the end, the institutional characteristics of the technology as it interacts with local contexts leads to benefits accruing mostly to wealthier farmers in the system.

Second: In resource-poor contexts, the government – while playing a very important role in the overall innovation system – often fails as a "last mile" actor to meet the needs of the poorest farmers. In Bihar, government programs directly targeting the agricultural sector through "last mile" interventions largely fail to help the poorest farmers, leading to increased rather than decreased inequality at the village level. The relatively poor performance of the public sector in the "last mile" in Bihar, should not be taken as an indication that the public sector has no role to play in reorienting agricultural innovation systems to meet the needs of the poorest. Instead, what my analysis indicates is that the public sector is poorly suited to act as a "last mile" actor connecting farmers to technology in the field. Instead, the strength of the public sector in Bihar has undergirded improvements in the agricultural innovation system at other stages. The public-sector expansion of the grid in Bathani and across Bihar has brought large benefits to all and will likely unlock the potential of many technologies for the poorest. Improvements in law and order which started at the highest levels of government, have led to the expansion of ISV availability in the state which has benefited both wealthy and poor farmers alike. Yet, despite these findings, the bulk of allocated spending in the 2008 and 2012 Agriculture Road Maps was for government programs that focused on "last mile" activities and technology subsidy programs.[90] This suggests that government resources might be better allocated not only to different stages of the agricultural innovation system, but even outside the agricultural sector where gains in security and energy access have greater secondary benefits for the poorest farmers.

[90] While the Agriculture Road Map budgets are not publicly broken down at a sufficiently granular level to calculate the exact percentage of spending on "last mile" activities, my best estimate based on publicly available data for the 2012 Agriculture Road Map was that at least two thirds of the budget was allocated to "last mile" activities.

This chapter also contributes directly to the innovation literature. In particular, it complements the findings from the multi-level perspective (MLP) on innovation systems in the sociotechnical transitions literature (Geels, 2002, 2004, as discussed in Chapter 1, Section 1.2.3). The sociotechnical transitions literature argues that in order for new technological innovations to achieve scale, they need to overcome barriers in path dependency created by both incumbent physical technologies, and social and institutional systems that have developed alongside them. Sociotechnical transitions are thus seen as systems innovations which involve several different physical technologies, in conjunction with institutional change by a diversity of actors (Steward, 2012). In other words, the sociotechnical transitions literature argues that for any new technology to reach *widespread use*, an alignment between the physical dimensions and the institutional dimensions of technology(ies) is required.

In this chapter I demonstrated the applicability of a sociotechnical approach to the evaluation of technology in the developing world. My findings across the six case studies showed that ensuring the poorest farmers benefit from the fruits of technology innovation is not only about selecting the right physical technology (getting the physical dimensions right) nor is it just about designing the right incentive scheme (getting the institutions right). Rather, there is a need for a 'fit' between the physical and the institutional dimensions of the technology, that align to meet the needs of the poorest.[91] For example, in the case of the System of Rice Intensification, while the physical dimensions of the technology appear on the surface to meet the needs of the poorest farmers, the lack of infrastructure for timely irrigation combined with the poorly designed subsidy program, concentrate the benefits of the technology toward wealthier farmers. Likewise, in the drip irrigation case, while the physical dimensions

[91] The idea of fit between institutional and physical dimensions while novel in the agricultural innovation systems literature is not novel to the literature in sustainability science more broadly. Oran Young's insight that critical to global agreements to solve environmental challenges is a "fit" between the institutional dimensions of the global regime and the particularities of local context is similar in some ways to the need for fit between institutional and physical dimensions of technology. See for example Young's 2002 book "The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale" (Young, 2002).

of the technology were not suitable for the needs of the poorest farmers, I discovered that the institutional design of the subsidy program had explicitly selected higher cost drip irrigation systems at the expense of lower cost drip systems that may have physical dimensions more appropriate for the poorest farmers.

The findings of this chapter not only confirm that the core findings of the sociotechnical transitions literature are relevant to the developing world, they also extend the methodology used in this literature by focusing on distributional outcomes borrowing tools from the methodological approach used in this literature. I am unaware of any work in the sociotechnical transitions literature that explicitly focuses on the distributional outcomes of technological change.

This chapter argues that a "transition" toward innovation systems that benefit the poorest requires changes in the evolutionary pathways of agricultural technologies, that ensure both the physical and institutional dimensions of technologies are designed in ways that the poorest can extract more well-being from their *widespread use.* Focusing on an alignment between the institutional and physical dimensions of technology allows an analyst to ask what needs to change in the innovation system to ensure that the technology in question benefits the poorest. At times this may mean intervening at the *invention* or *adaptation* stage of the innovation system, to tweak the physical dimensions of the technology or demand entirely new technology. Or it may mean intervening in the broader sociotechnical regime to ensure better access to infrastructure. Or it may mean intervening in the design of the institutional incentives to promote technology adoption. Whatever the case, the sociotechnical perspective gives the analyst a much wider lens with which to identify barriers and solutions to meet the needs of the poorest.

If technology is to achieve any human purpose, then from a sociotechnical perspective, there needs to be a measure of fit between the institutional and physical dimensions of the technology. To achieve the specific human purpose of helping the poorest, requires the alignment of physical and institutional dimensions that gives the poor the ability to access and use these technologies in ways that both reduce their risks and improve their well-being. Even though finding an alignment can be difficult, it is also encouraging, as it means that most of the time, most technologies can benefit the poorest when the physical and institutional dimensions are nudged in the right direction. For example, in the case of solar irrigation pumps, while the technology is currently failing on both dimensions of variance discussed in the introduction to Section 2.6 (benefits accrue to the wealthiest farmers and benefits to users are low), the case study demonstrated that by slightly tweaking the physical and institutional dimensions of the technology, the Government of Bihar could bring greater benefits to the poorest farmers. On the physical side, the design of the solar irrigation pump system currently in use in Bihar should be modified to allow quick conversion from SIP to a diesel engine (for use at night or under cloud cover). Also, on the institutional side, by targeting the subsidy program at the poorest farmers (rather than allowing the wealthiest farmers to capture all of the benefits), the thousands of SIP units that are already in Bihar could be improving the well-being of the poorest, rather than languishing in the fields of the wealthy.

CHAPTER 3. The System of Rice Intensification: The challenges of technology selection for meeting the needs of the poorest farmers

3.0 Abstract

The System of Rice Intensification (SRI), is a technology for growing rice that emerged onto the global stage in the early 2000s. SRI has an unconventional innovation history. It was invented by a French Jesuit missionary working with local farmers in Madagascar in the 1980s. SRI consists of a set of practices, including earlier transplanting and wider spacing of seedlings. In theory, SRI has the potential to be a "pro-poor" technology because it increases yields while decreasing input costs, including for seeds and irrigation. Many of the initial reports on SRI specifically argued that it was an appropriate technology for "resource limited farmers" (Stoop, Uphoff and Kassam, 2002; Africare, Oxfam America and WWF-ICRISAT, 2010).

However, almost as soon as SRI emerged on the global stage, the technology received virulent pushback from the formal rice research community, including scientists at the International Rice Research Institute (IRRI). The first part of this chapter analyzes the controversy surrounding SRI at the transnational level. This section of the paper demonstrates several challenges at the selection stage of innovation systems in prioritizing the needs of the poorest farmers and demonstrates how the established rice research community engaged in boundary-work to protect their own epistemic authority (Gieryn, 1983). The second part of the paper grounds the discussion of SRI in a local context (Bihar, India) in order to bring greater clarity and nuance to the debate around SRI and most importantly to understand if, how, and under what conditions SRI is a "pro-poor" technology, as many of its proponents claim. The paper finds, that while the physical dimensions of the technology have the potential to benefit the poorest farmers, in Bihar, relatively wealthier farmers are benefiting more from SRI than their poorest neighbors. The benefits of SRI are failing to reach the poorest farmers because of the limited and expensive access to

irrigation facing poor farmers in Bihar, but also because the institutional design of the government's support policy is not well-targeted at the poorest farmers. These findings demonstrate that even when the physical dimensions of a technology are "pro-poor," the ability of the poorest farmers to realize these benefits requires reorienting the entire sociotechnical regime undergirding innovation systems towards the needs of the poorest. The paper concludes that actors on both sides of the 'rice wars' fell victim to more general challenges in the *selection* stage of agricultural innovation systems for meeting the needs of the poorest farmers, including 1) propensity for silver bullet thinking; 2) failure to take into account variance and uncertainty in local conditions, where all agricultural technologies are ultimately applied; 3) selection of technology based on institutional incentives not aligned with the needs of the poorest farmers (e.g. political and professional incentives). The paper offers some potential solutions drawn from science and technology studies for overcoming the challenges of technology selection. These solutions include institutionalizing greater reflexivity into innovation systems through greater focus on *framing* and *distribution* (Jasanoff, 2003).

3.1 Introduction

On April 25th 2015, I sat in a conference center at in the Palaputra Hotel, one of the two more upmarket hotels in Patna, the capital of India's second largest (by population) and poorest (by absolute poverty) state. The conference focused on rural development, a topic that had become a central concern not only of the state itself but of outside actors, such as the World Bank and the Bill & Melinda Gates Foundation, as well as researchers from Harvard and MIT, among other institutions. They had all flocked to the state after the election of a new Chief Minister, Nitish Kumar, who promised a new era of technocratic reform and the implementation of an evidenced based approach to development.

At 11:41 in the morning (Indian Standard Time), the conference center we were sitting in was rocked by an earthquake with its epicenter in neighboring Nepal. Attendees quickly evacuated the building without fuss and waited outside for under five minutes before returning to the conference. Our experience of the earthquake had been *relatively* mild (we still had little knowledge of the devastation that we would later hear about in Nepal) and it seemed best to proceed with the conference.

After such an experience, the group of conference attendees developed a greater level of comradery and the tone of the conference became notably more informal. That is until a controversial subject was raised in a question by one of the attendees. This subject, though not originally on the agenda, sent the mood of the room downward into icy silence, pitting development expert against development expert with unspoken disagreements. What controversial subject could have shifted the mood of a room brought together by the mutual survival of an earthquake? The topic that so quickly transformed the comradery in the room was one I was already familiar with – the Government of Bihar's (GoB) strong endorsement of and financial support for a controversial rice growing technology called the System of Rice Intensification.

The System of Rice Intensification, also known as SRI, is a methods-based technology for improving rice yields. Proponents of the technology claim that it increases rice yields, decreases input costs, and saves water (Uphoff, Kassam and Harwood, 2011). Detractors worry that the substantial yield improvements claimed by SRI proponents are unsubstantiated by rigorous field trials, and are concerned that resources are being devoted to the technology at the expense of more time-tested methods, specifically the development of improved seeds, such as high-yielding varieties (HYVs) and more recently, genetic engineering approaches to improve seed varieties (Sheehy, Ferrer and Mitchell, 2008).

The question of how a technology that is primarily made up of a package of agronomic practices without controversial genetic modifications or even chemical fertilizers could foster so much animosity in an otherwise friendly environment, is one I will explore in depth in this chapter. It turns out that the answer to this question illuminates several important and ongoing challenges for technology selection to meet the needs of the poorest farmers.

There are three important findings that came out of this study. First, despite the fact that SRI has been framed as a "pro-poor" technology, in Bihar, wealthier farmers realize significantly more benefits from SRI than the poorest farmers. Second, the barriers preventing the poorest farmers from capturing more benefits from SRI involve both physical and institutional dimensions of technology. And finally, failure to understand interactions between the physical and the institutional dimensions of technology, and the context specific opportunities and barriers facing the poorest farmers in Bihar, skews the benefits of technology towards wealthier farmers.

I structure the chapter as fellows: In Section 3.2, I review the theoretical approach and data used in the study. Analytically, I study SRI through the lens of innovation systems thinking, looking specifically at the mechanisms and barriers that drive innovation for the poorest farmers across stages of the innovation system, including *invention, selection, initial adoption, adaptation, production, widespread use,* and in many cases *retirement*.

In Section 3.3, I analyze the history of SRI from its *invention* in Madagascar through its *selection* by international civil society actors and *adoption* in over 50 rice growing countries worldwide.[92] In Section 3.3, I also discuss how the technology was promoted as a "pro-poor" technology by some actors, while being ridiculed as "unconfirmed field observations" or "non-sense" by others (Stoop, Uphoff and Kassam, 2002; Sinclair and Cassman, 2004; Sheehy, Sinclair and Cassman, 2005). My goal in Section 3.3 is to illustrate how the *selection* stage of agricultural innovation systems, primarily for technologies that are "pro-poor," is a particularly fraught stage of innovation systems in the transnational arena. To explain

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[92] Note that according to the SRI International Network and Resources Center based out of the Cornell International Institute for Food, Agriculture and Development, SRI has been demonstrated in over 50 countries. This does not mean that it is in widespread use in these countries. According to the SRI International Network and Resource Center, SRI has attained "notional policy support" and is "firmly established in multiple regions" in a number of countries including India, Cambodia and Vietnam. In addition, SRI has "broad institutional and government support; substantial farmer adoption in multiple regions" in an additional 10 countries in Sub-Saharan Africa and Asia. See SRI map here: http://sri.ciifad.cornell.edu/images/global/SRI_World_Map_2016.png

the challenge of technology selection, especially for the poorest, I draw on literature from science and technology studies (STS), including literature on boundary-work and the demarcation of science from non-science (e.g. Gieryn, 1983).

In Section 3.4, I shift my analytical lens from the transnational innovation system, to a specific regional case study and discuss the selection of SRI in Bihar, one of India's poorest states. This section demonstrates that many of the controversies surrounding SRI in the transnational arena are mirrored at the local level, with local political realities and incentives adding an additional dimension of conflict to the conflicts over power and resources discussed at the transnational level.

In Section 3.5, I discuss my findings from a mixed methods study of the impact of SRI in Bihar. The findings are based on my own survey data, focus group interviews, and ethnographic work in Bihar, undertaken between 2011 and 2016. The findings from my research in Bihar further demonstrate the challenge of technology selection for the poorest farmers, and show that even when a technology's physical dimensions are "pro-poor", that without an alignment between the physical and institutional dimensions of the technology and local context, that the "pro-poor" potential may not be met.

I conclude in Section 3.6 with a discussion of the challenges of technology selection for the poorest farmers. In the case of SRI, actors for and against the technology fell victim to a number of what I argue, are more general challenges in the selection stage of innovation systems, aimed at meeting the needs of marginalized and impoverished communities including: 1. The tendency of actors to engage in "silver bullet" or "panacea" thinking; 2. The failure to properly understand the relationship between general principles and the complexities and uncertainties of local context; 3. The selection of technology based on professional and political incentives not aligned with the needs of the poorest farmers. Finally, drawing on literature in organizational studies and science and technology studies, I offer some reflections on approaches for reorienting the institutions at the *selection* stage of the innovation system to overcome the challenges identified in the chapter.

3.2 Theory and Data

3.2.1 Theory: Using Innovation Systems as an Inductive Approach

As discussed in Chapter 1, the overarching goal across the three empirical studies in this dissertation is to understand the barriers preventing the poorest farmers from realizing greater benefits from agricultural technology. The second chapter looked at this question across a wide-range of technologies, focusing on the sociotechnical causal mechanisms (STCMs) preventing the poorest farmers from accruing greater benefits from these technologies. This chapter takes a different approach. The chapter is a deep dive into the innovation system of a single technology that has been promoted by many NGOs, donors, academics, and governments as a technology that is *a priori* "pro-poor". By studying the innovation system of a "pro-poor" technology, the chapter identifies challenges in the innovation system that may be specific to, or at least more likely to arise in, the context of this type of technology.

Methodologically, I use an innovation systems approach to analyze the case of SRI. The innovation systems approach is an inductive method of analysis. As discussed in Chapter 1, innovation takes place within a complex system, which includes the actors and institutions that shape innovation processes across different sectors and scales (Lundvall, 1992; Nelson, 1993). Improving the well-being of the poorest farmers almost certainly requires knowledge and technology appropriate to the conditions of the poorest farmers.[93] This knowledge and technology must be *invented* whether in laboratories or in farmers' fields; *selected,* whether by private companies, state extension services, or NGOs; *produced,* whether by governments, private companies, or other actors and groups of actors; *adopted,* whether by

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[93] This is especially true if farmers are unable to expand their landholdings This idea is generally discussed as extensification vs. intensification. If farmers are able to expand their landholdings (extensification), then they can continue to produce more irrespective of improved knowledge and technology. But if farmers are limited to a specific piece of land, the only way to increase their production or income to keep pace with inflation, growing families, and more generally increasing global food demand is to adopt new knowledge and technology (intensification).

farmers themselves or, in the case of supporting infrastructure, by governments and other entities; *adapted,* whether by farmers, other actors in the innovation system, or a partnership of both; and finally, put into *widespread use* (Anadon *et al.*, 2014; Harley, Holbrook and Clark, 2015).

Using this perspective, the chapter treats technological innovation as a complex system with overlaps and feedback loops between different stages of the system, including invention, selection, production, adoption, widespread use, adaptation and retirement (see Figure 3.1) (Anadon *et al*., 2014).

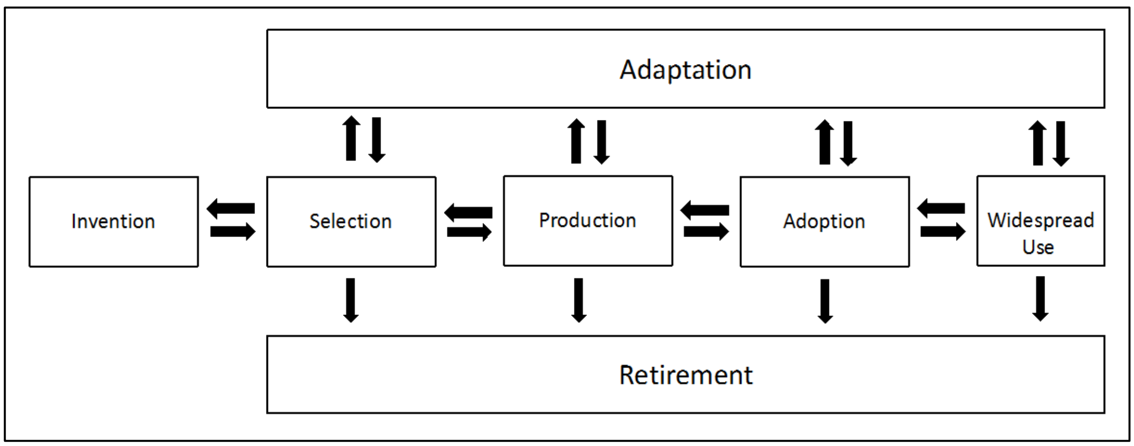

Figure 3.1: Simplified heuristic model of an innovation system.
Source: (Adapted from Anadon et al., 2014)

In the chapter, I use the innovation systems approach, developed by the Initiative on Innovation and Access to Technologies for Sustainable Development[94] at Harvard Kennedy School (of which I was the agriculture sector lead), as a structured inductive approach for unpacking the SRI case study. Using this inductive approach, I identify the *selection* stage in the SRI case as the most analytically interesting because of the novel and under-studied barriers to innovation for the poorest farmers that the case

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[94] More information about the Project on Innovation and Access to Technologies for Sustainable Development can be found here: https://www.hks.harvard.edu/centers/mrcbg/programs/sustsci/activities/program-initiatives/innovation/projects/innovation-and-access-to-technologies-for-sustainable-development

highlights. This is not to say that other stages of the SRI's innovation system are not interesting, and I discuss many of them in detail, but the case focuses on the challenges of technology *selection* because this focus offers the most analytically rich insights, with respect to the overarching research question of the dissertation—understanding *how* and *why* the poorest farmers benefit (or fail to benefit) from agricultural technology innovation.

Using the innovation systems framework to interrogate the SRI case, several important themes emerge that link to larger literatures in science and technologies studies, sustainability science, and public policy. First, the concept of boundary-work is analytically useful both for understanding the causes of the controversy over SRI and for understanding the efforts to bring social-scientific closure to the virulent debates surrounding the technology. Thomas Gieryn defined "boundary-work" in a 1983 paper in the *American Sociological Review* as the "demarcation of science from other intellectual activities" and identified boundary-work as a "practical problem for scientists" (Gieryn, 1983, p. 781). He argued that scientists engage in boundary work in "pursuit of professional goals: acquisition of intellectual authority and career opportunities; denial of these resources to "pseudoscientists"; and protection of autonomy of scientific research from political interference" (pp. 781). In section 3.3.4, I demonstrate how Gieryn's idea of boundary-work is particularly useful for understanding the causes of the virulent debate surounding SRI.

Related scholarship on boundary-work from the sustainability science literature is also useful for understanding other aspects of the SRI case. This literature widens the definition of boundary-work beyond the demarcation of science from non-science identied by Gieryn, and uses the concept as an analytical lens through which to better understand the interface between science and policy (Jasanoff, 1991; Guston, 2001; Clark *et al.*, 2016). Clark et al. (2016, p. 4615) show how since Gieryn, the definition of boundary-work has been fruitfully expanded, arguing that "[t]he central idea of boundary work is that tensions arise at the interface between communities with different views of what constitutes reliable or useful knowledge…Active boundary work is therefore required to construct and manage effectivly the interfaces among various stakholders engaged in harnessing knowledge to promote action." For clarity's sake, I will call this second type of boundary work "mediating boundary-work." In section 3.3.5, I show how the World Bank engages in mediating boundary-work in an effort to bring social-scientfic closure to the debate over SRI.

In the discussion in section 3.6, I draw on the literature on reflexivity in public policy, organizational studies, and science and technology studies, to discuss policy relevant insights for overcoming some of the challenges of technology *selection* for the poorest farmers identified in this chapter. I show how early work in organizational behavior by Chris Argyris (1976) identified some of the organizational causes of the controversy that arose around SRI. Argyris' work also began to hint at some institutional solutions to the problems he identified, focusing on institutionalizing greater reflexivity or "double loop learning" in organizations. Later work in public policy and development studies by Matt Andrews, Lant Pritchett, and Michael Woolcock further articulates policy solutions that I argue could be effective at overcoming some of the challenges of technology *selection* for the poorest farmers identified in the SRI case (Andrews, Pritchett and Woolcock, 2017).

Finally, I conclude drawing on Sheila Jasanoff's argument that "[t]he design of technology is likewise seldom accidental; it reflects the imaginative faculties, cultural preferences and economic or political resources of their makers and users" (Jasanoff, 2004, p. 16). The SRI case shows how actors in the SRI innovation system attempt to define the boundaries of what constitutes appropriate knowledge making in order to control the cultural imagination of what constitutes the future of rice research and technology. This is an effort – previously identified in the science and technology studies literature – to establish their own "right to interpret science," often in ways that further their own professional interests (Jasanoff, 1987, p. 195). This argument, of course, is similar to Gieryn's idea of boundary-work, but Jasanoff goes a step further to identify a set of tools or "technologies of humility," that can help decision makers involved in technology *selection* for the poorest overcome the challenges identified in the case study (Jasanoff, 2003). These "technologies of humility" include institutionalizing a greater focus on both *framing* and *distribution* in the sociotechnical regimes structuring innovation systems, particularly at the technology selection stage.

3.2.2 Data: A Mixed Methods Approach

This chapter is a mixed-methods study that draws upon data from multiple sources (Jick, 1979). Sections 3.3 and 3.4, which focus on the dynamics of technology selection of SRI at the transnational level and at the local level in Bihar, rely on expert interviews, peer-reviewed literature, NGO reports, and newspaper articles.

For Section 3.3, which focuses on the selection of SRI at the transnational scale, I immersed myself in the literature on SRI. I also spoke to colleagues about their opinions on the technology at multiple development conferences and in semi-structured interviews, conducted both on the edges of conferences and in their offices. I interviewed experts who support SRI, both from academic and NGO backgrounds. For example, I spent several days interviewing Professor Norman Uphoff at his home and office in Ithaca, New York. I also interviewed scholars and development practitioners who are more skeptical of SRI.

For Section 3.4, which focuses on the selection of SRI in Bihar, one of the poorest states in India, I interviewed policy makers, bureaucrats, local academics, NGO officials, and journalists in order to develop an understanding of the selection of SRI in Bihar. As part of this effort, I conducted multiple field visits to Bihar between 2011 and 2016. In my first field visit (and thereafter) I relied heavily on the support of an NGO, PRAN, whose mission is to promote SRI in Bihar. I became close to the director of this NGO, Anil Verma, and over time joined the board of PRAN, which allowed me to interact with other SRI practitioners from across India at the bi-annual board meetings. However, I was also careful to ensure that my close collaboration with the NGO did not color my perception of the technology in Bihar. To do this, I met frequently with actors in the state who were more skeptical about the benefits and potential of SRI. I was also careful to interview farmers in villages outside of the regions where PRAN operates, both in focus groups and one-on-one settings.

For Section 3.5, I gathered data not only on the selection of SRI in Bihar, but also on how the technology is performing in the state, and whether it is living up to the expectations of the actors responsible for technology selection in the state. To do this, I conducted a total of 23 focus groups about SRI with farmers. These focus groups were divided into two categories. The first 15 focus groups were with SRI farmers supported by two separate NGOs (PRAN and JeeVika). I conducted an additional eight focus groups in randomly selected villages where neither NGO operates. The second set of eight focus groups was designed as a counter-weight to the focus groups I conducted with NGO supported farmers, where the opinions of farmers about SRI were overwhelmingly positive. To ensure that the additional eight villages were more unvarnished accounts of SRI, I selected villages for focus groups from regions of Bihar where neither PRAN nor JeeVika were active, and where SRI extension and training had happened exclusively through state-led extension programs.

Finally, I conducted a field survey of 11 villages in Bihar across three districts (see map in Figure 3.2). The total sample size of the survey was 338 households from UC (n=29), OBC (n=155), and SC/ST (n=152) castes (caste categories are discussed in Chapter 2). The survey captures both discrete responses (e.g. have you used SRI; where did you first learn about SRI) and more qualitative open-ended questions, which were coded to understand the multi-dimensional reasons why farmers adopted, failed to adopt, or disadopted SRI.[95]

[95] Note: this survey is smaller than the 12-village survey discussed in Chapter 2. This is because for strategic reasons I did not ask all of the SRI questions in Bathani village (my ethnographic site) that I asked in the other 11 villages. For some questions where I do have data on all 12 villages I include the larger sample in my analysis.

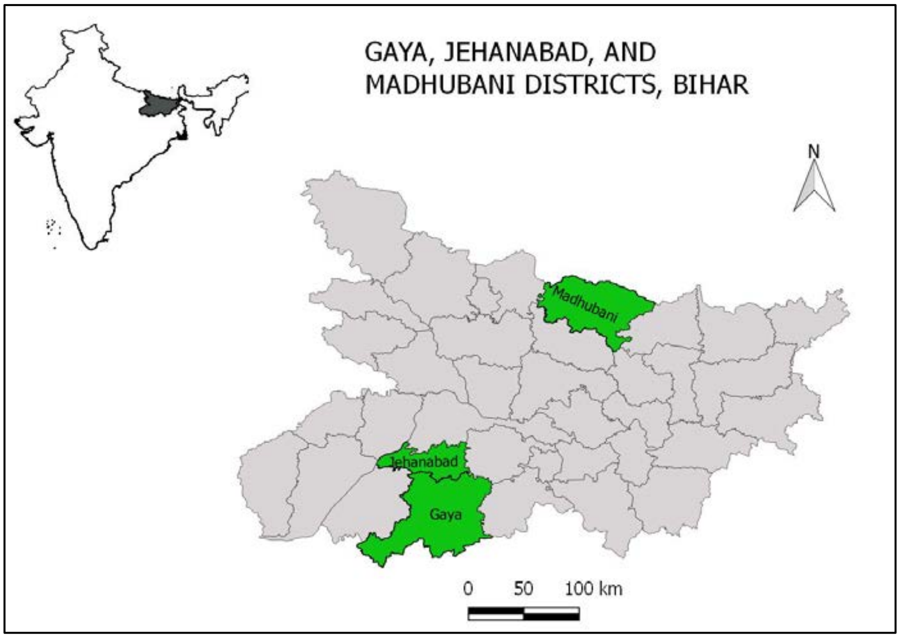

Figure 3.2: Map of three districts in Bihar where survey was conducted. Districts include Gaya, Jehanabad and Madhubani.

The study is thus one of a handful of large-scale evaluations of SRI, grounded in farmer's experiences of the technology rather than agronomic field trials. While much of the previous research on SRI has focused on agronomic evaluations of the technology, there are some evaluations of the technology in the social sciences. Many of these studies have been conducted by Professor Chris Barrett at Cornell University and his students. Professor Barrett's papers have used quantitative methods to isolate specific impacts of SRI. For example, Takahashi and Barrett (2013) evaluated the socioeconomic impact of SRI in Indonesia. They found that SRI generated significate yield gains, but they also argue that because SRI "induces a reallocation of family labor from non-farm to farm, SRI users enjoy no household incomes gains" (pp. 269). The authors asked why so many Indonesian farmers had adopted SRI (with low rates of disadoption at 18%) if it did not lead to household income gains. They conjectured that this "puzzling result may reflect non-monetary preferences for on-farm work over off-farm work, perhaps due to travel costs, to economies of scope in joint production of rice and perhaps child care, or to the social opprobrium associated with women working away from home in this heavily Muslim area" (pp. 285). While this is a useful insight, the notion that farmers include non-monetary items in their utility functions should not come as a surprise to those familiar with the larger literature on human well-being (Sen, 1999; Stiglitz, Sen and Fitoussi, 2009)

Moreover, as I will discuss at greater length in section 3 of this chapter, many of SRI's proponents argue that negative evaluations of the technology are the result of research methodologies that are not well-suited to capture the complex dynamics and "synergies" that emerge from the package of practices that constitute SRI in farmers' fields. Proponents argue that traditional agronomic trials on research stations, which are usually designed to test individual variables in a highly-controlled setting, are inadequate to capture the benefits of the multi-dimensional technology, because farmers are encouraged to experiment with different permutations of the technology to identify the best combination of practices for their individual circumstances (e.g. soil conditions and climate). Moreover, they argue that research stations often treat the soils with chemicals to ensure standardization of the experiment, which destroys the soil microbiome that is also essential to the superior results of SRI (Uphoff, 2003). Proponents of SRI argue that more complex and multi-disciplinary approaches to the study of SRI are needed to fully understand the benefits of the technology to small and marginal farmers in the field (Stoop, Adam and Kassam, 2009; D. Glover, 2011).

Taking these arguments to heart, I designed the empirical evaluation of SRI in Bihar using a mixed methods approach to agriculture technology adoption, including both qualitative field interviews and survey data. Unlike econometric evaluations, I did not measure yields, but rather relied on farmers' accounts of the ways in which SRI has contributed (or failed to contribute to) their household's overall well-being. I also relied on farmers' perspectives on the opportunities and barriers to SRI adoption at the household level. This approach places Bihari farmers' perspectives on SRI front and center.

Instead of focusing narrowly on yields or income changes, the empirical fieldwork in Bihar looked at broader concepts of well-being which included factors such as preferences for on-farm work. Because farmers' utility functions are complex and vary not only between villages but from farmer to farmer, well-being improvements can only be crudely measured by yield or income gains. Instead, I relied on a methodologically simple approach that overcame many of the challenges of external evaluators deciding what criteria was relevant to farmer well-being — I simply asked farmers for their own multi-dimensional evaluation of the technology as well as the barriers and opportunities for adoption.

3.3 Selection of SRI at the Transnational Scale

3.3.1 The Emergence and Spread of SRI as a "Pro-Poor" Technology

SRI is a practice-based technology for improving rice yields and reducing the costs facing farmers(Uphoff, 1999, 2003; H. De Laulanié, 2011). The technology consists of a set of management practices including earlier transplanting from nursery to field, line sowing, using fewer individual plants per mound when transplanting from nursery to the main field, increased spacing between plants, soil aeration often with mechanical weeders, and, perhaps most striking to the outside observer, keeping the rice field moist but not flooded throughout the season. See Table 3.1 for comparison of SRI management practices, "best management practices" as codified by IRRI, and management practices used by non-SRI farmers in Bihar.

Table 3.1: Comparison of rice management practices.

Source: The SRI management practices are adapted from Uphoff 2003. The "best management practices" are adapted from Sheehy et al. 2004, which links to a now defunct url in IRRI's Knowledge Bank. The farmers' practices in Bihar are taken from my own experience and specific questions in the 11-village survey.

Management Practices	**System of Rice Intensification**	**Best Management Practices (BMPs)**	**Farmers Practices (as practiced in South Bihar)**
Seedling age at transplanting	Younger seedlings: 8–12 days, generally not more than 15 days Fewer seedlings: 1; sometimes 2 if soil conditions less good.	Transplant seedlings within 15–30 days of germination, or direct-seed pre-soaked seed on the soil surface.	66% of farmers in the 11-village survey transplant from nursery to field between 26 and 30 days. 5% transplant at over 30 days and 27% at less than 25 days.
Plant spacing and density	Wider, sparser spacing: 25 25 cm to 35 35 cm, in square pattern, 16 to 9/m^2; with best soil, up to 50 50 cm, may have only 4/m^2.	Transplant two to three seedlings per hill in a square pattern of typically about 20 cm 20 cm (but only one seedling per hill in hybrid rice because seed is expensive).	51% of farmers transplant between 3 and 5 seedlings per hill. 38% transplant 1-2 seedlings per hill. 5% transplant 6 or more seedlings per hill. Seedlings are transplanted in lines but not in square pattern. Density is significantly higher closer to 15cm by 15cm.
Weed control	Weeding with simple mechanical 'rotating hoe,' starting 10–12 DAT; recommend up to four times, done also for soil aeration.	Combination of pre-emergence herbicides and hand-weeding to control early weeds up to 21 days after transplanting; thereafter, weeds have little effect on yield. Early flooding is also a weed control measure.	Practices differ significantly based on access to water and financial capital. Where possible fields are kept flooded. Hand weeding is also practiced and where farmers can afford it field is treated with herbicides.
Water Management	Keep soil from being continuously saturated during vegetative growth period; minimum water applications to maintain soil moisture, or alternating flooding-drying; shallow flooding (1–3 cm) during reproductive period.	Following transplanting, water levels in the field are maintained at approximately 5–10 cm. Fields are drained close to maturity. Mid-season drainage can occur for a short period. Intermittent drainage in later growth is practiced in Japan and Korea. In direct-seeded rice, soil is kept saturated during the first 2–3 weeks after seeding, followed by flooding.	When water is available farmers flood field. Farmers most often avoid paying for expensive diesel irrigation as much as possible, so when rains come standing water is left in field through system of earthen dams. When there is insufficient rain farmers will often irrigate 3-4 times in a paddy season. After each irrigation field is flooded, but often dries between.
Nutrient Management	Application of compost recommended, not required; best put on preceding crop.	Provide nutrients to the crop in the amount and at the time required, mostly through mineral fertilizers. Where available at low cost, use organic amendments only as a complement to mineral fertilizers.	77% of farmers use macronutrient fertilizers (NPK). A smaller number, 26%, use micro-nutrients such as zinc. 17% use organic compost often in addition to mineral fertilizers.

SRI is considered a "bottom-up" technology, in that it was not invented in a conventional laboratory or on a modern research station. Rather, SRI was invented in Madagascar in the 1980s, by a French Jesuit priest, Father de Laulanié, working in close collaboration with local farmers (De Laulanié, 1993; Uphoff, 2003; H De Laulanié, 2011). Because the technology was not developed through more traditional R&D channels, it can be thought of as a technology that was *invented* and at least locally *selected* by end-users. This makes SRI a particularly interesting case study because much of the literature on agricultural innovation systems suggest that involving end-users throughout the innovation process and specifically at the *invention* stage, is important to ensure technologies are appropriate or well-aligned to the needs of end-users (Biggs, 1990; Kristjanson *et al.*, 2009; Kilelu, Klerkx and Leeuwis, 2013). Because SRI is a technology that was *invented* and *selected* in close collaboration with end-users, it serves as a test case to understand the degree to which a technology developed by and for resource poor farmers in one context, can benefit the poorest farmers when transported to other contexts, where farmers face different sociotechnical and agro-ecological opportunities and constraints.

SRI spread from Madagascar to other countries via multiple pathways but most notably through the work of Norman Uphoff, a tenured political scientist at Cornell University, who traveled to Madagascar in the mid-1990s in his role as the director of Cornell's International Institute for Food Agriculture and Development (CIIFAD) and while there heard about SRI. Members of a local NGO Father De Laulanié founded, Tefy Saina, were so enthusiastic about the potential of SRI to raise farmers' yields that Professor Uphoff incorporated the technology into his own project. After three years of on-farm evaluations, Uphoff was very impressed with the results and began championing SRI as a promising technology for improving rice yields for small farmers outside Madagascar. Uphoff published his first journal article on SRI in 1999 in the *Journal of Environment, Development and Sustainability* (Uphoff, 1999). The article, was based off of data collected by Tefy Saina staff and his own observations between 1995 and 1999. In it, he reports that "[a] system of plant, soil, water and nutrient management for irrigated rice developed in

Madagascar has been yielding 5, 10 even 15 t ha^{-1} on farmers' fields where previous yields averaged 2 t ha^{-1}" (pp. 297). In addition to the substantial yield increases, Uphoff reported that the system works "using whatever variety of rice the farmer is already using and without having to utilize chemical fertilizer or other purchased inputs" (p. 297). Finally, he posited a causal explanation for the performance of this new technology that the SRI practices create "optimal growing conditions for plants," which can "bring out previously untapped genetic potential" (pp. 297).

The 1999 article was quickly followed by two more journal publications. In 2002, Uphoff and co-authors published a paper in the journal of *Agriculture Systems* (Stoop, Uphoff and Kassam, 2002) and in 2003 Uphoff published a third paper in the *International Journal of Agricultural Sustainability* (Uphoff, 2003). In the 2003 article, Uphoff described SRI as a technology with enormous potential to contribute to agricultural sustainability because of its ability to achieve higher yields with fewer external inputs. He explained that:

> The system of rice intensification (SRI) developed in Madagascar can raise irrigated rice yields to about double the present world average without relying on external inputs, also offering environmental and equity benefits. SRI methods change the way plants, soil, water and nutrients are managed – rather than utilising new-variety seeds, inorganic fertilisers or other agro-chemicals. SRI also reduces the need for irrigation water by about half and diminishes the requirements for capital and seed. SRI requires more knowledge and skill on the part of farmers and initially more labour per hectare. But greater labour intensity is compensated by farmers achieving higher returns for labour, and SRI can become labour-saving. SRI should make irrigated rice production more sustainable, as well as profitable. SRI experience may reveal other opportunities that can make agricultural systems more productive and beneficial for the long term (p. 38).

Uphoff characterizes SRI in these articles as a perfect "pro-poor" (see Chapter 1) – able to increase yields while decreasing expensive input costs, and thus risk, facing the poorest farmers. In addition, he contends that SRI has the added benefit of helping to improve the overall sustainability of rice cultivation by reducing water consumption in rice by about half.

It was clear from his writings that Uphoff felt that SRI had the potential to transform rice productivity for millions of rice farmers around the world and simultaneously protect the environment. Since the late 1990s, Uphoff has devoted his career to promoting SRI and growing an international network of NGOs and academics to support the technology. Uphoff had been director of Cornell's International Institute for Food, Agriculture and Development (CIIFAD) since 1990 and he was able to use CIIFAD as an institutional home for promoting SRI. While Professor Uphoff ended his tenure as director of CIIFAD in 2005, the CIFAAD website is still the most complete archive of SRI-related material which Professor Uphoff meticulously maintains with a staff of seven people. The website is a comprehensive archive with nearly everything that has ever been published about SRI, both in English literature as well as foreign language journals (especially Chinese). The website also includes links to instructional material, information about the history of SRI, and a huge archive of theses, conference proceedings, and field reports, amongst other grey literature on SRI. The website is also searchable by country with information about the networks of actors, activities, and publications of SRI practitioners and farmers in 59 countries (CIIFAD, 2018). The website serves as a central repository of all SRI related material, but also showcases the size of the global network that has grown to support what many SRI proponents have called a "civil society" innovation (Prasad, Prajit and Andrew, 2005).

Professor Uphoff's dedication to SRI's potential, showcased in the meticulous archive maintained on the CIIFAD website, is also evident in his daily communications. When I first expressed interest in working on SRI, he not only emailed me more material than I could possibly wrap my head around, but he graciously invited me to Ithaca to meet him, learn more about SRI, and stay in his lovely home with his wife over a four-day period in March 2011.[96] I have since learned that I am not a unique case. Almost everyone who knowns Uphoff agrees that his desire to help others learn about SRI can often be

[96] Indeed, the guest room I stayed in, overlooking a lake, led to some of the best sleep of my first year of graduate school.

overwhelming. And as I will demonstrate in the next sections (3.3.2- 3.3.5), Uphoff's enthusiasm for SRI has conflicted sharply with the reaction of the established rice research community, who have been far less receptive both to the "bottom up" innovation and to Uphoff's passionate promotion of the technology around the world.

3.3.2 SRI Selected by Transnational Actors

The 2002 article by Stoop, Uphoff and Kassam, all respected development experts from prestigious institutions, including the West African Rice Development Association (WARDA), Cornell International Institute for Food, Agriculture and Development, and the Food and Agriculture Organization of the United Nations (FAO) respectively, framed SRI specifically as a technology to help "resources limited farmers" (Stoop, Uphoff and Kassam, 2002). They concluded that a "major implication of SRI is that apparently there still exists substantial potential to raise rice yields through relatively simple but profound adjustments in agronomic management practices" (Stoop, Uphoff and Kassam, 2002). The notion that the poorest farmers could obtain increased yields not "through higher levels of external inputs, but rather through more productive use of natural resources (land, water, seeds and plant nutrients) and of labour, time and space," (p. 270) appealed to many development professionals, who by the 21st century were increasingly concerned with the negative consequences of the 20th century's Green Revolution and increasingly focusing on agro-ecological approaches to agriculture development, such as integrated pest management (IPM).

Much of the early spread of SRI happened through informal and civil society networks, usually with Professor Uphoff as the central node of these networks. The World Bank and other development organizations also began to show strong interest in SRI by around 2005, and helped the technology spread outside Madagascar through funding various pilot programs, often as part of larger development initiatives. A 2010 Report by Africare, Oxfam America, and the World Wildlife Foundation, served as an important transnational *selection* mechanism for SRI by three prominent funding and development agencies. The 33-page report entitled "More Rice for People: More Water for the Planet" argued that "[w]hen agencies as diverse as Oxfam, WWF and Africare, with missions focused respectively on social justice, human harmony with nature, and sustainable development independently come to support the same strategy to address critical global challenges, such a strategy merits wider attention and examination" (Africare, Oxfam America and WWF-ICRISAT, 2010). This report, like the paper by Stroop et al., argued that while SRI methods "work with any variety of rice and on any farm size, for subsistence farms to larger scale operations," because of the fact that SRI methods do not rely on many external inputs the method is "particularly suited to the needs of resource-limited households, reliant on small landholdings. Thus, SRI methods are fundamentally "pro-poor" (Africare, Oxfam America and WWF-ICRISAT, 2010).

As the SRI movement gained momentum, many scholars and development professionals became enormously passionate about SRI as a technology with the potential to raise yields for poor farmers while decreasing input costs and strain on water resources. For example, Robert Zoellick in 2009, when he was President of the World Bank Group, wrote about SRI in an op-ed in one of India's leading newspapers, *The Hindustan Times*, saying that "this emerging technology not only addresses food security but also the water scarcity challenge that climate change is making all the more dangerous" (Zoellick, 2009). He described the experience of Tamil Nadu with SRI, saying that the farmers in the state who had adopted SRI increased their yields 30 to 80% while also reducing water use by 30%. Zoellick continued that the experiences of India with SRI "are all lessons for our world." Notably, Zoellick failed to mention any continued controversy over the efficacy of SRI.

As positive reports about SRI became more frequent and more and more transnational actors began to support the technology, some advocates of SRI developed a faith in the technology that seemed to many observers to go beyond the empirical evidence and verged on the evangelical. These "SRI enthusiasts" appeared to treat the technology as a "silver bullet," with the potential to transform global rice production for the benefit of both farmers and the environment. For example, a scholar and advocate of SRI in India, Dr. B.C. Barah from the National Centre for Agricultural Economics and Policy Research, attributes multiple benefits to SRI, without also reflecting on any drawbacks. The benefits of SRI Dr. Barah cites in a paper and supporting PowerPoint presentation include: significant productivity enhancements; the technology's ability to save land, water, and time; its ability to enrich soil health and microbial dynamics; its organic nature; its ability to minimize risks facing farmers; its ability to provide employment opportunities; its potential to improve household food and nutrition security; and its higher profits (Barah, 2009; see PowerPoint slide in Figure 3.3 below).

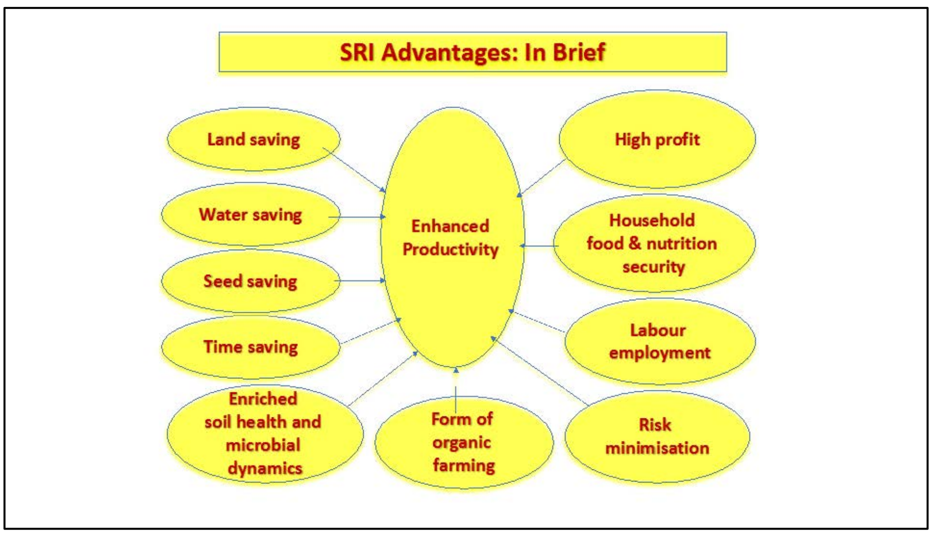

Figure 3.3: "Policy perspectives for upscaling SRI" PowerPoint presentation.
Source: (Dr. Barah, NABARD Chair Professor at IARI New Delhi)

For many, the benefits of SRI cited by SRI enthusiasts were simply too good to be true. Almost as soon as SRI began to gain international attention, there was also a strong pushback against the technology by the established rice research community.

3.3.2 The Rice-Wars

Since the Green Revolution of the 1960s and 1970s, a major international network of scientists focused on improving rice yields has grown up around the world. The center of this network is located in the Philippines at the headquarters of the International Rice Research Institute (IRRI), which is one among 15 institutes that make up the Consultative Group on International Agriculture Research (CGIARS), which are dedicated to agriculture and food systems research around the world. The CGIAR and its research centers were established after the Green Revolution in response to the need to institutionalize international agriculture research to ensure continued productivity grains (Sagasti and Timmer, 2008).

IRRI is a global organization, headquartered in Los Baños, Philippines. It has offices in 17 rice-growing countries in Asia and Africa and more than 1,000 staff. IRRI's budget in 2015 was approximately 92 million dollars. On their website, they claim to be "the world's premier research organization dedicated to reducing poverty and hunger through rice science; improving the health and welfare of rice farmers and consumers, and protecting the rice-growing environment for future generations" (IRRI, 2018). IRRI is at the center of a larger community of rice scientists around the world, including within the United States Department of Agriculture and many of the United States' land grant universities.

Almost as soon as the 1999, 2002, and 2003 articles by Professor Uphoff were published, scientists from the established rice research community mobilized to attack the technology in the literature. The first article to attack SRI was submitted by Achim Doberman, an agronomist at IRRI, to the journal of *Agricultural Systems* in 2002, but it was not published until 2004 (Dobermann, 2004). The article, was titled "A Critical Assessment of the System of Rice Intensification (SRI)". Dobermann's paper is interesting because at the same time that it mostly dismisses SRI by claiming "techniques such as SRI are not necessary for growing rice near the yield potential," he grants that "approaches such as SRI may serve the important needs of resource-poor farmers in areas with poor soils, but are likely to have little potential for improving rice production in insensitive irrigated systems on more favorable soils, where high yields can be achieved through implementation of more cost-efficient management practices" (pp. 262). What is interesting about this conclusion is that it acknowledges that SRI may be an important "pro-poor" technology, at the same time as it largely dismisses the value of SRI outside these limited circumstances.[97] From the perspective of development practitioners specifically concerned with finding technologies that would benefit the poorest farmers, the tenor of Dobermann's conclusion must have seemed very strange indeed. From their perspective, if a technology specifically benefited the poorest farmers, what could be better? Indeed, so many technologies they feared brought disproportionate benefits to wealthier farmers. Why would the research community shun a technology that was specifically beneficial to the poor?

However, the real opening salvo in what Shambu Prasad, a scholar and proponent of SRI in India, would later dub the "rice wars" (Shambu Prasad, 2009) was a widely read news feature in *Nature* written by Christopher Surridge, their senior biology editor, entitled "Feast or Famine?" (Surridge, 2004). The news feature on the most superficial level attempts to provide an even-handed report of the current debate over SRI, but reading between the lines, it is clear that the subtext of the article is meant to make the reader skeptical of SRI. For example, the caption on the main photo in the article, "Wonder rice? The System of Rice Intensification involves more sparsely planted, drier fields than is normal. Its supporters believe it gives more than double yields of conventional farming" (p. 360), almost immediately serves to make a potentially neutral reader an SRI skeptic. The news feature continues, claiming that "many imminent agronomists dismiss such achievements as the result of poor record keeping and unscientific

[97] Indeed, critics of SRI used this article, which was based entirely off of a theoretical review of previously published rice science and no new experimental evidence from SRI trials, as a reason to dismiss the potential of SRI entirely.

thinking. A new set of field trails published this month seems to support this view unequivocally" (p. 360).

The field trial that Surridge refers to in the *Nature* news feature is an evaluation of SRI by nine authors. The lead author, John Sheehy, is an ecologist at IRRI and the other eight authors, including Achim Dobermann, are all either directly or loosely associated with IRRI. The title of the article "Fantastic yields in the system of rice intensification: fact or fallacy?" immediately hints at the authors' evaluation of the technology, but also removes the potential for the existence of the kind of gray area that Dobermann's 2004 article had. The research and analysis in Sheehy et al. (2004) includes both field station trials conducted in three locations in China, as well as a theoretical modeling exercise that predicts maximum yields, and compares them to reported yields under SRI in Madagascar. The first part of the analysis in Sheehy et al. demonstrated that after a single season of trials in three separate locations, that the "conventional best management practices" as defined by IRRI, performed better in two locations. However, in the third location SRI performed better than IRRI's BMPs. Instead of exploring the reasons for variance in results, the analysis of the field experiments quickly concludes that "given this amount of variability in the results, we conclude that there is no consistent difference in yield between SRI and conventional [BMP) practice. Since SRI required an additional application of organic fertilizer and had higher labor requirements for weeding, its widespread adoption in China is unlikely" (p. 4).

Nevertheless, Sheehy *et al*. (2004) come down even harder on SRI in their analysis of the modeling results where they conclude all of the reported SRI yields from Madagascar were greater than the predicted maximum possible yield values in their model. Thus, if you believe the results of their model, the only possible conclusion to be drawn is that "the extraordinarily high yields" reported in Madagascar "are probably the consequence of some form of measurement error" (p. 7). And indeed, their conclusion "that SRI has no inherent advantage over the conventional system and that the original reports of extraordinary high yields are likely to be the consequence of error" (p. 1) dismisses SRI as complete fallacy.

In what can only be seen as a coordinated effort, as the Sheehy *et al*. (2004) paper was in press, two opinion pieces on SRI were also prepared by rice scientists who were not authors in either the Dobermann (2004) or Sheehy *et al*. (2004) studies. The first, by Thomas Sinclair, USDA, and Kenneth Cassman, University of Nebraska, was published as a discussion piece in a widely-read journal amongst agricultural scientists – *Field Crops Research*. In the two-page paper titled "Agronomic UFOs" they share their concern that "reports of unconfirmed field observations (UFOs) must not be accepted as bases for agronomic understanding" (p. 9). Their discussion then reviews the findings from Sheehy et al. (2004) that "the claimed SRI yields were approximately twice what was possible based on the energy available to support crop growth" (p. 9). They end the opinion piece by cautioning their readers that "it is human nature to hope for major advances that will improve the welfare of so many using technologies that are easily accessible to resource-poor farmers, but this innate desire must be balanced in the scientific arena with critical analysis and carefully designed experimental evaluation" (p. 10).

This last point is especially interesting given Dobermann (2004) finding that SRI, while not necessarily beneficial to the average farmer, may indeed have specific benefits for resource-poor farmers. Instead, they conclude simply that SRI is unlikely to benefit anyone and continuing to spend research money on the topic would be a waste of scarce research funding. In addition to this opinion article, the lead author, Thomas Sinclair, published a second opinion article in the magazine *Rice Today,* a periodical with broader readership than most academic journal, which also argues SRI is an "Agronomic UFO" which is a "waste of valuable scientific resources" (Sinclair, 2004). A final discussion article, also in *Field Corps Research,* by John Sheehy, Thomas Sinclair, and Kenneth Cassman is perhaps the most venomous attack on SRI and on the scientific credentials of its proponents (Sheehy, Sinclair and

Cassman, 2005). The discussion piece, titled "Curiosities, nonsense, non-science and SRI" accuses Stoop, Uphoff and Cassman (2004) of being both "careless" and "indifferent to" the scientific method.

3.3.3 SRI's Network Grows

Despite the controversy surrounding SRI, the network of actors who determined that SRI merited further attention and investment continued to grow, and more and more journal articles and reports from the field documented SRI results that supported the benefits of the technology. Based on the accumulating evidence, a 2011 report commissioned by the Bill & Melinda Gates Foundation found that "it is fairly well established that SRI cultivation methods cause changes in the physiology and morphology of rice plants, which can lead to improved productivity and grain yield under favorable conditions" (Berkhout and Glover, 2011). The report concludes by encouraging the Gates Foundation to continue funding research and promotion of SRI, arguing that if progress can be made in answering a number of remaining knowledge gaps, both pertaining to the biophysical mechanisms undergirding SRI, as well as the sociotechnical dynamics of SRI adoption and use in farmers' fields, "useful, practical progress can be made in developing rice cultivation systems that answer the felt needs of the poor and marginal farmers" (p. 141).

By 2017, SRI had been *adopted* in over 50 countries (CIIFAD, 2018). In many of the countries, adoption was limited in geographic scope, and the actors involved with initial adoption were either NGOs, civil society organizations, or individual farmers who heard about SRI often through forums on organic or agro-ecological approaches to agriculture. Yet in at least 23 countries, SRI had achieved broader adoption across multiple regions and with multiple organizations supporting the technology. In three countries – Cambodia, India, and Vietnam – SRI was in widespread use in multiple regions and supported by central and or state governmental initiatives (see map in Figure 3.4).

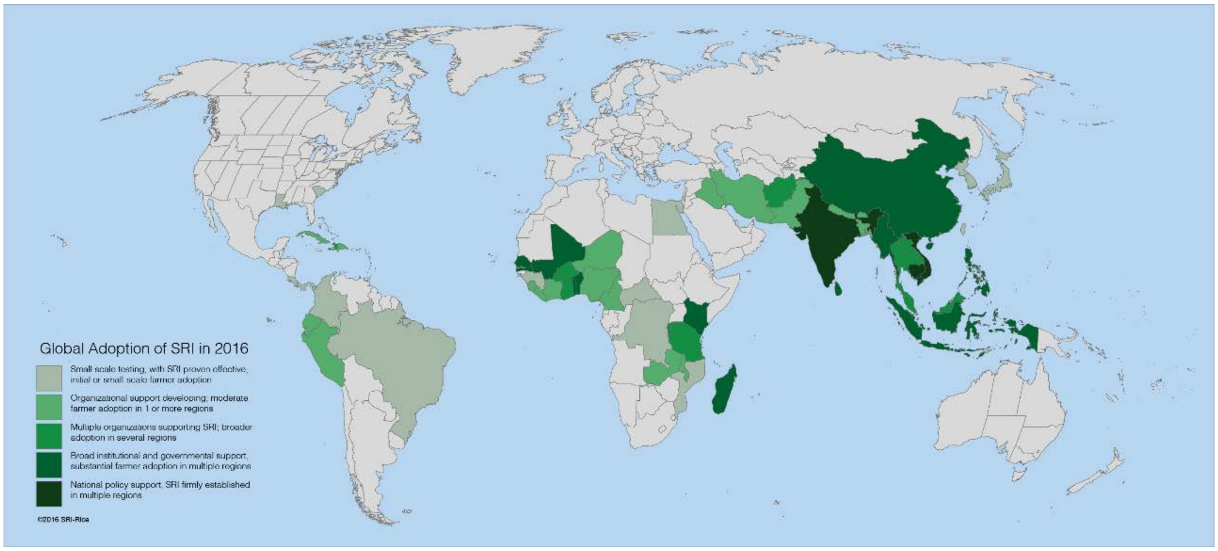

Figure 3.4: Global SRI Adoption as taken from the CIFFAD website.
Source: *(http://sri.ciifad.cornell.edu/images/global/SRI_World_Map_2016.png)*

In addition to the rapid growth in the number of countries where SRI has been demonstrated and adopted into widespread use, the technology also amassed a large publication record. Beginning with Father De Laulanié’s 1993 publication in the French journal *Tropicultura*, over 900 articles about various aspects of SRI were published through the end of 2018 (see Figure 3.5).

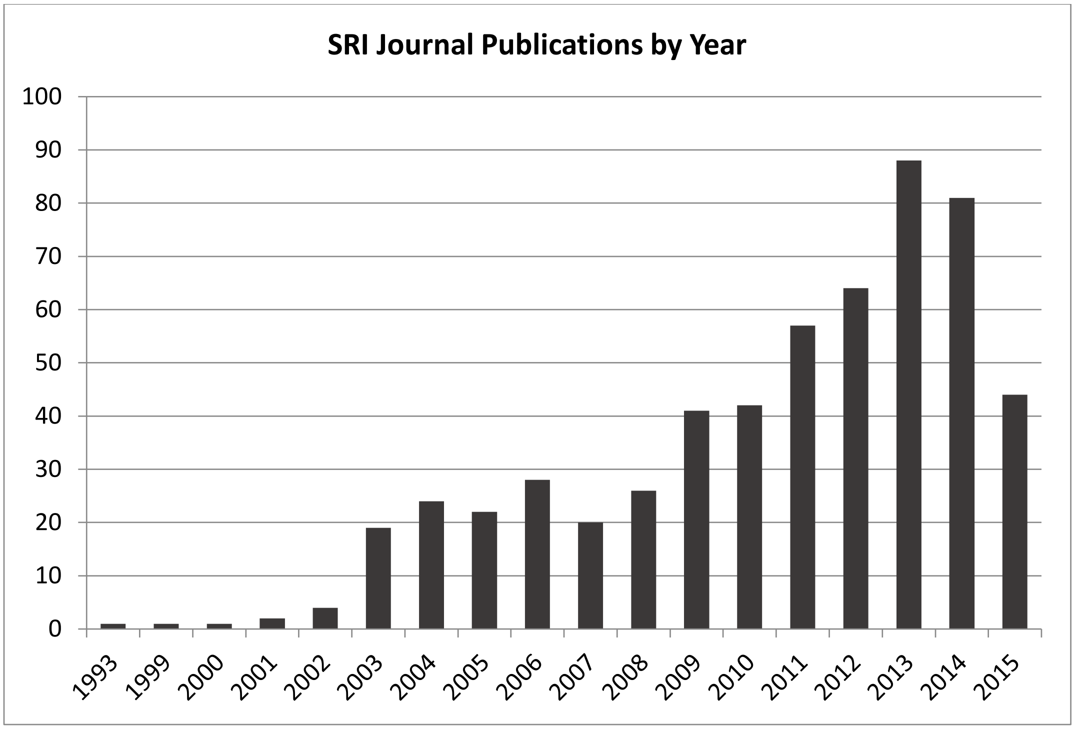

Figure 3.5: Number of journal articles about SRI per year through 2015.
In total, by 2018, over 900 journal articles about SRI have been published according to data maintained by the SRI International Resources Network.

This impressive publication record is largely a result of Professor Uphoff's dedication to fostering a network of researchers around the world that both promote SRI and respond to the critiques leveled at SRI by its skeptics. Indeed, Professor Uphoff and his staff maintain a database in Zotero citation software of all available SRI publications, including journal articles, books, conference papers and theses and dissertations.[98] The articles in the database include publications that critique SRI (e.g. Dobermann, 2004; Sheehy *et al.*, 2004; Sinclair, 2004; Sinclair and Cassman, 2004; Surridge, 2004; Sheehy, Sinclair and

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[98] The SRI Zotero database maintained by Professor Uphoff can be found here: https://www.zotero.org/groups/344232/sri_-_system_of_rice_intensification_research_network/items/collectionKey/SEMP6Z3T/q/Uphoff

Cassman, 2005). However, the vast majority of the articles in the database serve to support the claim that SRI is a “beneficial” technology, at least to some farmers under some circumstances.

Uphoff played a central role in facilitating the transnational network of scholars who developed this impressive publication record. Out of the 973 journal articles in the database, Professor Uphoff is an author or co-author on 54 of them. It was especially important to Uphoff to encourage soil scientists to study SRI, as he was convinced that many of the mechanisms that make SRI effective could be explained by the interaction between SRI’s methods and the health of the microbes and biota living under the soil (Uphoff, 2012). Uphoff was ultimately successful in drawing the attention of the soil science community to SRI. A 2013 study by scientists in Thailand and the UK, found that SRI practices increased the diversity of Arbuscular mycorrhizal fungi (AMF) in the soil. This finding served to validate Uphoff’s hypothesis because in agricultural ecosystems, AMF are necessary for the proper management of beneficial symbiosis in root systems (Watanarojanaporn *et al.*, 2013). A second study by scientists in India concluded that SRI practices “create more aerobic soil conditions under which beneficial microbes and other soil organisms can prosper and improve the soil’s structure and fertility” (Mahender Kumar *et al.*, 2017, p. 394).

At his own university, Cornell’s agronomists were among the early SRI skeptics.[99] A 2005 study by three scholars from the department of earth and atmospheric sciences and from the department of crop and soil sciences, evaluated yield differences between SRI and BMP based on data from trials in multiple countries, including Madagascar, Nepal, China, Thailand, Laos, India, Sri Lanka, Indonesia, Bangladesh, and the Philippines (Mcdonald, Hobbs and Riha, 2006). They concluded that “[a]side from one set of experiments in Madagascar where SRI more than doubled rice productivity with respect to BMP, we found no evidence of a systematic or even occasional yield advantage of this magnitude elsewhere.” In

[99] A fact which deeply bothered Professor Uphoff when I interviewed him at Cornell in March 2011.

response to this article, Uphoff and colleagues countered in a 2008 article in the same journal (Uphoff, Kassam and Stoop, 2008) that their conclusion was based on secondary data which was "assembled selectively from diverse sources" and that their study left out extensive field trials in China, India, and Indonesia which would have led to a more favorable analysis of SRI vis-à-vis BMPs.

Despite critiques from the agronomists at Cornell, scholars from both the economics department and the soil sciences department were willing to take the technology more seriously and conduct their own disciplinary evaluations. Christopher Barrett, Professor of Applied Economics and Management with a focus on development economics and international agriculture development, co-authored four journal articles on SRI between 2003 and 2013 (Moser and Barrett, 2003, 2006; Barrett *et al.*, 2004; Takahashi and Barrett, 2013). While Barrett's early evaluations of SRI in Madagascar showed yield improvements, they also showed that SRI was labor intensive, which they argued limited the widespread adoption of the technology (Moser and Barrett, 2003). By 2013, Barret's evaluation of SRI in Indonesia demonstrated both significant yield gains and widespread farmer adoption (with low rates of disadoption), but the authors still argued that the increased labor requirements likely negate the overall impact of the increased yields on overall income (Takahashi and Barrett, 2013).

An evaluation of SRI out of Cornell's soil science department also offers a more positive view of the merits of SRI and supports Uphoff's argument that the key to understanding the benefits of SRI is developing a better understanding of the rice plant's roots and their interaction with the soil. A 2010 study by an international group of soil scientist, including Janice Thies, professor of soil biology at Cornell, found significant differences in the soil microbial community between paddy plots managed with SRI as opposed to BMPs (Sooksa-Nguan *et al.*, 2010).

In addition to SRI's increasing network amongst NGOs, donors, and scholars, SRI also began to penetrate the private sector as part of the larger whole foods movement. In 2014, SRI became a marketing strategy for a high-end organic rice company, Lotus Foods, who claim on their packaging that their rice is grown using SRI methods, which "requires a lot less water and seeds to produce more crop per drop. … We're taking rice production beyond organic" (see Figure 3.6).

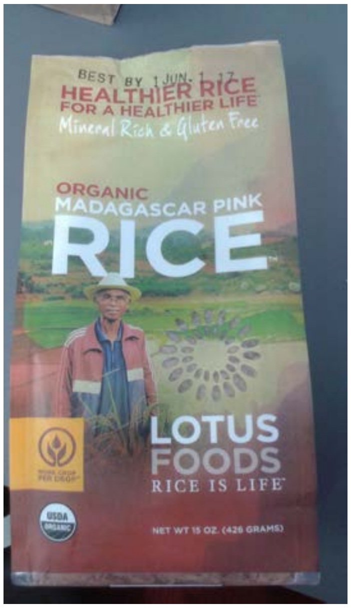

Figure 3.6: "SRI" branded rice.

Packaging for Lotus Foods Rice which highlight SRI as a technology for saving water and seeds (see right image bottom, right text)

3.3.4 The Causes of the Controversy: Three Hypotheses

There are multiple explanations for the causes of the virulent conflict over SRI. Many people I spoke with at conferences and other professional forums, attribute the animosity surrounding SRI to the passion with which Uphoff promotes SRI. Uphoff promotes SRI with a particular zeal that makes many scientists nervous. Indeed, in my experience simply emailing Uphoff a short question can quickly lead to a five-page return email with 10 attachments, including drafts of upcoming papers and reports that he hopes will finally put the SRI debates to rest. Many scholars and some development experts automatically discredit SRI simply because Uphoff's demeanor and belief in SRI verges on the evangelical. They feel this kind of passion has no place in rational scientific discourse. Others who have a higher opinion of the value of SRI still believe that Uphoff is "his own worst enemy," fanning the flames of the debate through his dogged promotion of the technology.[100]

A second explanation of the virulent debate over SRI, focuses on the different epistemological orientations between the two communities of scholars and practitioners on opposite sides of the "rice wars." Dominic Glover, a scholar of technology and sociotechnical change, and a research fellow at the Institute for Development Studies in the UK, argues that the controversy around SRI is a product of differences between the epistemological orientations of research communities (D. Glover, 2011). On the one hand, breeders and agronomists prefer controlled field trials where the impact of a specific intervention can be cleanly studied and quantified. In contrast, proponents of SRI claim that SRI as a system (albeit one that has enormous variance at the field level) can only be understood by believing that the whole is greater than the sum of the parts, and that the "synergistic effect of all these components" is what makes SRI so effective (pp. 361, T.M. Thiyagarajan, dean of the Agricultural College and Research Institute in Killikulam, India, as quoted in Surridge 2004). In response to the epistemic debate over what qualifies as appropriate methods for quantifying the benefits of SRI, Glover (2011) suggests that the controversy over SRI can be put to rest by in-depth evaluation of SRI in farmer's fields through "close technographic observations of farming activities and the interaction between farmers and their fields, plants and tools" (pp. 217). Glover concludes that SRI is a phenomenon that extends beyond variables that can be easily tested in research station trials and suggests that evaluations of the technology begin with a "set of rather open questions about what happens when SRI *as a system of knowledge* flows into rice farming *as a system of practice*" (pp. 222).

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[100] I have heard the exact phrase "own worst enemy" on at least four separate occasions when talking to development experts about SRI and Norman Uphoff. I have chosen not to name these experts because I do not feel that attributing the quotation improves the quality of my argument nor contribute to deeper insights, and could be damaging to relationships within the academic community of which I am a member.

While there is no doubt some truth to the idea that closer study of SRI in farmers' fields can help adjudicate the debate over SRI – and indeed Section 5 of this paper also attempts, in some ways, to add an empirical perspective with evidence from Bihar – the virulence of the debate around SRI and especially the set of 2004 publications constituting the "rice wars," cannot be explained only by different epistemological approaches to research.[101] If this were the case, the scholars who so strongly critiqued SRI would more likely have ignored the technology as uninteresting to their own research agendas.

Instead, the virulence of the debate suggests that in addition to epistemological differences, there was something larger at stake for scholars on both sides of the 'SRI Wars'. A useful perspective on the root causes of controversy over SRI comes from Ray Offenheiser[102], President of Oxfam America (Offenheiser, personal interview, January 11, 2016, Boston MA). Offenheiser has a valuable perspective on SRI because he has worked in organizations that have landed on opposite sides of the SRI debate. Offenheiser earned his master's degree in development sociology at Cornell University in the 1970s, where he first met Professor Uphoff when he played volleyball with other "Cornell Ag-ies" in Professor Uphoff's backyard. After graduating from Cornell, Offenheiser went to work at a sister organization to IRRI, the International Potato Center (CIP). Both IRRI and CIP sit under the larger umbrella organization the Consultative Group for International Agriculture Research (CGIAR). Finally, as President of Oxfam America, Offenheiser funded successful programs supporting SRI in Vietnam, and in 2010 Oxfam co-

[101] The term "rice wars" is an explicit reference to the "science wars" which much like Glover's explanation of the "rice wars" hinged on differences in opining between intellectual communities about the nature of scientific theory and intellectual inquiry. On one side of the debate, scientific realists like Paul Gross and Norman Levitt (Gross and Levitt, 1994) and Alan Sokal (Sokal, 1996), accused a growing community of what might be called post-modern philosophers of science and technology of having rejected any form of scientific objectivity. On the other side of the debate, postmodernists pointed to work by Thomas Kuhn (1962) among others to argue that science is socially constructed and must be interpreted within its social and institutional context (Jasanoff, 2004, 2017).

[102] Note that Ray Offenheiser has stepped down from his position at Oxfam America and is now the Director of the Notre Dame Initiative for Global Development and a Distinguished Professor of Practice at Notre Dame.

authored a report on the benefits of SRI (Africare, Oxfam America and WWF-ICRISAT, 2010).[103] Offenheiser, with experience funding SRI and having been within organizations on both sides of the SRI debate, is perhaps uniquely positioned to provide insight into the root causes of the debate over SRI.

During an interview I conducted with Offenheiser in his office in Boston, he placed the majority of the blame for the intense animosity around SRI at the feet of IRRI saying "In some sense they [IRRI] picked that fight" (Offenheiser, personal interview, Jan 11, 2016). He continued, that there was no real reason for IRRI researchers to be so concerned about the spread of SRI. Almost all farmers using SRI methods were also using high-yielding seed varieties, so there was no intrinsic tradeoff between SRI and the work that most of the scientists at IRRI were doing, but nonetheless "the researchers were out of their mind that they needed to kill this [SRI] thing. The virulence of the attack was shocking and somewhat disgraceful."

Offenheiser said that his own staff at Oxfam were taken off-guard by the strength of the debate over what many of them saw as a seemingly innocuous approach to rice cultivation. Offenheiser relied on his graduate training in development sociology and specifically what he referred to as his coursework in the "sociology of knowledge," to help his staff understand that "SRI was turning the job of improving yields from the breeders to the social scientists and agriculture economists. This impinged on the turf of the breeders, giving other disciplines more political space within the CGIAR." Offenheiser concluded that the fear of losing power and authority over the direction of research was the reason for the coordinated attack against SRI in 2004. The breeders and other scientists at IRRI, as well as sister research institutes around the world, feared that if they started to lose control of the message, there was no telling what the ultimate implications might be for the direction of research, and in particular, the implications for

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[103] Oxfam American became involved with SRI in 2005 through a Cambodian agronomist working with Oxfam. Meanwhile other Oxfam offices like Australia were also experimenting with SRI. All of these trials developed through informal networks and were not coordinated.

research funding. In other words, Offenheiser concluded that the virulence of the “rice wars” was driven by the professional incentives of the established rice research community to safeguard their power and authority over the direction of rice research and development.

Corroborating Offenheiser’s viewpoint that the virulent debate over SRI is driven by competing professional incentives is difficult. Indeed, both Uphoff and Glover point out in an exchange of comments in the *Wageningen Journal of Life Sciences* that it is very hard to find decisive evidence to prove that conflicts of interests are biasing scholarships (Glover, 2012; N Uphoff, 2012). And, while there is no smoking gun, there are multiple indications that professional incentives have played a major role in driving the debate over SRI.

Even before SRI emerged as a topic for debate in the transnational agriculture research community, the same editor that wrote the opening salvo in the “rice wars” in *Nature* in 2004 (Surridge, 2004), wrote a similar news feature in *Nature* two years prior, looking at the potential of genetic engineering to create a new type of rice plant that would significantly increase productivity (Surridge, 2002). This news feature had nothing to do with SRI, but it did frame what was at stake in terms of professional incentives and prestige for rice scientists in improving rice yields. The news feature began with these words: “feeding the world in the twenty-first century could require a second green revolution, but that may involve the most audacious feat of genetic engineering yet attempted.” This phrase immediately underscores two points. First, any success in genetic engineering that meets the world’s food needs would be an “audacious feat” on the part of scientists, comparable to the achievements of Norman Borlaug, who won a Nobel Peace Prize in 1970 as the father of the first Green Revolution. The news feature continues, that rice is the world’s most important staple crop, but that yield growth is approaching a “theoretical limit set by the crop’s efficiency in harvesting sunlight” (pp. 576). To overcome this theoretical limit and ensure rice production keeps pace with global demand, the article quotes IRRI’s John Sheehy (who would later author one of the key anti-SRI papers), “the only way to increase yields and reduce the use of nitrogen fertilizers is to increase photo-synthetic efficiency." Indeed, John Sheehy's own research agenda was firmly intertwined with this effort to boost rice's photosynthetic efficiency by manipulating a suite of genes responsible for the type of photosynthesis the rice plant uses to assimilate $C0_2$ (Sheehy, Ferrer and Mitchell, 2008; Sheehy and Mitchell., 2013; The C4 Rice Project, 2017). Sheehy claims that his project is "the next frontier" of plant science and the only way to meet the growing global demand for rice (Surridge, 2002, p. 578).

But the news feature in *Nature* also alludes to nervousness on the part of scientists about whether sufficient funding will be available to achieve their goals, showing particular concern that Japan's economic problems will cause their largest benefactor to reallocate funding away from their efforts to re-engineer photosynthesis in rice (Surridge, 2002, p. 578). In a world of limited funding and high professional stakes, it is almost not surprising that two years later, both Surridge and Sheehy would respond with such animosity to a technology that claimed to achieve yields similar to those they were aiming for with their genetically engineered rice, with nothing more than a few changes in management practices by farmers in their fields.

Many of the other articles published during the "rice wars" also allude to concerns over money and resources as a reason why SRI should be quickly abandoned by both scientists and donors. Sinclair and Cassman for example cautioned that the "scientific system has had to spend considerable time and resources in rebutting the claims of SRI yields … Such time and resources could be better utilized in research with direct benefits" (pp. 9-10, Sinclair and Cassman, 2004). A second article is more forthright about their concern over allocation of financial resources, "no doubt the admirers of SRI will continue in their advocacy and some funding agencies will waste money by diverting it from hypotheses developed with logical consideration of the relevant theory and substantive preliminary experiments. Eventually, SRI will go the way of other non-science and disappear into obscurity" (Sheehy, Sinclair and Cassman, 2005).

In summary, all three hypotheses – individual credibility, different epistemological orientations, and professional conflicts over power and authority – played some role in giving energy to the debates surrounding SRI. But in many ways, it seems that the debates would never have gained the furor and attention they did had there not been tensions grounded in real concerns about whose vision for rice research the big donors would fund and who could claim the mantle of success in feeding the world in 2050. Gieryn's notion of boundary-work is a useful theoretical lens through which to understand this debate. The established rice research community used forums such as journals and opinion articles in popular scientific press to demarcate what they saw as valid science, from what they saw as invalid. They certainly employed the language of epistemic differences in their arguments, but in their arguments only one epistemic approach was valid. However, what seems almost certain is that the virulence with which the established rice research community attacked SRI demonstrates the ways in which SRI was perceived as a threat to their professional goals and required swift action to deny "resources to 'pseudoscientists'" (Gieryn, 1983, p. 781).

3.3.5 Attempts at Closure: Finding Common Ground?

In response to the virulent controversy over SRI, the World Bank Institute developed a toolkit to explain SRI titled "SRI Achieving more with Less: A New Way of Rice Cultivation." Instead of avoiding the controversies around the technology, the World Bank addressed them directly by interviewing farmers, researchers, practitioners, and development agency staff about their views on SRI.[104] The World Bank's Toolkit is an example of mediating boundary-work in an effort to help bring closure to a debate

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[104] While the website has unfortunately been taken down by the World Bank, I had the interviews transcribed before the website was taken down. I have included these interviews in Appendix 4. These interviews shed important light on the SRI debate and demonstrate the interesting role the World Bank took on as boundary spanning role in mediating the controversy over SRI technology.

over “what constitutes reliable or useful knowledge” (Clark *et al.*, 2016, p. 4615). The need for boundary-work between the communities on opposite sides of the “rice wars” by 2010 was clear. The extent to which the World Bank’s project worked in finding common ground between the two communities is debatable, as strong disagreements persist. However, what the toolkit did do was put IRRI on notice that major players in international development (the World Bank happens to by a major funder of the CGIAR) were eager to move beyond the “rice wars” and further evaluate the potential of SRI as one technology for improving the livelihoods of resource poor farmers.

IRRI, to their credit, realized that their early reactions to SRI did not reflect well on their credibility. Knee-jerk publications with titles like “Agronomic UFOs” and “Curiosities, nonsense, non-science and SRI,” rather than putting the controversy to rest, fanned the partisan flames and legitimized the fears of SRI proponents that IRRI was ignoring their contribution without doing its own due-diligence. Indeed, discussions with Professor Uphoff and other proponents of SRI regularly descended to the semi-conspiratorial, where funding opportunities were rumored to have been declined to SRI researchers to prevent them from proving the value of SRI in a more scientifically rigorous manner. SRI proponents even occasionally suggested that when SRI trials were conducted by IRRI researchers or by researchers within National Agricultural Research Systems (NARs), that the outcomes were purposely sabotaged to ensure that no positive data about SRI became mainstreamed. More problematically, the virulent reaction of IRRI to SRI did little to assuage the concerns of outside observers that IRRI was purposely sabotaging SRI. It also put SRI into the same narrative as genetically modified crops (GMOs), with SRI standing in direct juxtaposition to GMOs, thereby gaining the sympathies of a wide variety of organizations opposed to GMOs.

IRRI decided that it needed a more nuanced approach to SRI and in 2014 it developed a website that addressed SRI without directly criticizing the technology (IRRI, 2014). IRRI’s website has five pages devoted to their official interpretation of SRI. They say that SRI “is an evolving set of practices, principles, and philosophies aimed at increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients". And indeed, this definition of SRI would not be controversial amongst proponents of SRI. A few sentences later, IRRI makes an interesting epistemological move, essentially bringing SRI underneath the umbrella of BMPs already advocated by IRRI:

> Offering farmers a menu of practices that are science-based, have a solid track record of performance, and that can be tested, adapted, and integrated by farmers locally, is a powerful mechanism to bring improvements to their production systems. Such a menu of practices tallies well with IRRI's approach of offering best management practices as listed in the Rice Knowledge Bank (IRRI, 2014).

By framing SRI as a menu of practices that are science-based, IRRI attempts to move past the heated controversies where SRI was ridiculed as having "no inherent advantage over the conventional system" (pp. 1, Sheehy *et al.*, 2004). Instead, the debate has evolved to a point where IRRI recognizes some of the management practices associated with SRI, but minimizes their novelty or uniqueness. Essentially, the technology that came out of Madagascar according to IRRI was a combination of best management practices that were then codified under the label of SRI.

What IRRI's most recent explanation of SRI fails to grapple with is the fact that both farmers and NGOs around the world have realized benefits from the package of practices associated with SRI that they were not realizing before they learnt about SRI. Whether farmers and NGOs had not been exposed to other improved agronomic practices (e.g. IRRI's BMPs) before being introduced to SRI – either because the BMPs had not been sufficiently promoted in their region, or because there is something specific about SRI that is different than other BMPs – remains unaddressed in their official discussion of SRI.

Here it is important to return to Sheehy's 2004 critique of SRI which concluded that "SRI had no inherent advantage over the conventional system" (Sheehy *et al.*, 2004). The question of course is what is meant by the conventional system? By conventional, Sheehy *et al.* really meant IRRI's BMPs which were used in their field trials. But conventional is an ambiguous word that can easily refer to the methods farmers in a given region use to cultivate rice. Most evaluations of SRI have been done against BMPs, but at least in the case of Bihar, these practices are significantly different from what the average farmer is doing in their own field. Their field trials were thus conducted comparing SRI with IRRI's BMPs and found no advantage of SRI over BMPs (which include expensive inputs such as herbicides and mineral and organic fertilizers). Neither the Sheehy article from 2004, nor the current discussion of the merits of SRI on IRRI's website, addresses the key phenomenon of SRI – whether or not there is something specific about the unique set of management practices in SRI, which themselves are adaptable to local conditions, or whether the SRI movement has tapped an unmet need to improve agronomic practices amongst small and marginal farmers, where traditional knowledge extension efforts have failed. This paper was not designed to elucidate the relative merits of SRI vs. BMPs defined by IRRI, but it is clear that there is something to the SRI movement that has jumpstarted a greater focus on agronomy and management practices, which IRRI has often ignored. Instead, IRRI has been focusing most of their resources on improving seed varieties that can be easily distributed through public and private sector channels, without the need for wide-spread behavior change on the part of small and marginal farmers. This approach serves two agenda's. First, it is a way to improve yields irrespective of the robustness of the local extension system and second, it ensures that crop scientists can continue to pursue high-end laboratory science while satisfying themselves that they are contributing to long-term global food security.

However, for many of the poorest farmers, SRI seems to offer an approach to growing rice that according to many NGOs, researchers, and most importantly, small farmers around the world, improves the well-being of farmers by decreasing input costs and improving yields. Whether this is an outcome of a scientifically unique approach to rice cultivation, or a packaging of best management practices in a way that has made them accessible, transportable, and useful to small farmers, is in many ways unimportant from the perspective of mobilizing technology to meet the needs of the poorest farmers. The unwillingness of IRRI to acknowledge the power of SRI at least as a powerful heuristic for improving agronomic practices, demonstrates their continued need to secure their own knowledge domain, even when their efforts are at best unhelpful to improving the ability of the poorest farmers to benefit from agricultural technology.

3.3.6 Transnational Summary: Three Points of Lingering Controversy

Beginning with the publication of the World Bank's toolkit, the virulent debate diminished, and by 2014, when IRRI published its more even-handed description of SRI on its website, the debate was at a low simmer. People on all sides of the "rice wars" developed more nuanced and specific theories about the benefits of, and science behind, SRI. Scholars who were originally skeptical of SRI writ large, generally began to acknowledge some yield advantages associated with SRI's package of practices, while also developing more nuanced critiques of specific aspects of SRI. One of the main points of continued controversy was over the question of the labor requirements of SRI. Proponents of SRI believed that SRI did not necessarily increase labor requirements, while critics continued to claim that it did. Analyzing the interviews in the World Bank's 2010 SRI toolkit provides a useful window into the evolving terms of the lingering conflict. The themes that emerge from an analysis of these interviews are useful for two reasons. First, they demonstrate the evolving processes of scientific closure as a negotiated sorting out and reframing of arguments and claims on scientific certainty in the technology selection stage of an innovation system. Second, they highlight remaining knowledge gaps, which I further investigate in the empirical work conducted in Bihar in Section 3.5.

The interviews included in the toolkit begin with four farmers. From the start, it is clear that the World Bank is largely sympathetic to SRI technology, as each of the four farmers exclusively discuss SRI as a useful technology. The first farmer, cites both the reduced quantity of seeds as well as reduced labor as the main benefits of SRI, saying “normally, I would need 30 kilos of seed to be used for one acre of land, but with this new process I use 3 kilos of seed for one acre of land.” Additionally, “before, I used 20 laborers, now I use only 10.” The second farmer interviewed in the toolkit is excited by SRI because it both increases yields and reduces labor costs, “with the old method the yield was 20-25 bags for one acre and with the new method I get more like 30 bags.” In addition, “less labor is required because I am using a weeder”. The third farmer interviewed claims that in addition to using less labor and less water, he has improved his fields by about one third. The fourth farmer, claims that SRI requires less labor and improves yields as well as overall plant health: “the new method results in 45-50 tillers per plant all healthy and as a result the yield is increasing. In each of the tillers I used to get 130-150 grains, now I get about 250-3000 grains per tiller. Wider spacing results in healthier plants.”

What is interesting about the text the World Bank chose to include from farmers is that not one farmer discusses any barriers or drawbacks to SRI. Moreover, all four farmers discussed the issue of labor and claimed that SRI methods required less labor. Because the labor demands of SRI had emerged as a key issue in the controversy over the economics of SRI, by including four farmers, all claiming that SRI requires less labor, the World Bank foregrounded this issue and highlighted the seemingly unimpeachable voices of farmers claiming that, in fact, SRI did not require more labor.

The next three interviews in the World Bank Toolkit were from researchers on different sides of the debate, including Dr. Norman Uphoff, discussed at length earlier in the chapter; Dr. Amir Kassam, a Professor at the University of Reading in the School of Agriculture, Policy and Development, who had published at least three journal articles in favor of SRI; and Dr. Achim Dobermann, the soil scientist and agronomist at IRRI who published “A critical assessment of the system of rice intensification” in the journal of *Agricultural Systems* in 2004 (Dobermann, 2004) and coauthored “Fantastic yields in the system of rice intensification: fact or fallacy?” (Sheehy *et al.*, 2004) which concluded that “SRI has no inherent advantage over the convectional system and that the original reports of extraordinary high yields are likely to be the consequence of error" (pp. 1).

The interview with Professor Uphoff addresses the controversy in the first question, with the interviewer asking, "Why is there resistance to the acceptance of SRI?" Professor Uphoff responds that "SRI is really a paradigm shift from an earlier understanding of how we can get the most out of rice crops. … The Green Revolution was very successful and had a very simple paradigm which was you improve the genetic potential of the crop and then you add extra inputs, more fertilizers, more water, more agrichemicals and so forth. And it works." The alternative paradigm of SRI is one where you change the "soil, the water and the nutrients to get a better phenotype from any genotype. And so, it is a whole different approach to the way in which we can nurture and benefit from crops."

In framing the debate as a paradigm shift, Professor Uphoff essentially makes the claim that the scientific principles that undergirded the Green Revolution, namely the improvement of crop genotypes through breeding, may not be sufficient to understand the benefits of SRI. At the same time, he aligns SRI with an entire worldview that is already amenable to low-input agriculture and especially those groups that are weary of genetically modified crops. He also tunes into a much broader literature on scientific revolutions that is likely to be familiar to many of his colleagues, who are sympathetic to critiques of mainstream science. Thomas Kuhn's 1962 "The Structure of Scientific Revolutions" (Kuhn, 1962), which argued that normal scientific progress usually proceeds linearly through "development-by-accumulation" but occasionally, the conceptual continuity of normal science is interrupted by periods of revolutionary science in which fundamental "paradigms" change, forcing scientists to re-investigate old assumptions and fundamentally re-directing the course of scientific research. Kuhn's book is very famous. Currently in its fourth addition, it has been cited more than ninety-eight-thousand times according to Google Scholar and is especially well-known in Science & Technology Studies (STS), a field that is also well-integrated into alternative development movements, like the Farmer First Movement (Chambers, Pacey and Thrupp, 1989; Scoones and Thompson, 2009). By framing SRI in these terms, Uphoff argues that this technology, developed not by formally trained scientists but by farmers and civil society in Madagascar, has the potential to revolutionize our approach to agricultural science, all while raising yields, reducing inputs, and making agriculture more resilient in the face of climate change. Moreover, by employing Kuhn, Uphoff is shielding himself and SRI against the claims of the established rice research community who argue that his claims about SRI are impossible according to established rice science.

When Uphoff was asked about the question of labor intensity of SRI, he replied that “when we first started working with SRI, we were working in Madagascar where farmers found the methods to be fairly labor intensive requiring more work per hectare to get their result.” Uphoff continued that despite the apparent labor intensity of SRI, that SRI’s benefits still outweighed the increased labor costs, saying “we accepted that this is a labor-intensive technology but that is the price you pay to save water, to save seeds, to have higher yields and so forth.” But as Uphoff and his colleagues gained more experience with SRI with a wider variety of farmers, under a wider variety of conditions, he became convinced that SRI was not necessarily more labor intensive. Some farmers in Madagascar, for example, started telling Uphoff’s research team that “after the second or third season it started saving labor.” Based off of the experience of GTZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) in Cambodia in 2004, Uphoff continues that “if you look at the SRI farmers, some are new farmers some are experienced farmers. And the new farmers they take 10-20% more labor per hectare for their results. But once farmers get used to the methods and technologies and acquire both skill and confidence, it’s less labor.”

A separate interview with Dr. Willem Janssen, Senior Agricultural Specialist at the World Bank, who was involved with the Bank’s own SRI project, provides perhaps the most useful insight on the labor question. He explains that there are big differences between SRI and farmers’ traditional practices in terms of when in the cropping cycle labor demands peak. The implications of Janssen’s insight is that changes in the temporal patterns of labor intensity of rice cultivation not only require individual behavior change on the part of the landowner, but often require community wide behavior change as rice cultivation is almost always done either with hired-labor for wealthier farmers, or with shared community labor for the poorest farmers, who exchange labor between households.

Towards the end of the interview, when Uphoff is asked if there are any downsides to SRI, he claims that there are none, “when we started we were sure that there had to be some downsides to this. I mean I have worked in the development for 40 years and nothing is ultimately as good as it appears at first. At first as I said we thought that labor intensive [of SRI] is going to be a sticking point but that has not proved to be the case.” Uphoff continues, that the only potential downside is that increased yields might reduce market prices, but of course this is a risk with any technology in the agricultural sector and therefore cannot be viewed as a critique of SRI as much as evidence of its success. Uphoff continues, that “I have been looking for the negatives, we are not afraid of them. First of all, we have got so many positives that we can certainly absorb some negatives but I just haven’t seen them.” He concludes his response to the question about drawbacks by listing even more positive attributes of SRI, “on top of our paddy yields, we get 15% more milled rice because there are less breakage of grains and less chaff. That’s the unfilled grains in the paddy. So, see that is really a nice bonus. We find that the crops mature one to even three weeks sooner which means we use less water for irrigation and we also have land freed up for vegetable and other crops.”

Professor Uphoff’s response to the question of downsides to SRI is exactly the type of response that has driven many of his critics to openly disparage SRI. The idea that any technology could have no drawbacks seemed to many agricultural scientists either naïve or willfully disingenuous. One mainstream agronomist I interviewed in India, who asked to remain anonymous, told me they thought Professor Uphoff wanted to save the world, and when he was unable to do this as a political scientist, he went out and found a technology that he imagined could save the world, and he has been fighting to realize his dream ever since, with no regard for the actual facts.

The World Bank's Toolkit continues with an interview of Dr. Dobermann. When Dr. Dobermann is asked about his reservations about SRI, he directly counters Professor Uphoff's claims that SRI is a paradigm-shifting technology. Instead, he says that "it is important to understand first what SRI means. It is essentially a set of management practices, nothing else." The interviewer follows-up, asking "are you saying that SRI is simply a set of good management practices?" and Dr. Dobermann replies that "some of them [SRI management practices] are the same we recommend, some of them I think are unnecessary or are very difficult to implement by farmers. … We don't call it SRI, we call it good management practices or best management practices or recommended management practices". Dobermann continued that "if you compare SRI with what we would promote as a best management practice, there is no significant difference."

In so doing, Dobermann is making an argument that would later be made on IRRI's website—namely that there is nothing specifically unique about SRI—it's just one set amongst many of good management practices. This is an interesting rhetorical move because it moves IRRI away from the controversy, while ensuring that SRI receives very little credit as a novel innovation worthy of funding.

At the same time, Dobermann dismisses SRI as simply "good management practices" he also makes a second interesting point that "I have often seen in these [positive] reports on SRI, is SRI being compared in farmers' fields against something that is called conventional management. What is called conventional management has nothing to do (or very little to do) with what we would consider being a best management practice. What I am trying to say is that "yes," if you implement these practices very carefully you will get pretty good rice yield but we know we can achieve that." This argument, that SRI is not particularly interesting because its being used in farmers' fields to get yields similar to what IRRI can do with its BMPs, is also illuminating because while Dobermann is using the argument as a strike against SRI, most development professionals would consider a technology that closes the yield gap between what expert agronomists are achieving and what resource poor farmers are achieving, as a highly promising technology, rather than something worthy of dismissal.

Finally, directly contradicting Uphoff, Dobermann argues that that the dynamics of labor in SRI are complex and highly contingent on the expertise of the farmer practicing SRI. Instead, Dobermann argues that "we have strong reservations in terms of the claims being made about the general applicability of SRI. Because it is a very labor intensive practice, it is a very knowledge intensive practice." He continues, "[t]here are many rice cropping systems in the world where it will be next to impossible to convince farmers to use management practices of the labor-intensive kind that the SRI represents." He concludes, almost as an afterthought, that for the poorest farmers "where plenty of labor is available" SRI may have some value. In framing his argument around SRI and labor around the average socioeconomic trends of rice farming towards mechanization and away from labor intensity, he almost completely dismisses the potential value of the technology for one specific group of farmers – the poorest farmers – whom IRRI, especially under the millennium development goals (MDGs), should be particularly concerned with.

A third issue that is raised repeatedly throughout the interviews in the World Bank's toolkit is that of water. Uphoff addresses the dynamics between SRI practices and water in his comments. He explains that with SRI "you have to ensure that the soil is not continuously flooded, not hypoxic, not suffocating the plant roots and the soil organisms." In order to do this, it is "very critical to get enough water but not too much." Janssen from the World Bank goes a step further and points out that irrigation infrastructure is actually integral to the adoption of SRI, because "water must come at different moments and that might be one of the more difficult things to manage [in SRI]." Janssen continues, that "many irrigation systems in India work with quite big bulk delivery of water. So, at a certain moment the canal opens up, the water starts coming out. Farmers have water for a day or two and then it stops again in the gravity systems. An important aspect for SRI systems would be that the amount of water that arrives at the farm must be smaller, but it should come more often." These changes Janssen points out would be substantial changes for many irrigation systems in India.

In summary, there are three main areas of continued controversy and knowledge gaps that come out of a close reading of the World Bank's toolkit. First, while SRI reduces overall water requirements for rice cultivation, farmers practicing SRI still requires access to water and specifically, more flexible control over when and how frequently they water their fields. While Dr. Janssen sees this as a major concern for widespread adoption of SRI, Uphoff does not cite this amongst the drawbacks of SRI, which he claims do not exits. But from a sociotechnical perspective on innovation, if the irrigation infrastructure does not fit the requirements of the technology on the ground, then there will be major barriers to widespread use of SRI. In Section 3.5, we will see that this issue plays a major role in limiting widespread use of SRI in Bihar, and more importantly, that the relationship between access to irrigation and success of SRI in Bihar is mostly overlooked by the government programs attempting to rapidly scale the technology.

Second, the World Bank's toolkit highlights the continued controversy over the labor dimensions of SRI. While SRI's proponents (and some more dispassionate observers) argue that although SRI requires more labor in the initial years as farmers learn a new skill-set, after two to three years SRI is either labor neutral with farmers' pervious management practices, or even reduces labor requirements. However, the labor debate, even in 2018, is still far from settled. This is at least in part because there are so many variations in how, and by whom, the labor is performed. With the variations, including those by country and region, it becomes almost impossible to have a definite and generalizable resolution to the labor question. I will discuss these themes further in Section 3.4, as this issue emerges as a central point of contention in controversy around SRI at the local level in Bihar.

Finally, and perhaps most existentially, the World Bank's toolkit highlights continued controversy over the degree to which SRI is a new technology with emergent prosperities, that make the specific set of management practices embodied in SRI technology more than the sum of the parts. Or alternatively, whether SRI is nothing more than a re-packaging of management practices that have all individually been around for decades, if not centuries, and included in various BMPs or historical rice cultivation methods. While this aspect of the continued controversy may seem almost irrelevant – after all, as long as SRI methods benefit farmers does it matter exactly when they were invented – I will argue that the controversy is demonstrative of a tendency on the part of the established rice research community to overlook an important aspect of the SRI phenomenon. Namely, whether or not SRI is something entirely novel or not, the SRI movement both in Bihar and other parts of India has catalyzed farmers to adopt improved agronomic practices, both in rice cultivation as well as across a wide spectrum of crops. In this sense, SRI has been a powerful sociotechnical phenomenon for changing farmers' behavior in an aspect of agriculture that is relatively knowledge intensive. That IRRI agronomists would choose to overlook the importance of an approach to changing farmer behavior that has proven to be effective (irrespective of the scientific underpinnings of the approach), is indicative of siloed and disciplinary thinking within the rice research community, that is a barrier for reorienting agriculture innovation systems towards the needs of the poorest farmers.

3.4 Selection of SRI at the Local Scale

While the transnational debate around SRI was taking place in research journals and conferences, a similar debate was simultaneously occurring at the national and local levels, around the world. This section specifically looks at the selection of SRI in Bihar, one of the poorest states in India. The section focuses on the mechanisms that drove the selection of SRI in Bihar as well as the controversies surrounding SRI in Bihar, which both mirror and shed light on the controversies at the transnational level.

Some of the same actors that appear in the transnational story also play an important role in Bihar. Both Norman Uphoff and Achim Dobermann engage at times at the local level in Bihar and the experience of SRI in Bihar is channeled back into the transnational discussion through features in international newspapers like *The Guardian* (Vidal, 2013) and *The New York Times* (Kumar, 2013).

The history of SRI in India was meticulously documented through 2006 by Professor Shambu Prasad at the Xavier Institute of Management in Orissa (Prasad, 2006).[105] SRI was first introduced in India around 1999 through multiple pathways that all had their roots in civil society and left-leaning community organizations. It first attained more widespread use in southern India, including Tamil Nadu, Andhra Pradesh, and Karnataka in the first decade of the 21st century. In 2010, the SRI-India network in collaboration with WWF, surveyed members of the growing network of SRI practitioners in India and estimated that the technology had been introduced in at least 30 of India's 36 States and union territories. By another metric, SRI had been introduced in 246 out of 564 rice-growing districts in India.

However, most adoption of SRI through 2010 had been facilitated by NGOs, international donors, and academic research institutes with only minimal support from either state or central government. That would change in 2011, when the state of Bihar in eastern India decided to incorporate SRI as a central component of its agricultural strategy. The formal selection of SRI by the state government in Bihar led to my decision to use the state for my case study. In this section, I focus on understanding selection mechanisms for SRI at the state level, including ways in which conflicts over SRI at the state level mirrored the transnational debate. In section 3.5, I evaluate the performance of SRI as a "pro-poor"

[105] It is worth noting that the research for this report was funded by WWF which is listed before the Xavier Institute of Management in the publication details. When I visited Professor Prasad at his university in Orissa in the summer of 2011, I met a man deeply committed to SRI and who like Professor Uphoff had been deeply shocked by virulent debates around SRI in 2004. This project was a clear response to those debates and an effort to catalog every detail of this history of SRI in India to ensure that its successes and the people responsible for those successes were not forgotten in the debate. In many ways, Professor Prasad was not unlike Professor Uphoff – so convinced by the promise of SRI and so incensed by the reaction of the established rice research community to the technology that he devoted a considerable amount of time and effort to the documentation of every facet of the technology and its history in India and was willing to meet with anyone who he felt he could bring to his side.

technology in Bihar, focusing specifically on some of the lingering controversies identified in the analysis of the World Bank's Toolkit.[106]

3.4.1 Initial Selection of SRI in Bihar

While there are some reports of initial experiments with SRI at Bihar's Rajendra Agricultural University (RAU) as early as 2004, there is limited documentation or information about what was done. The first documented promotion of SRI outside RAU was during the monsoon season of 2007. Anil Verma, a rural livelihoods development professional with the NGO Pradan, opened a satellite Pradan office in the city of Gaya that year and began teaching SRI practices in a single village. He was so impressed with the performance of the technology and its potential to help the poorest farmers in Bihar increase their yields without investing in expensive technologies, that he eventually started his own NGO exclusively focused on the promotion of SRI, which he called PRAN (Preservation and Proliferation of Rural Resources and Nature).

After the first year of success, Anil began to invite local political figures and agriculture specialists to observe the high yields farmers were getting with SRI in the villages where he worked. The farmers he worked with reported doubling their yields using SRI methods, while also saving money on input costs because SRI required fewer seeds per acre. Though many of Anil's initial visitors from the government and Indian agriculture research centers were skeptical of SRI, conversations with the farmers practicing SRI in these villages changed their perceptions.

[106] Note that I discuss Bihar at length in Chapter 2. I will thus leave important background out of Chapter 3, assuming that readers can access this information in Chapter 2.

3.4.2 SRI as a Political Agenda: Government Support for SRI in Bihar

Interestingly, while the selection of SRI as a "pro-poor" technology at the transnational scale was the product of a large network of actors across NGOs, donor agencies, and academic departments, the selection of SRI at scale in Bihar was a highly centralized and top down affair. Except for the small group of NGOs who promoted SRI between 2007 and 2010, the technology was not widely known in Bihar. That all changed between 2010 and 2011, when Nitish Kumar, the technocratic Chief Minister of the State, designated 2011 the official year of SRI in Bihar, launching a plan for a "*SRI Kranti*" or "SRI Revolution." Nitish declared that SRI would help make Bihar a "rice basket" for India. He followed up his rhetoric with real funding. The 2012-2017 Agriculture Road Map allocated substantial financial support to promote SRI amongst Bihar's farmers. The total budget for SRI promotion was 144 million dollars, which was approximately 8% of the total budget allocation in the 2012-2017 Agriculture Road Map of 1.8 billion dollars (see Table 3.2).[107]

Table 3.2: SRI as portion of total budget for 2012-2017 Agriculture Road Map.
In totality, SRI receives 7.9% of the 1.8-billion-dollar investment over the five-year plan - 144 million dollars.

Spending Category	2012 - 13	2013 - 14	2014 - 15	2015 - 16	2016 - 17	2012-2017
System of Rice Intensification subsidies and extension	9.6%	8.9%	7.9%	6.9%	6.3%	7.6%
Conoweeder or Weeder Technology	0.5%	0.3%	0.2%	0.2%	0.1%	0.2%
Budgetary spending on System of Rice Intensification as a proportion of total agricultural budget	10.1%	9.2%	8.1%	7.1%	6.4%	**7.9%**

[107] As discussed in Chapter 1, the 2012-2017 Agricultural Roadmap outlined a broad and ambitious strategy for improving agriculture productivity and ameliorating rural poverty in the state. As a sign of the Chief Ministers technocratic ambition, Bihar's roadmap was the first state-level agriculture sector road map in India.

The subsidy package for SRI provided by the government is not a monetary reward for following SRI methodologies, but rather a subsidized kit of inputs, including of 2kg of seeds and 3kg of fertilizers per subsidy recipient. This subsidized kit is designed to be sufficient to cover one acre of land using SRI methods. In some cases, *conoweeders* are also provided through the subsidy program (though the rule for which farmers receive a *conoweeder* was never entirely clear, and while the government claimed that all recipients of the subsidy received *conoweeders,* in fact, many farmers who got the subsidy claimed to have only gotten seeds and fertilizer). The number of subsidy kits available is also limited on a geographical basis with approximately 1,000 kits available in each administrative block. There are a total of 534 blocks in Bihar, with an average population of 350,000 households per block, meaning that the SRI subsidy package is only available to a fraction of the households in any block.

In a resource-constrained state, with a minimal tax base which relies heavily on support from the central government in New Delhi (Singh and Stern, 2013), 144-million dollars is a substantial amount of money to earmark for a technology that in 2012 (and even today), remains controversial amongst many experts both transnationally and within India. This raises the important question of why Nitish selected SRI as such a central part of his Agricultural Road Map, when technologies with more proven track records were widely available.

While many of Nitish's advisors visited villages where SRI was practiced and were clearly convinced that the technology had the potential to benefit Bihar's farmers, there were also important political considerations that led Nitish to select SRI so quickly and earmark so much financial support to promote the technology. Unlike most of the other technologies in the Agriculture Road Map, SRI came pre-packaged in a narrative that was extremely attractive to Nitish Kumar. This narrative included two elements. First, SRI could be promoted as a specifically "pro-poor" technology and given that the vast majority of Nitish's voting base consisted of the rural poor, promoting such a technology had real political advantages for his electoral strategy. Second, SRI was also a technology that could bring Nitish the type of recognition he craved from the central government (in 2012, Nitish still had his eye on the Prime Minister's seat). I discuss both of these elements in more detail in Sections 3.4.2.1 and 3.4.2.2 below.

3.4.2.1 SRI as a "Pro-Poor" Electoral Strategy

As Nitish approached his second election in 2010, there was a clear need to appeal to the rural poor who made up the majority of Bihar's electorate. SRI presented a powerful opportunity to showcase Nitish's commitment to this group because the technology already had symbolic value as a "pro-poor" technology, both internationally and increasingly, amongst the poor farmers working with PRAN to adopt the technology.

Nitish capitalized on the "pro-poor" symbolism of SRI by bringing onto his 2010 election ticket a female SC farmer who was an early adopter of SRI, Jyoti Devi (Jha, 2011). Jyoti Devi came from a particularly disadvantaged scheduled caste known as the *Musahars,* who are infamous amongst Bihar's higher castes for eating rats as part of their diet. In fact, an article that ran in the Times of India about Jyoti's election was even titled "Beyond the Rat Race" (Times of India, 2010). This article is particularly revealing in the way it described how Jyoti became part of Nitish's election ticket in 2010. From Jyoti's description, she was essentially plucked out of thin air to be on the ticket, making it clear that Nitish had sought out her candidacy for the things she symbolized – lower caste empowerment, female empowerment, and the potential of SRI to transform the well-being of the poorest farmers.

Jyoti embodied the power of SRI to transform the well-being of the poorest farmers in Bihar in her election campaign (Devi, Jyoti, personal interview, August 2011). She won her seat in the 2010 election and remains a member of Bihar's Legislative Assembly (MLA) in the lower house. Since then, she has continued to champion SRI amongst her constituents and she continues to work with PRAN. Indeed, today when PRAN has a political problem, Jyoti Devi is often the first person that Anil reaches out to in order to find a solution.

For Nitish, his support of Jyoti Devi served as a living symbol of his commitment to female empowerment and the needs of the rural poor. Jyoti's place in his political party after the election continued to underline the fact that so much of the funding in Bihar's Agriculture Road Map was allocated for the "pro-poor" technology she pioneered.

3.4.2.2 SRI as a Geopolitical Strategy

A second key factor motivating the significant political and financial resources allocated to SRI by Nitish had less to do with local politics than with national, and even global, politics. In 2010, when Nitish began the process of selecting SRI, the reported yield increases rivaled some of the highest rice yields achieved anywhere in India. The ability of Bihari farmers to compete with the yields of India's major rice growing regions, including West Bengal and Punjab, showcased Nitish Kumar's technocratic bonafides.[108]

The value of SRI as a symbol of Nitish's broader achievements in developing Bihar's agriculture potential came in 2012, when a small farmer in Nalanda district, Sumant Kumar, reportedly harvested 22.4 metric tons of paddy from a single hectare of land, breaking a world yield record held by a farmer in China (Ahmad, 2013). Fueled by competitive geopolitics, Sumant's agricultural achievements garnered widespread domestic and international attention. His yield record was reinterpreted as a triumph for Bihar's chief minister and for the country as a whole (Krishnan, 2013; The Times of India, 2013; Vidal, 2013; Times of India, 2014). For his achievements, Sumant was awarded a prize in New Delhi by the Union Minister of Agriculture (Nadimi, 2012).

[108] Recall from Chapter 2 that when Nitish Kumar took over leadership of the state, it was seen by many as India's most under-developed state. Moreover, over the past five decades, Bihar had witnessed the slowest agriculture growth rate of any state in India (Kishore, Sharma and Joshi, 2014)

The geopolitical importance of Sumant's yield record is underscored by two facts. First, widely read articles on Sumant's yield record, and the transformation of Bihar's rice production through SRI were written in both *The Guardian* (Vidal, 2013) and in *The New York Times* (Kumar, 2013). This leant both international credibility to Nitish Kumar's efforts, and much needed visibility on the international stage, for a politician with national political aspirations. Second, the yield record was swiftly contested by the Chinese government, as well as the farmer who had previously held the global yield record, Yuan Longping. Longping, known as the father of hybrid rice in China, had claimed the yield record prior to Sumant's claims, and he quickly responded that the yield record in Bihar is "120 percent fake," despite having published positively about the potential of SRI in the past (Krishnan, 2013). Nonetheless, Sumant was inundated with domestic and international visitors (including delegations from China), hoping to learn more about how a poor Bihari farmer achieved such high yields

In addition, Sumant's reported yield record inserted Bihar into the transnational debate over SRI. In response to the yield record, Achim Dobermann published a blog post on IRRI's website titled "Another new rice yield record? Let's move beyond it" (Dobermann, 2013). Dobermann's response was critical of the widespread support for SRI in Bihar without the "scientific evidence" to back up claims of SRI's potential, "we need to concentrate our efforts on actionable solutions that are science-based and tailored to the local situations and needs."[109]

3.4.5 Selection Controversies at the State Level

Since the selection of SRI in 2011 as a major component of Bihar's Agriculture Road Map, the Government of Bihar has labelled the SRI program as an unqualified success. In public statements, government officials have causally attributed overall increases in paddy yields in the state to the adoption

[109] In highlighting the importance of tailoring solutions to the local situation, Dobermann in fact hits on one of the key challenges to the Bihari government's massive SRI program, which as I will demonstrate in Section 3.5, largely fails to live up to its reputation and potential.

of SRI by farmers (Times of India 2013). In 2013, Bihar's agriculture production commissioner, Alok Kumar Sinha, said that "SRI requires less water and gives 2-3 times the yield compared to traditional cultivation of rice" and "is set to change the face of paddy cultivation in the state as thousands of farmers have been adopting it following encouraging results" (Business Standard, 2013). A report published by the GoB's Finance Department in 2015, directly credited the adoption and widespread use of SRI as the causal driver behind increased paddy yields since 2011. It stated that "because of the use of new 'SRI' technique and new agricultural implements, there was an enormous rise in rice production" (Government of Bihar, 2015).

According to the GoB, in addition to SRI's benefits in terms of increased yields, the technology also has a second important physical dimensions in the drought-prone state – SRI not only requires less water in general, but it can also help farmers withstand drought. During a year where droughts affected many of Bihar's districts, the Principal Secretary of Agriculture for Bihar, A. K. Sinha, credited SRI with helping farmers overcome the drought, saying in the *Times of India* that farmers planting with SRI methods would not be affected by the drought because SRI requires less water for irrigation (Dayal, 2011).

However, not all experts in the state are as excited about SRI as the government. For example, in conversation over tea during a conference at Rajendra Agricultural University (RAU), Bihar's premier agriculture research institute, a group of agronomists told me that they believed the government's figures for SRI adoption were inflated by as much as 75%. They believed that the data on increased paddy yields statewide was likely true, but that the causality had been misattributed. While they were not sure all of the reasons that yields had risen, they credited improved access to higher quality seeds, as well as favorable monsoons, as two likely factors that led to improved paddy yields in 2011 and 2012.

These same agronomists argued that the Bihari government should shift some of the funding out of SRI and towards a different approach to rice cultivation – direct seeded rice cultivation (DSR). Of course, this recommendation also aligned with their own professional incentives, given that they were conducting research on direct seeded rice. They had taken multiple meetings in Bihar's capital, Patna, to convince the government to shift funding out of SRI and towards DSR. And according to news reports, their advocacy is being heard in Patna where in 2015, the government increased funding for DSR (Fernandes, 2015).[110]

The agronomists even showed me a summary of a study which they claimed "proves" that DSR is superior to SRI. The study these agronomists showed me is worth discussing in some detail. While it had not been formally published in a peer-reviewed journal, a summary of the study is available in a report from the Borlaug Institute for South Asia (BISA), a research center near RAU, funded by the CGIAR where many of the scientists have dual-appointments (Borlaug Institute for South Asia, 2015). The summary is short and excludes many of the important details one would need to properly evaluate its credibility, but a few things stood out that I discussed with my colleagues at RAU.

The BISA study found that while in upland conditions SRI led to the highest yields (as compared to DSR and locally traditional techniques), the net return of SRI was lower than for either DSR or traditional methods, and in lowland conditions they found that the net returns for SRI were negative (Borlaug Institute for South Asia, 2015).

While the underlying data for the study has not been published, I asked the agronomists how they came to these figures that have already begun to influence policy in Bihar. I found that their calculations about net profits are driven by their assumptions about higher labor demands of SRI. The main issue is quantifying the additional labor required under SRI. Many evaluations of SRI have found that SRI methods require additional labor-hours (Moser and Barrett, 2003); however, as discussed in section 3.3, proponents of SRI contend that after an initial period where new farmers adopting SRI must learn new

[110] Incidentally, in January 2016, I observed local extension agents demonstrating DSR to farmers in Gaya district. While there is not space here to discuss DSR in detail, suffice it to say that this technology is not appropriate for the poorest farmers. It requires a fairly large tractor and upfront investments in herbicides.

skills, that the labor investments are similar or less than traditional management practices. Many farmers I spoke with in Bihar, agree with this assessment.[111] If this is true, then the study's calculations for net profit are fundamentally flawed. However, even assuming that SRI does require some additional labor to traditional management practices or DSR, their calculations may still be wrong. This is because they used a figure for the value of a day of labor far above the actual wage-rate most farmers receive in the state.

To estimate the daily agriculture labor wage, they used the wage-rate stipulated by the *Mahatma Gandhi National Rural Employment Guarantee Act* (NREGA) which at the time in Bihar was approximately USD 2.50 per day. However, many farmers, and especially female farmers, report not having access to NREGA opportunities, and where NREGA work can be found, laborers often do not receive the full daily wage due to corruption (Dutta *et al.*, 2012; Liu and Barrett, 2012). Instead, based off of data I collected in the 11-village survey, my estimate of the regularly available daily wage for agricultural labor is approximately USD 1.00 per day – less than half of the wage rate used in the BISA economic evaluation of SRI. Not only does the inflated wage rate used by the BISA report's authors undercut their empirical findings that SRI compares negatively with DSR and traditional practices in terms of net profits, it also demonstrates that the authors are out of touch with the realities facing Bihar's farmers, where lucrative off-farm employment opportunities, especially for women, are limited.

[111] While my own field survey did not focus on solving the question of labor requirements SRI, I did find that, in 15 focus groups with SRI practitioners supported by, when asked about the labor requirements of SRI, no focus group said that the labor involved in SRI was significantly more arduous or time consuming than their former management practices. Focus group respondents overwhelmingly said (all 15 focus groups) that in the first year of practicing SRI, the new skills required increased time and attention to detail, but after they had mastered the SRI skill set, the consensus was that the labor required to plant using SRI methods was either the same as their earlier management practices (eight focus groups) or that SRI actually decreased the labor intensity of rice cultivation (seven focus groups). However, in the additional eight focus groups I conducted with randomly selected SRI practitioners, I found a wider range of responses. In five of these focus groups, increased labor costs were raised as an impediment to SRI adoption. However, in most of these discussions it turned out the claims of higher labor costs were usually associated with the need on the part of larger farmers to hire labor for transplanting the paddy crop from the nursery into the main field. Some larger farmers (especially those farmers who had received a government subsidy for SRI) were unable to find labor willing to use SRI methods. Overall, it was not clear that any of the farmers actually felt that SRI increased overall labor as measured by man hours, but for many larger farmers the transaction costs of finding laborers willing to deviate from traditional transplanting practices is not worthwhile.

In summary, just as at the transnational level, actors at the local level in Bihar contested the benefits of SRI. Both the proponents of SRI (especially the government) as well as the critics, were guilty of selecting SRI (or critiquing SRI) based more on their own professional incentives than on the actual merits of SRI as a strategy for helping the poorest farmers in Bihar. In fact, the actual performance of SRI as a "pro-poor" technology (beyond the strong results demonstrated by farmers working directly with NGOs) remained largely unknown and un-studied in Bihar, even in 2015 when the BISA report was published.

3.5 Evaluating Success of SRI as "Pro-Poor" Technology in Bihar

SRI was selected by Bihar's government as a "pro-poor" technology that could help Bihar's poorest farmers improve their yields and withstand drought. Since the official selection of SRI in 2011, the government has declared SRI a success and a causal factor leading to Bihar's yield improvements in paddy. Bihar's reported success with SRI has also been championed internationally in the *Guardian* and the *New York Times.* The well-known NGO, Ileia, which aims to provide alternatives to Green Revolution technology, highlighted Bihar's success with SRI in 2013, in an article written by Anil Verma from PRAN in their quarterly magazine, *Farming Matters* (Verma, 2013).

Surprisingly, for a government program with such a large budget targeted at promotion of a controversial technology, and in a state where multiple development research organizations are actively working (e.g. The Jameel Poverty Action Lab (JPAL), IDinsight), relatively little independent information is available on the successes and failures of SRI in Bihar. While I was in Bihar, JPAL was in the midst of conducting an evaluation of the effectiveness of training videos from the NGO Digital Green, which taught farmers about the methods involved in SRI. However, the assessment was focused on the value of videos as an extension methodology and not on evaluating SRI as a technology. Nonetheless, it would have provided some useful insights on SRI in Bihar. Unfortunately, the project seems to have languished and data collection was never completed.

Without better data, what is known about SRI comes from government figures which many experts believe are exaggerated (recall the experts at RAU think they are inflated by as much as 75%). The lack of better data leads to potentially spurious causal claims about the benefits of SRI. For example, in Anil's article on SRI for Ileia he said, "[d]uring the 2011-2012 season the state's statistics showed 335,000 hectares of SRI rice, involving thousands of families. The total production of paddy in Bihar, 7.2 million tons, broke the previous state record of 4.6 million tons. Much of this increase has come from SRI fields, where the average yields are around seven tons/ha" (Verma, 2013, p. 44). Here, Verma makes a large assumption when he claims that the adoption of SRI on 335,000 hectares is responsible for the overall increase in paddy production in the state of more than 50%. Even if the 335,000 figure is credible (which it may not be), this figure is only 10% of Bihar's 3.2 million hectares under paddy cultivation. The idea that changing cultivation practices in only 10% of the total paddy could raise overall paddy production by more than 50% strains credibility. But more problematically, there is simply a lack of verifiable data, either from 2011 or later years, substantiating the governments claims about SRI. When I asked a lower-level staff member in the Department of Agriculture about the methodology behind the government's adoption data, they suggested that they used the quantity of subsidy provided as a proxy for overall adoption. However, the likelihood that there was both "leakage" in funding for the SRI subsidy program and that not all farmers who received the subsidy actually practiced SRI, is very high. This means that GoB's estimates of SRI adoption by farmers in Bihar are suspect.

Apart from the incomplete JPAL evaluation, two reports and one journal article looking at SRI in Bihar have been published— all three since 2016 (Pandey, 2016; Sethy *et al.*, 2016; Waris, 2017). These three articles provide interesting and complementary insights to my own data collection and I include their findings in addition to my own in this section, evaluating the performance of SRI in Bihar.

My own evaluation is based on the 11-village field surveys and the 23 farmer focus groups, in addition to months of emersion in Bihar's agriculture system. The evaluation sheds light on multiple important sociotechnical dynamics that mediate the relationship between the physical and institutional characteristics of SRI in general, and the benefits the poorest farmers in Bihar realize from SRI.

My overall findings (detailed below) are that SRI is providing important benefits to some farmers in Bihar. However, adoption is likely not as widespread as government figures suggest. Moreover, the benefits of SRI have largely accrued to wealthier farmers, undercutting the government's "pro-poor" claims about SRI. In addition, the government's statements that SRI has helped Bihari farmers overcome draught is also highly suspect, because the biggest reason farmers give for not adopting SRI is lack of water. Finally, the state's flagship SRI subsidy program is benefiting wealthier farmers at much higher rates than the poorest farmers.

Despite my overall skeptical evaluation of the benefits of SRI in Bihar, there are several areas in which some of the poorest farmers in Bihar have realized clear and unambiguous benefits. First, villages where NGOs rather than the government are the main extension provider are more likely to have proportions of the poorest farmers adopting the technology. Second, farmers who have been using SRI methods for more than three seasons, overwhelmingly report positive benefits from the technology, including higher yields, decreased input costs, and fewer labor-hours. Above and beyond the direct benefits of SRI to adopters, SRI has also led to an interesting cultural shift in Bihar toward a greater focus on the importance of improved agronomic management practices. Indeed, a kind of SRI-phenomenon has encouraged farmers throughout Bihar to think more about the agronomic practices they follow rather than just what inputs they use. This cultural shift, towards more thoughtful agronomy in Bihar, is perhaps the most important impact SRI has had on farmers in the state.

This evaluation is not an econometric assessment of the yield or profit gains associated with SRI in Bihar. Rather, it is a broader sociotechnical evaluation of the adoption mechanisms at work in Bihar, with specific focus on the mechanisms impacting adoption by the poorest farmers. Because SRI benefits the poorest farmers in Bihar only under a limited set of circumstances, the findings shed light on the limits of a technology with explicitly "pro-poor" physical dimensions, when the technology meets the sociotechnical and agroecological realities of local conditions. This finding is of interest, both for its own sake, but also because it sheds light on the larger theme of the chapter – the challenge of technology selection for the poorest farmers. The finding demonstrates how actors responsible for technology selection in Bihar overlook the actual performance of SRI in order to frame a narrative that supports their own political and professional incentives. Below I discuss seven specific findings from my evaluation of the performance of SRI in Bihar.

3.5.1 Limited Overall Adoption, But Adopters Report Positive Benefits

The results of the 11-village survey were surprising in several ways. First, 88% of households had heard of SRI. In many ways, this was an impressive performance for a technology that was only introduced to farmers in the state in 2007 and has been marketed exclusively by the state and NGOs (as opposed to through private sector channels). In some villages, knowledge of SRI in the sample was as high as 100%.[112] In contrast, only 15% of farmers had heard of drip irrigation and less than 1% of the farmers in the 11-village survey had adopted the technology, despite the fact that the technology has been highly subsidized since 2006 (see Chapter 2).

However, despite widespread knowledge about SRI, actual adoption of the technology is not nearly as widespread and data failed to corroborate the government's reports that SRI is transforming rice production across Bihar. Of the 338 households surveyed, only 19% of households (62 households in total) reported practicing SRI at least once. Of those 62 households, 38 households had only used SRI

[112] Villages where knowledge of SRI was between 95 and 100% were either villages close to major roads (where government extension support is more intensive) or in one case in a village where the NGO PRAN operates.

once, 11 had used it twice, eight had used it three times, two had used it four times, two had used it five times, and one had used SRI seven times. In summary, this means that only 7% of all farmers in the dataset (including adopters and non-adopters) had used SRI for more than a single season. These findings call into question the government's claims that SRI is transforming rice productivity across Bihar. Indeed, it is far more likely that increased adoption of high yielding and hybrid paddy varieties, as measured by improved seed replacement rates, play a larger causal part in the improved paddy yield data in the state, with SRI playing, at best, a secondary role (see Chapter 2).

However, the experience of SRI by farmers who have adopted the technology are significantly more positive than the results from the 11-village survey might initially suggest. Out of the 62 households who reported using SRI at least once, 52% of users reported that SRI was very beneficial to their paddy crop, an additional 29% of farmers reported that SRI was somewhat beneficial to their paddy crop, and 19% reported that SRI was not at all beneficial to their paddy crop (see Table 3.3). Moreover — and perhaps unsurprisingly – farmers who reported practicing SRI for more than a single season were much more likely to report higher satisfaction with the technology, with 88% of farmers who used SRI two or more times reporting that SRI was very beneficial to their paddy crop, and 100% of farmers who used SRI three or more times reporting that SRI was very beneficial.

Table 3.3: Evaluation of SRI by adopters from 11-village survey.

Farmers who reported practicing SRI for at least 1 season were asked to evaluate the benefits of the technology on a 3-point scale. Overall 52% of farmers found SRI very beneficial, 29% found SRI somewhat beneficial and only 19% found SRI not at all beneficial.

Caste Category	# Total Adopters	# Very Beneficial	% Very Beneficial	# Somewhat Beneficial	% Somewhat Beneficial	# Not Beneficial	% Not Beneficial
UC	4	0	0%	2	50%	2	50%
OBC	44	23	52%	13	30%	8	18%
SC/ST	14	9	64%	3	21%	2	14%
Total	62	32	52%	18	29%	12	19%

Of the 50 households that found SRI to be very beneficial or somewhat beneficial, most households said that the main benefits of SRI came either in terms of increased yields (42 households) or decreased input costs (32 households). Most households cited both of these factors. Out of the 50 households, a total of 13 households also mentioned increased crop robustness and/or pest resistance of the paddy crop under SRI cultivation practices. Nine households cited reduced labor requirements as a benefit of SRI, however an additional seven households, who claimed that SRI was either very or somewhat beneficial, said that labor requirements were higher than with their previous management practices. Only four households mentioned decreased water requirements as a benefit of SRI. However, in each of these cases, these benefits were in addition to the improved yields or decreased input costs cited by all households who reported that SRI was very beneficial or somewhat beneficial to their paddy crop (note that these numbers were calculated from open-ended responses).

In addition, data from 15 focus groups conducted with SRI farmers supported by two separate NGOs, reported overwhelmingly positive evaluations of SRI. Farmers in the 15 focus groups conducted in communities supported by NGOs reported that SRI increases yields (often by more than 100%) and decreases input costs. Farmers in all but one of the focus groups also reported that SRI yielded more resilient crops that withstood storms and pest outbreaks better than their neighbors plots planted with traditional methods. Perhaps most strikingly, SRI farmers reported improved community level cooperation, though this is more likely due to the design of the extension interventions than to the physical characteristics of SRI technology. Farmers in these 15 focus groups also reported some drawbacks of SRI which I will discuss at greater length in the following sections (3.5.2).

Of the 40% of households in the 11-village survey (n=24) who were unsatisfied with SRI, many reported that they had received insufficient training to properly practice SRI (n=11) and other households reported that they did not see yield benefits (n=9). Many of the wealthier households reported that they were unable to practice SRI because they could not hire labor willing to use SRI practices, but they were also unwilling to pay a wage-premium to their labor for using SRI (n=6).

3.5.2 Benefits of SRI Skewed Towards Wealthier Farmers

Despite perceptions of SRI's widespread success in Bihar, fueled both by the media and the government, a more detailed analysis of the data from the 11-village survey is less supportive of the government's narrative of SRI as a "pro-poor" technology. The results of the 11-village survey showed that the majority of farmers who had used SRI were wealthier farmers in terms of both landholding and caste. Out of the 55 households in the survey with more than a hectare of land (2.5 acres), 42% had used SRI at least once. In contrast, out of the 283 households with less than one hectare of land, only 13% had used SRI. In terms of caste, 14% of UC farmers and 24% of OBC farmers had used SRI, whereas only 8% of SC/ST farmers had used SRI.[113]

The poorest farmers were also the least likely to have heard about SRI, with only 82% of SC/ST farmers having heard of SRI, in contrast to 97% and 97% of UC and OBC farmers respectively. This suggests that the poorest farmers were not being effectively reached by extension services. And indeed, whereas the majority of UC and OBC farmers had heard about SRI through their block level extension officers, the majority of SC/ST farmers who had heard of SRI, learnt about it from another farmer.

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[113] As discussed in Chapter 2, Section 5.2, caste is a useful measure of overall wealth in rural Bihar and has some advantages over landholding measurements. In order to discuss castes, I use the terminology in common use in Bihar to refer to different caste groupings. The caste groupings include: 1. "upper castes" (UC). These castes have traditionally formed India's elite. In Bihar, the major forward castes have traditionally controlled the vast majority of agriculture land. The lower castes are grouped into several categories. The first, known as "other backward castes" or OBCs are generally the most socially and economically empowered of the lower castes. Scheduled Castes and Scheduled Tribes (SCs and STs) are a level below OBCs in terms of the social and economic empowerment. It is also worth noting, that the most common way to refer to the three caste categories is to use acronyms to describe OBC and SC/ST castes but to use the full words when describing UC castes (upper castes). I find this discrepancy unfairly biased and use acronyms in most cases to describe all three groups. I sometimes continue to use the full spelled out version when the use of the caste category is meant as a descriptive adjective rather than a noun (e.g. upper caste hegemony; lower caste empowerment).

However, for those farmers that actually adopted SRI, the poorest farmers were more likely to report that SRI was "very beneficial". For example, 64% of SC/ST adopters reported that SRI was very beneficial. In contrast only 52% of OBC farmers and 0% of UC farmers reported that SRI was very beneficial.

In summary, the results of the survey showed that the poorest farmers in Bihar are adopting SRI at far lower rates than their wealthier neighbors. To the extent that adoption of SRI implies benefits, wealthier farmers are realizing greater benefits from SRI and are certainly realizing greater benefits from the government's subsidy program. However, when the poorest farmers do have access to SRI, they report greater satisfaction with the technology than their wealthier neighbors. The sociotechnical reasons why the poorest farmers are adopting SRI at lower rates than their wealthier neighbors will be discussed further below but include differentiated access to irrigation, differentiated access to extension services, and differentiated access to the government's subsidy program.

3.5.3 Water Biggest Barrier to Adoption of SRI

Water access and control is the biggest barrier to SRI adoption discussed by farmers in the 11-village survey. Out of the 234 households who had heard of SRI but not adopted the technology, 83% listed lack of access to or control over water among the primary reason that they had not adopted SRI (other reasons included increased labor requirements, 44%, and lack of government support, 17%).[114]

The fact that access to water is the biggest barrier to adoption of SRI is surprising, both because one of the key attributes of SRI is that it saves water and because the Bihari government has publically claimed that the technology is helping farmers overcome drought conditions. However, what is often lost

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[114] Note: the fact that non-adopters list increased labor requirements as a reason for non-adoption of SRI should not be taken as robust evidence that SRI does increase labor. First, non-adopters would have little data to base this claim on, and second, non-adopters may have observed their neighbors putting in extra effort as the learnt the skills in the first year. Alternatively, non-adopters may simply not wish to learn the new skill. This is not to say that SRI requires less labor, but simply that data from non-adopters describes their perceptions which are critical in the technology adoption process, but not necessarily reality.

in the excitement over the fact that SRI uses less water, is that it requires more control over water resources. This is because in order to practice any type of water-saving technology, farmers need a higher level of control over their access to water. If for example, a farmer has access to water today, but is not sure whether or not she will have access to water in the next week, she will choose to flood her field today in order to mitigate the risk of crop damage should she face challenges accessing water over the course of the next week. In contrast, a farmer who is confident that she will have access to water tomorrow, can choose to irrigate less today with the knowledge that she can easily give her crop more water tomorrow.

The importance of water control for practicing SRI is particularly well illustrated by one anecdote from Rajapur village, on the main highway leading from the district capital, Gaya.[115] All households in the village belong to SC/ST caste categories. The village itself was created from government wasteland and given to landless families under the Government of Bihar Ceiling Act between 25 and 30 years ago. The original land was largely barren and difficult to cultivate.

PRAN, the NGO lead by Anil Verma, began working with the village in 2008 and in many ways the village became the NGO's showcase village. Rajapur is a useful showcase village for two reasons. First, the residents come from extremely marginalized castes, highlighting PRAN's focus on the poorest farmers. Second, the village is well-located for visiting politicians, development agency staff, and academics, as it is only a 10 to 20-minute drive from the tourist destination of Bodhgaya (where the Buddha attained enlightenment) as well as an airport which serves the flights from Bihar's capital, New Delhi (except during the summer's low season), and many international charter flights from Japan, Thailand, and other Buddhist countries. For this reason, the village receives more attention and resources from PRAN than any other village, and I had gotten to know the residents very well since 2011. Not only

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[15] Villages where knowledge of SRI was between 95 and 100% were either villages close to major roads where government extension support is more intensive according to farmer responses about their source of information about SRI or in one case, in a village where the NGO PRAN operates.

have they received extensive training from PRAN on SRI, but PRAN has also funded the construction of a water retention structure on their land, implemented a drip irrigation project, and built (in conjunction with Jyoti Devi, the SRI MLA) a community meeting house in the village.

The benefits of PRAN's intensive work in Rajapur village are evident on several dimensions. The village, which consists of 49 households on 12 acres of land has transformed from barren wasteland to extremely fertile and abundant farmland. In addition to very high paddy yields (averaging 9.2 tons per hectare), they also grow vegetables in both the winter and summer seasons with drip irrigation. The villagers also credit PRAN with giving them a voice to fight injustices. When a wealthy UC landowner in a nearby village tried to take some of their land, the villagers marched directly to the District Collectors office and demanded to speak with him. When men from outside the village tried to attack some of the women who were in their fields at dusk, the villagers marched directly to the police station and demanded justice. Both of these actions, they told me, they would never have had the courage to do before PRAN began to teach them, not only about SRI, but also about their own value as human beings and the power of community.

What makes this anecdote interesting with respect to the relationship between SRI and water is that in three different focus groups with various families from this village, I asked them all which was the most important intervention they had received from PRAN, or any other government or civil society development agency, in terms of the impact of the intervention on their well-being. Despite the introduction of SRI, the building of a community center, and lessons from PRAN about collective action and empowerment, the most important intervention, according to all three groups, was the construction of the water retention structure, which stored water from monsoons that could be used at little to no cost in the winter and summer seasons. This water retention structure, they believed, unlocked the potential of all of PRAN's other interventions. Without the water retention structure, growing rice using SRI methods would be risky because they would lack the necessary water control to ensure the survival of the young seedlings after they were transplanted, as well as to maintain the right levels of moisture in the field, which requires frequent, if limited, irrigation. And like SRI, the drip irrigation system PRAN and JAIN Irrigation Systems Ltd donated to the village, would not be useful without the precise water control that the water retention structure gives them. Even the empowerment training from PRAN, they argued, would be useless “if they did not have food to eat.”

Lack of control over water resources is far more likely to impact the poorest farmers in Bihar than the wealthiest. This is because while 24% of UC farmers and 5% of OBC farmers own their own wells, only 4% of SC/ST farmers own their own wells. Farmers who do not own their own wells are forced to buy water from neighbors and the poorest farmers are often discriminated against in water markets by UC well-owners. Thus, the average SC/ST farmer will likely be able to buy water from a neighbor if they have the required financial capital (which in and of itself is a big if) but the neighbor is likely to prioritize other UC and OBC water buyers over the SC/ST farmers. This means that SC/ST farmers not only have to pay high (often inflated) prices for water in Bihar, they are also never certain when the well-owner will grant them access to their well and diesel pump. For many of the poorest farmers, the risk of planting using SRI methods is thus, simply too high.

In qualitative interviews, more than one SC/ST household told me that they had tried SRI, but because the monsoon arrived late and they could not afford to buy irrigation, they lost their crop after they had transplanted the seedlings from the nursery to the main field. Had they chosen not to plant using SRI methods and waited until the seedlings were older to transplant them from the nursery to the main field, they would likely not have lost their crop (leaving the price they paid for their seeds and their own labor efforts as sunk costs).

PRAN recognizes the increased risks associated with lack of water control for SRI farmers and does their best to help mitigate these risks. They focus on building water storage facilities in the villages where they work and they promise to help cover the costs of new seeds should the monsoon arrive late, causing farmers to lose their first transplanted crop. However, PRANs impact is very limited in the context of Bihar's larger effort to promote SRI, and outside the villages where PRAN works, water remains the biggest barrier to SRI adoption amongst both SC/ST and OBC farmers.

The need for water control is not a new finding in the literature on SRI. Even the 2002 article by Stoop et al, mentions the importance of water control to the practice of SRI (Stoop, Uphoff and Kassam, 2002). A more recent study from Indonesia, explaining the slow diffusion of SRI despite its yield advantages, also finds that access to water is a major barrier limiting the adoption and continued use of SRI (Takahashi, 2013). What is novel about the empirical finding that water is the main barrier to the adoption of SRI in Bihar, is the degree to which it has stymied Bihar's 144-million-dollar investment in SRI. While, the physical characteristics of SRI in isolation may have the potential to benefit the poorest farmers, in the context of Bihar, there is a lack of fit between the physical characteristics of the technology and the local context, where access to irrigation is limited by high costs and lack of electricity infrastructure.[116]

The fact that government officials in Bihar championed SRI as a technology for helping the poorest farmers overcome draught conditions, paired with the reality that the poorest farmers in Bihar are unable to adopt SRI because of their limited access to water demonstrates one of the generalized conclusions of the chapter—that technology selectors are often out of touch with the local realities facing the poorest farmers. Specifically, the politicians and bureaucrats responsible for selecting SRI in Bihar failed to understand the relationship between the general principles of SRI and the complexities and uncertainties facing the poorest farmers in Bihar.

[116] As discussed in Chapter 2, access to irrigation is especially limited for the poorest farmers who are least likely to own their own wells and face high rental costs and limited control over timing of irrigation access.

3.5.4 Limited Access to Extension Services for Poorest Farmers

Another barrier specifically affecting the access of the poorest farmers to SRI was the types of programs promoting SRI in Bihar. Data from the 11-village survey showed that the most common source of information about SRI was other farmers (50%) with the second most frequent source of information being block level agriculture officers (30%). However, while UC and OBC farmers were almost equally likely to learn about SRI from a neighbor as opposed to an agriculture official from the government, only a tiny fraction of SC/ST farmers had heard about SRI from their block level agricultural official, indicating a failure on the part of the state extension service to promote SRI amongst the poorest farmers. Moreover, while a relatively small number of households in the sample had first heard about SRI from an NGO, the poorest farmers were equally likely to have learned about SRI from an NGO than they were from a block level agriculture officer.

Limited access to extension services is almost certainly lowering the benefits the poorest farmers in Bihar are realizing from SRI. An interview I conducted with a block level extension officer in Gaya district underscored this point – he said that while he did his best to reach out to small and marginal farmers, he had a limited staff and a large mandate, and it was often easier to promote SRI amongst wealthier farmers. His concern was mainly that wealthier farmers had all of the necessary tools to practice SRI, including access to irrigation and also the education and literacy required to read the government's handouts on SRI. Helping the poorest farmers adopt SRI, in contrast, he said required significant hand-holding by his field agents.

More generally, Bihar's agriculture extension officers tend to have closer relationships with wealthier farmers in the villages where they are assigned. There are a number of factors that go into the social dynamics between extension agents and the village, but in almost every setting where I have observed an agriculture officer enter a village he (I have never met a female extension officer in Bihar) will go directly to the home of one of the wealthiest members of the village first. He does this both out of respect, but also because if he wants to share something with the larger community he can rely on the wealthier farmers to have the social capital to call a meeting that other farmers in the village will also attend. However, this also means that the wealthiest farmers in a village, as well as their close relatives, are the first to learn about new technologies or other opportunities from government extension staff. This qualitative finding is supported by quantitative data from the 11-village survey. For many UC and OBC farmers, agriculture extension agents are often the most trusted source of information (after seed sellers and other farmers), but for the poorest (SC/ST) farmers, extension agents rank below almost every other source of information.

Relatedly, farmers who had adopted SRI in the three villages surveyed where the main extension provided was an NGO rather than a state extension agent, were more likely to report that they had found SRI very beneficial (64% of farmers in NGO supported villages said that SRI was very beneficial versus 52% overall). What is more, out of the 9 total SC/ST farmers in the 11-village survey who had adopted SRI, 5 of these farmers came from villages supported by NGOs, and 4 out of these five reported that SRI was very beneficial. The fifth SC/ST farmer who had adopted SRI in an NGO-supported village reported that the technology was not beneficial because he was unable to afford any water for irrigation. Overall, the trend (albeit one based on a limited number of SC/ST SRI adopters in the overall dataset) indicates that NGOs in Bihar are significantly more effective at supporting the poorest farmers in adopting SRI than the public-sector extension agents. Moreover, in my work with PRAN, I have visited villages with majority SC/ST populations where over 80% of all households are practicing SRI, demonstrating that under the right circumstances and with both the necessary irrigation infrastructure and extension support, the poorest farmers can realize significant benefits from SRI.[117]

[117] To ensure that I was being in no-way "hoodwinked" by PRAN into believing that these villages had more widespread adoption than was actually the case, I sent my survey team without PRAN's knowledge or my presence into two villages where PRAN had worked for over 4 years. It was clear when they reported out that almost the entire village in both of these cases was practicing SRI. However, PRAN has limited resources and these two villages had received intensive support from PRAN for four

3.5.5 Limited Access to Subsidy Package for Poorest Farmers

The SRI subsidy kit of 2kg seeds and 3kg fertilizers, intended to encourage farmers to adopt SRI, is also skewed towards wealthier farmers. Across the 11-village survey, while only 8% of all households received the subsidy kit, the poorest farmers in the survey were much less likely to receive the subsidy. While 14% of UC households and 12% which were OBC received the subsidy kit, only 3% that were SC/ST households received the subsidy kit. Looking only at the households who have adopted SRI, the percent of subsidy recipients is, of course, much higher and also skews decidedly towards the wealthier farmers. Out of the four UC adopters in the survey, three or 75% received the subsidy package. Whereas 52% of the 44 OBD adopters received the SRI subsidy package and 38% of the 14 SC/ST adopters received the subsidy package.

Not only is the SRI subsidy program disproportionately helping wealthier farmers, but in focus groups with female farmers who have used SRI methods for more than three years and report high satisfaction with SRI, many express consternation with the design of the government's SRI subsidy program. The main point these women farmers make is that for a technology that requires fewer seeds, it makes little sense for the government to incentivize adoption of the technology by giving farmers seeds and fertilizer. Instead, these farmers repeatedly suggested that the government could more effectively support SRI adoption by improving access to irrigation by poor farmers and by hiring more and better extension agents to teach SRI to farmers in their fields. The only input the government should subsidize, according to many SRI farmers, are the *conoweeders* which are unique to the practice of SRI but can be shared within a village community so that only one weeder per 15-20 households is needed. Unfortunately, while the 2012-2017 Agricultural Road Map earmarked 144 million dollars for SRI, only

years or more. Other villages supported by PRAN, such as my main field site Bathani, where the NGO had devoted more limited resources had SRI adoption figures more similar to the larger dataset. This demonstrates that SRI can be widely adopted with sufficient extension support, but without intensive handholding, diffusion of the technology in Bihar is likely far more limited than government reports suggest and is certainly not benefiting the poorest farmers most.

0.2% of this budget was allocated to providing *conoweeders* to farmers. In addition, it remains difficult for farmers to purchase *conoweeders* independently on the private market in Bihar, so virtually, farmers only access to the technology is through the limited supply from NGOs and the government subsidy program.

On the other end, anecdotal data indicates that many of the larger farmers who receive the SRI subsidy do not actually follow SRI practices. My own translator's family received the subsidy, but was unable to find labor willing to work in their fields using SRI methods. So, my translator's family accepted the seeds and fertilizer from the government (despite the fact that they were likely the wealthiest household in their village), but then planted their fields with traditional methods.[118] I heard a similar story from at least one other UC farmer I interviewed. My guess is that failure to follow-through on SRI practices, especially amongst wealthier farmers, is widespread, but farmers are reticent to admit to this in a formal survey as opposed to an informal conversation over tea.

In summary, the government's massive investment in SRI appears to not only be disproportionately helping wealthier farmers, but it is also not well designed in terms of its overall performance. Wealthier farmers are accepting the subsidy and not following through the practices in some cases and the poorest farmers would benefit more from *conoweeders* and improved hands-on extension training, rather than a package of seeds and fertilizers accompanied by an instructional booklet.

What is clear about the story of SRI in Bihar is that the technology will not fulfill its potential as a "pro-poor" technology until the SRI is paired with both access to irrigation and improved extension service provisions that places greater emphasis on working with the poorest farmers.

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[118] In all likelihood, the government recorded in the official record books that my translator's family had practiced SRI – spuriously increasing the overall number of SRI adopters in the state.

3.5.6 SRI as a Cultural Movement

Perhaps the most important impact the SRI movement has had on agricultural in Bihar has less to do with the adoption of specific SRI package of practices for growing rice, but rather a broader cultural movement towards improved agronomic practices across crops and seasons.

In Bihar, SRI is referred to as "*sri-vidhee.*" In Hindi, "*vidhee*" is translated as "method." Thus, a direct translation of *sri-vidhee* might be SRI-Method. However, serendipitously, "*sri*" also has its own meaning in Hindi – "respected." So, when Bihari farmers talk about SRI, what they say and hear is a "respected method" of rice cultivation. This translation is taken very seriously by the farmers who use SRI, and who see the approach as a more respectful and thoughtful method for growing crops. Indeed, songs promoted both by PRAN and the state-funded NGO JEEViKA draw on this dual meaning of SRI.[119] A verse from song 1 is reproduced here:

> We will practice SRI method,
> We will propagate it to every person,
> Sisters, we will collectively develop the world,
> SRI method is very great.
> We will enhance our knowledge on PRAN (spirit of life),
> We will keep going on the path of truth,
> Sisters, God will be found in every people,
> SRI method is very great.

The text from this verse builds an association between *sri-vidhee* and religious ideas. By linking the practice of SRI directly to a "path of truth" that will "develop the world," SRI takes on a meaning that is much greater than the sum of its parts. The symbolism of SRI as something more than just a physical technology capable of improving rice yields indicates that in Bihar the institutional dimensions of SRI

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[119] I had six of these songs translated from Hindi to English and they can be found in Appendix 5.

interacted with local culture in ways that endowed SRI with a unique place amongst other available agricultural technologies which Bihari farmers have access to. In other words, while the vast majority of farmers in Bihar know they can walk to their local seed seller and buy high yielding seed varieties, they never associate these seeds with religious sentiment.

In Bihar, the link between SRI and spirituality is further emphasized by the NGOs promoting SRI who encourage farmers practicing SRI to wear yellow *saris* to promote the technology. *Saris* are a traditional attire worn by women in India, and while urban women are increasingly turning to other wardrobes, most female farmers in Bihar wear *sari* on a daily basis. By wearing exclusively yellow *saris*, a color with tremendous religious and devotional symbolism, SRI practitioners are visually linking SRI with the devotional aspects of practitioners' daily lives. SRI practitioners wear these highly visible yellow *saris* whether they are attending weekly SRI meetings with other farmers in surrounding villages, going to agricultural fairs or as pictured below (see Figure 3.7) at a Republic Day Celebration in the district capital.

Figure 3.7: Farmers promoting SRI in Gaya district Bihar in a fair to celebrate Republic Day

Female farmers wear yellow saris which is both an auspicious color and a symbol of their belief in the benefits of SRI as an agronomic technology with significant benefits for Bihari farmers. Photo Credit Author, January 26 2015.

3.5.7 Changing Agronomic Practices Across Bihar

The adoption of SRI in Bihar should also be understood within the broader context of rapid technological change in the state's agriculture system. As discussed in Chapter 2, since the election of Nitish Kumar as Chief Minister in 2005, the rate of technology adoption by Bihar's farmers has risen dramatically.

Data from the 11-village survey showed major changes in rice cultivation practices over the past 20 years, with 77% percent of households reporting significant changes in their technological approach to paddy cultivation over this time period. These changes included switching to new irrigation systems, new types of seeds, and new planting techniques.[120] The vast majority of farmers said that the changes that have been made in their use of technology in paddy cultivation have taken place since 2005, with a large spike reported in 2010. Apart from the new irrigation methods, which included increased use of groundwater (either extracted with diesel engines or electric motor pumps, rather than relying on monsoon rainfall) and increased use of high yielding and hybrid seeds purchased at local seed stores, farmers also reported shifts in the agronomic practices they use when planting paddy in the field. While most farmers still transplant paddy from the nursery to the field between 26 and 30 days of age, many farmers reporting transplanting seedlings significantly earlier, whether or not they report using SRI methods. The number of seeds transplanted per unit area in the main field has also begun to decrease. Farmers attribute this variously to SRI or to the increased availability of improved seed varieties, which means that more of their seedlings will survive in the main field, allowing them to transplant fewer per unit area.

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[120] Overall, 69% of UC farmers, 84% of OBC farmers and 72% of SC/ST farmers report significant changes in their use of technology in paddy cultivation over the past 20 years. It's unsurprising that the percentage is lowest amongst UC farmers, many of whom practice agriculture more out of sentiment and tradition than financial need.

While these changes are consistent with SRI practices, many farmers pick and choose from the SRI practices they observe in their neighbor's fields while not adopting the entire suit of practices, and report benefits, especially in terms of decreased input costs. Other farmers are often unable to say whether their changing agronomic practices are part of the SRI package of practices or not. This is not to say that many farmers have not explicitly adopted SRI, but that SRI methods may be influencing agronomic methods, even when farmers have not explicitly adopted the technology.

Making matters even more confusing from the perspective of data collection and analysis, all changes in agronomic practices in Bihar are increasingly difficult to disentangle from SRI. As the term *sri-vidhee* has taken on its own meaning in Bihar, almost any effort on the part of farmers to modify their cultivation practices to attain better results is now called *sri-vidhee*. This phenomenon has been encouraged by the broadening of the SRI technology to include other crops, such as wheat, sugarcane and vegetables, and the re-branding of the term SRI as the "system of root intensification" (Thiyagarajan and Gujja, 2012) . One particularly humorous anecdote demonstrating the degree to which any new agronomic practice in Bihar is now referred to as *sri-vidhee,* was when I was invited by a block-level agriculture officer in Gaya district to observe his demonstration of a tractor designed to be used with the DSR practice discussed in Section 4 of this chapter. Recall that agronomists at RAU promoting DSR have specifically argued that DSR is a more profitable ***alternative*** to SRI. Ironically, given this background, the farmers in the village seeing that the agriculture officer was teaching them a new agronomic approach also called it *sri-vidhee.* For them, a renewed focus not only on inputs but on methods was what defined the SRI phenomenon in Bihar and any improved method should be given a respectful honorific.

While the widespread adoption of the term *sri-vidhee* in Bihar makes SRI as a specific technology more difficult to study, the fact that the *sri-vidhee* movement has placed greater emphasis on the value of improving agronomic practices in Bihar should not be dismissed. Efforts to change the behavior of farmers around their agronomic practices has always been considered an uphill battle in the agriculture extension community, and is one reason why so many agriculture experts see seeds as a better solution to increasing yields, because with seeds farmers don't have to substantially change their daily practices. The fact that the *sri-vidhee* movement is helping farmers see value in changing agronomic practices is thus not a trivial matter.

3.6 Discussion

Today, the role of SRI as one technological pathway to improved well-being for some farmers, is widely accepted (Zoellick, 2009; Berkhout and Glover, 2011; Nature Plants, 2017). There are still skeptics that argue that although SRI improves yields, other negative drawbacks, such as increased labor requirements, limit the technology's widespread use. However, the balance of evidence demonstrates that SRI is capable of playing an important role in improving the well-being of farmers who have the access, desire, and necessary capabilities and resources to adopt it.

At the same time, just as SRI has value as one technology amongst an arsenal of technologies needed to meet the needs of farmers facing a variety of socioeconomic and agro-ecological conditions and constraints, SRI is also not a panacea.[121] In Bihar, the barriers preventing the poorest farmers from capturing more benefits from SRI are both physical and institutional. We saw this both in terms of how water access prevented the poorest farmers from benefiting from SRI, and how the implementation of the subsidy program disadvantaged the poorest farmers.

[121] It's worth noting here one of the first articles published in the Sustainability Science Section of PNAS by Elinor Ostrom et al. (2007), "Going Beyond Panaceas" argues that in the context of governance of complex social-environmental systems, individual governance approaches are not likely to be effective across different contexts. While Ostrom et al. focused exclusively on institutional design, their theoretical argument extends equally well to technology innovation systems which include both physical and institutional dimensions. The findings in this study support Ostrom's argument in that while SRI has proven to be affective for some farmers in some circumstances, it is also not a panacea and that a fit between the technology and local conditions is integral to the success of the technology. This argument also complements the approach of the STEPS Centre, a research organization within the Institute for Development Studies at the University of Sussex which argues for a pathways approach to pursuing sustainable development – one that acknowledges the need for multiplicity of policy and technology responses to sustainability challenges (Leach, Scoones and Stirling, 2007).

The disconnect between the government's narrative that SRI helps the poorest farmers overcome drought, and the reality that farmers need control over their irrigation sources to practice SRI, demonstrates a failure on the part of the government to see SRI within the broader context of the opportunities and constraints facing the poorest farmers. This failure led to a lack of fit between sociotechnical characteristics of SRI and the local physical and institutional conditions facing farmers in Bihar. This failure had the most negative consequences for the poorest farmers, because these famers are the least likely to have access to and control over water resources, and are least likely to benefit from government support programs in general.

Taken as a whole, this case study demonstrates that within the context of agricultural innovation systems, the stage of technology *selection* for the poorest farmers is mired by challenges. Just as SRI was unfairly maligned by the transnational rice research community, largely to protect their own power and authority, SRI was selected in Bihar based off of considerations that had more to do with political incentives than with the actual ability of SRI to benefit Bihar's poorest farmers:

Transnational Level: At the transnational level, the case demonstrates that these challenges include the professional incentives facing employees in agriculture research organizations, who are driven by a wide range of goals that undoubtedly include increasing global yields and improving the well-being of farmers, but who also have to ensure the longevity of their research program and funding for their disciplines. Funding is, of course, largely linked to the perceived relationship between their research programs and the potential for their programs to contribute to meeting global food demands, or other goals articulated by donors (e.g. poverty alleviation, climate change mitigation and adaptation). However, in efforts to serve goals as disparate as feeding the world, helping the poorest, and ensuring the longevity of their research agendas and departments, actors in research and development organizations suffer from competing incentives, which can lead to a failure to imagine alternative solutions to the problems they are concerned with than the solutions that solve all of their goals at the same time.

Local Level: At the local level, *selection* challenges in many ways mirror the challenges in the transnational arena. Despite the "pro-poor" narrative around SRI espoused by the Bihari government, benefits of the technology are skewed towards wealthier farmers, and the government's 144-million-dollar support program for SRI seems to have been more of a political ploy than well-thought-out effort to benefit the poorest farmers. While the physical characteristics of SRI have the potential to benefit the poorest, unless they are paired with assured irrigation, no amount of funding for SRI will make the technology a "pro-poor" success in Bihar. Failure of the government to recognize the inter-dependencies between SRI and assured irrigation in Bihar, underscores the degree to which the technology was selected based on the professional incentives of Bihar's politicians and bureaucrats.

The pro and anti SRI voices at both transnational and local levels, demonstrate the complexities and challenges of technology *selection* for the poorest farmers. The challenges of technology *selection,* as demonstrated by the SRI case study, are likely to hold true in other innovation systems, especially for "pro-poor" technologies. This is because traditional models of demand-pull technology selection are less effective for the poorest communities, since these groups lack the ability to communicate their demands through their purchasing power across stages of an innovation system.[122] Instead, other actors in the innovation system, such as international donors, academics, transnational and local NGOs, and national and regional agriculture departments are often put in the position to select appropriate technology on behalf of the poorest farmers. These actors are usually at significant social distance from the end-users and can easily overlook their objective functions, as well as the specific opportunities and barriers they face – especially when overlooking these issues aligns with their own professional or political incentives.

[122] The challenges of traditional models of innovation that rely on the demands of end-users being effectively communicated to other actors in the innovation system were discussed in Chapter 1, Section 1.4. Note that this argument also applies to future generations who also lack the voice to demand technologies from innovation systems that meet their needs, such as technologies that reduce greenhouse gas emissions or limit nutrient runoff into coastal waters.

Actors responsible for technology selection in the SRI case, fell victim to a number of more general challenges in the technology selection process, including: 1) silver bullet or panacea thinking; 2) failure to fully understand local context facing the poorest farmers; and 3) selecting technologies based on professional and political incentives rather than the needs of the poorest farmers. For technology innovation systems to more effectively meet the needs of the poorest farmers, the community of experts and policy makers concerned with the needs of the poorest must build strategies for avoiding these three pitfalls of technology selection.

While this chapter focused on identifying the challenges of technology *selection*, the case of SRI also showed efforts by stakeholders to find common ground. The World Bank's SRI toolkit is an example of the efforts to perform mediating boundary-work at the interface of science and policy in order to find common ground and produce closure amongst competing communities of experts, over an issue with profound importance to the future of rice research and the lives of millions of rice farmers (Clark *et al.*, 2016). In the toolkit, the World Bank attempted to move the debate away from absolutist claims about "theoretical yield limits" above which extant rice plants could not produce (Surridge, 2002; Sheehy *et al.*, 2004), and refocus the debate on problem-driven solutions rather than scientific controversy. They were only partially successful. While IRRI did develop more nuanced and specific critiques of SRI, real common ground that allowed for the two communities to work together to ensure that farmers had the opportunity to benefit from both SRI and improved seed varieties, did not emerge. In Bihar, even after the government allocated substantial financial support to SRI, the efforts of rice scientists at the state's leading agricultural university, RAU, remained focused on undermining the credibility of SRI, rather than finding ways to ensure the success of the SRI program.

The challenges of reaching social-scientific closure in the debates around SRI demonstrate the need on the part of actors interested in technologies for the poorest, to mitigate scientific controversies and move towards more fruitful problem-driven research agendas that overcome the three common pitfalls encountered by experts on both sides of the SRI debates.

One approach to navigate social-scientific controversies in innovation systems is to institutionalize greater reflexivity into agricultural research and development organizations. Literature from the late 1970s on knowledge management and organizational learning is a useful starting point (e.g. Argyris, 1976; Argyris and Schön, 1978). In a 1976 article in a top organizational studies journal, Chris Argyris identified many of the underlying causes of the *selection* challenges seen in this chapter. He argued that for organizations to more effectively manage knowledge, they needed to institutionalize processes that increased effective learning. *Effective* of course being the operative word. To increase *effective* learning Argyris argued that organizations needed to increase their "receptivity to corrective feedback" (Argyris, 1976, p. 365). Through his research, Argyris showed that individuals in organizations are encouraged to learn "as long as the learning does not question the fundamental design, goals, and activities of their organizations" and that "factors that inhibit valid feedback tend to become increasingly more operative as the decisions become more important and as they become more threatening to participants in the decision-making processes" (1976, pp. 366–367).

In many ways, Argyris identified the factors which led to the "rice wars" two decades before the controversy began. To overcome this organizational tendency to avoid learning when new information is threatening to the status quo, he argued that organizations needed to foster within their membership what he called "double-loop learning," or the ability to be more aware of "one's present theory in use," and then reflexively question how one's theory in use governs one's actions, as well as the extent to which there are alternative theories that may be equally valid (p. 370). Perhaps, had the researchers at IRRI been more willing to explore ideas that appeared to question their "present theory in use" as they first learned about SRI, the early debate around SRI would have been less virulent and more constructive.

A book applying the frameworks of policy analysis to the challenge of rural development by Johnston and Clark (1982), which came out shortly after Argyris' work on organizational learning, argued that an important barrier to rural development was failure to learn from past experience. Johnston and Clark reasoned that "development strategy should include an explicit emphasis on learning *how to learn* from the actual experience of development, and thereby how to contribute more effectively to a continuing process of adaptive implementation and policy redesign" (p. 4). This approach shares much in common with Argyris' emphasis on ensuring feedback within organizations. Unfortunately, like Argyris, Johnston and Clark also fail to give concrete advise on how exactly to institutionalize opportunities for learning and reflection in organizations central to the development process (*e.g.* IRRI). Instead, Johnston and Clark conclude their study arguing that "[s]urely it is time for a perspective that stresses the necessity of building cumulative development capabilities from a combination of trial-and-error experience, novel ideas, increased organizational capacity, and enhanced individual talents" (p. 270). While Johnston and Clark offer useful strategic and systems perspective on the complex processes of rural development and useful inputs into decision analysis, what they do not do is offer concrete approaches for how to get organizations to actually learn. Scholarship that evaluates the successes and failures of different approaches to development is not enough if the organizations responsible for making development happen are not receptive to multiple perspectives, reflection and change. IRRI's virulent response to SRI at the start of the 21st century underscores the point that several decades after the publication of Johnston and Clark's book, development organizations had not yet *learned how to learn*.

Despite Argyris' call for increased reflexivity within organizations and Clark and Johnston's call for a greater focus on learning in development studies, both efforts fail to shed significant light on effective strategies for building the capacity for reflexivity into innovation systems. Fortunately, later work in both development policy and science and technology studies offers some useful strategies for more effective learning by actors and organizations that may help overcome some of the challenges of technology selection identified in the SRI case. The "problem-driven iterative adaptation" approach developed by Andrews, Pritchett, and Woolcock focuses on building state capability (Andrews, Pritchett and Woolcock, 2017). Their arguments also apply to effective capacity within organizations that play important roles in innovation systems. They argue that problem-driven approaches are critical to success in development projects: "we believe that problems force policy-makers and would-be reformers to ask questions about the incumbent ways of doing things, and promote a search for alternatives that actually offer a solution (rather than just providing new ways of doing things)" (p. 141). Moreover, problem driven approaches, they argue, must be iterative in that "finding and fitting solutions to complex problems requires first identifying multiple ideas and then trying these out, in an experimental manner, to allow the emergence of hybrids" (p. 177).

The "problem-driven iterative adaptation" (PDIA) approach overcomes several of the challenges of technology *selection* identified in the SRI case. At the transnational level, a greater focus on the problem of improving the well-being of the poorest is what ultimately led to more attention being paid to SRI by organizations like Oxfam and the World Bank. In Bihar, had the government been more focused on not only identifying the problem of helping the poorest through their SRI policy, but of iteratively adapting the solution to context, perhaps less of the money earmarked for SRI would have been wasted, if earlier interventions were put in place to ensure that recipients of the subsidy program also had access to water for irrigation.

However, the PDIA approach would likely not have been sufficient at the transnational level to overcome all three of the challenges of technology *selection* identified by the SRI case. This is because for the established rice research community, their problem was already well identified from the perspective of the community's members. They saw their mission as not only clear, but as critically important to global food security and poverty reduction (Surridge, 2004). The *selection* problem was thus not a failure to identify a problem-driven research agenda, but rather a failure to imagine alterative solutions to the problem than their favored solution—namely efforts to boost rice's photosynthetic efficiency through genetic engineering—which they had devoted their careers and the considerable resources of their organizations to.

Three generalized challenges for technology selection for the poorest were identified in the SRI case including: 1) silver bullet or panacea thinking; 2) failure to fully understand local context facing the poorest farmers; and 3) selecting technologies based on professional and political incentives rather than the needs of the poorest farmers. The most wicked problem among the three, and the one that the literature from organizational behavior as well as the PDIA approach does not yet have solutions to, is the third challenge—namely the tendency of organizations identified by Argyris to ignore opportunities for feedback and learning, when the learning threatens the identity of the organization. Fortunately, the field of science and technology studies has perhaps the most to offer in terms of insights and tools for overcoming the three *selection* challenges identified in the SRI case.

Sheila Jasanoff, in her research, shows how the technologies actors in positions of power chose to *invent, select,* and *produce* tend to "reflect the imaginative faculties, cultural preferences and economic or political resources of their makers and users" (Jasanoff, 2004, p. 16). In order to overcome these tendencies in innovation systems and institutionalize technology *selection* mechanisms that meet the needs of the poorest farmers, science and technology studies has several recommendations which could prove useful for institutionalizing reflexivity (or the ability to question the constitutional assumptions of our fields) into innovation systems. Jasanoff, in her 2003 essay "Technologies of Humility," identifies four strategies to achieve reflexivity in order to "make apparent the possibility of unforeseen consequences; to make explicit the normative that lurks within the technical; and to acknowledge from the start the need for plural viewpoints and collective learning" (Jasanoff, 2003, p. 240). Two of these strategies are ***framing*** and ***distribution***. I discuss these two strategies individually as tools for improving institutional design within technology innovation systems, in order to meet the needs of the poorest.

Framing: Jasanoff argues that “when facts are uncertain, disagreements about the appropriate frame are virtually unavailable and often remain intractable for long periods of time. Yet, few policy cultures have adopted systematic methods for revising the initial framing of issues” (p. 241). In the case of agricultural innovation systems, progress has long been framed as an effort to increase yields to avoid a ‘Malthusian Famine’ (Pingali, 2012). While actors and organizations within the global agricultural innovation system have slowly broadened the set of appropriate goals beyond yield, to include things like profits, income, and environmental protection, the tendency amongst the scientific community is still to return to yield as the ultimate arbiter of success and failure in their work. Further work to re-frame the goals of actors and organizations in the agricultural innovation system away from yields and towards the needs of the poorest farmers may help improve the functioning at the *selection* stage of agricultural innovation systems, to better meet the needs of the poorest farmers.

Distribution: Jasanoff argues that “[a]ttempts to engage systematically with distributive issues in policy processes have not been altogether successful” (Jasanoff, 2003, p. 242). She points to two examples from the developed world, where organizations tasked with evaluating the socioeconomic impacts of technology have been overlooked or disbanded. Yet the case of SRI demonstrates the need for stakeholders, who play active roles in agricultural innovation systems, and who are at least nominally tasked with improving the well-being of the poorest (anyone working within the CGIAR system would certainly fall into both of these categories), to ensure that their assessments of the benefits of technology take into account distributional issues. As we saw in the literature review in Chapter 1, however, very little of the innovation systems scholarship has grappled seriously with the issue of distribution. At the same time, it seems that the knee-jerk reaction of the established rice research community to SRI also ignored distributional issues. The idea that SRI could be a potentially useful technology for the poorest farmers did not redeem (in the eyes of the established rice research community) the gravity of failures on the part of the proponents of SRI in publishing “agronomic UFOs” in the academic literature. Efforts to institutionalize evaluation of distributional impacts of technology, would help overcome technology *selection* challenges associated with the failure to take seriously the needs of the poorest at this stage of the agricultural innovation system.

In conclusion, this dissertation is broadly concerned with institutional design for reorienting innovation systems to meet the needs of the poorest farmers. The case of SRI demonstrates several challenges in the *selection* stage of innovation systems, that create barriers to the functioning of innovation systems to meet the needs of the poorest. Institutionalizing greater reflexivity on the part of actors operating within agricultural innovation systems, specifically with respect to issues of ***framing*** and ***distribution***, may help overcome some of the challenges of technology selection identified in this case.

CHAPTER 4. Subsidies for whom? Comparative evaluation of India's Drip Irrigation Subsidy Program

4.1 Introduction

This chapter evaluates a large-scale subsidy program to promote widespread use of drip irrigation in India.[123] The subsidy program, known as the National Mission on Micro Irrigation (NMMI) is a modern and sustained effort to bring a new technology into widespread use. The effort to scale drip irrigation in India required the establishment of a broad institutional infrastructure by the national and state governments. This institutional infrastructure included specific mechanisms to target the poorest farmers. Both the size of India's drip irrigation subsidy program (it has likely cost the central government over one billion dollars between 2006 and 2014), as well as the explicit effort on the part of the government to ensure benefits to the poorest farmers, make drip irrigation in India a good case study for evaluating goal-oriented efforts to ensure the poorest farmers benefit from a new technology.

The chapter demonstrates that India's drip irrigation subsidy program leveraged both public and private sector strengths, to achieve widespread use of the technology across multiple states in India. However, despite inbuilt institutional mechanisms in the subsidy program to target the poorest farmers, the program largely failed to benefit this group. The failure of the drip subsidy program to benefit the poorest farmers is due to both the institutional and physical dimensions of drip irrigation technology in India, which are not well aligned to the needs of the poorest farmers.

[123] Drip irrigation is one of several technologies that collectively are called micro irrigation systems. The other major micro irrigation technology is sprinkler irrigation. This chapter primarily focuses on drip irrigation for two reasons. First, drip irrigation has low-cost versions that have "pro-poor" physical dimensions. Second, drip irrigation is a more interesting technology from a sustainability perspective because it has greater water savings. For this reason, the government's subsidy guidelines prioritize drip over sprinkler irrigation. The conditions under which the subsidy applies to sprinkler irrigation are when drip irrigation is inappropriate for the crop. If both drip and sprinkler irrigation are appropriate, the guidelines mandate drip irrigation is used because it has greater WUE. For these reasons and for bounding the scope of fieldwork, I focused on drip irrigation, though many conclusions apply equally well to all micro irrigation systems.

On the institutional side, the subsidy program attempts to create increased demand from the poorest farmers by offering larger subsidies to small and marginal farmers.[124] However, the subsidy program fails to offer the private sector dealers responsible for "last mile" technology delivery, their own incentives to work with the poorest farmers. Indeed, private sector dealers incur increased overall costs, in terms of their time and earnings, when working with the poorest farmers. As a result, the poorest farmers do not learn about the drip irrigation subsidy program.

On the physical side, the standards embedded in the subsidy program exclude low-cost drip irrigation systems. While low cost drip irrigation systems had gained traction in some parts of the country prior to the introduction of the subsidy program, the subsidy program pushed these technologies out of the available technology space in favor of more expensive designs. The failure of the subsidy program to include low-cost drip irrigation models under the umbrella of the program, negatively impacted the poorest farmers by making it harder for drip irrigation companies focused on low-cost technology, to compete.

The chapter demonstrates the difficulty of both leveraging private sector strengths in last-mile technology delivery, while also ensuring the needs of the poorest farmers are met in public-private partnerships in the agricultural sector. The chapter is organized as follows:

- In Section 4.2, I discuss the theoretical approach to the chapter, as well as the sources of data I draw on.
- In Section 4.3, I discuss the background on drip irrigation, including the generalized physical and institutional dimensions of the technology, its origins in Israel, and the initial adoption of drip irrigation on a global scale. I then focus on India and the history of the technology in the

[124] In India, small and marginal farmers are defined as farmers with less than two hectares (five acres) of land. While small and marginal farmers are often lumped into a single category for the purposes of policy making, marginal farmers are defined as farmers owning up to one hectare of land, and small farmers are defined as owning one to two hectares.

country. Finally, I describe India's national level subsidy program to promote widespread adoption of drip irrigation.

- In Section 4.4, I analyze data from the four regional case studies, as well as interviews conducted with actors at the national level from government, the private sector, and academia.
- In Section 4.5, I discuss the reasons for the two main empirical findings: First, variation in success of the subsidy program is driven by the institutional differences in state level implementation programs. Second, despite the success of the program in supporting widespread use of drip irrigation (in some states), institutional incentives embedded in the design of the subsidy program failed to ensure that the poorest farmers benefit from drip irrigation technology.
- Finally, in Section 4.6, I discuss my findings within the context of emerging innovation systems literature on the role of government in 'market-creation' (Mazzucato, 2016). I argue that India's drip irrigation subsidy program can be analyzed as a large-scale effort to support the emergence of a new market and industry. From a policy perspective, given the large publicly funded investment drip irrigation, I argue that the government should demand more from the private sector in return for its investment. In particular, the subsidy program should be re-written so that the incentive structures created by the program ensure that the private sector provides last mile extension services and capacity building specifically to the poorest farmers.

4.2 Theoretical Approach and Data Collection

4.2.1 Theory: Sociotechnical Approach to Innovation Studies

This chapter relies on the sociotechnical approach to the study of technology adoption outlined in Chapter 1, Section 1.2.1. Recall that this approach, first articulated by Harvey Brooks, widens the lens of technology research beyond the artifacts and practices associated with the physical dimensions of technology, to include the social supporting systems that are required to achieve *widespread use* of technology (Brooks, 1980).

As in the other three chapters, I use the language of physical and institutional dimensions of technology. The physical dimensions of technology include technical aspects of design, as well as the agronomic practices associated with using the technology in the field. The institutional dimensions of technology include the rules, norms, culture, and beliefs that together make up the social supporting systems necessary to apply the physical dimensions of the technology at scale.

I also use innovation systems theory and language to discuss the relationship between the physical and institutional dimensions of technology and the process by which technology is *invented, selected, produced, adopted, adapted* and sometimes *retired* (Anadon *et al.*, 2014). An innovation systems perspective is useful for identifying barriers to *widespread use* of a technology either in general or for specific socioeconomic groups (e.g. small and marginal, or lower caste farmers).

Finally, I situate this chapter within an emerging literature in innovation systems scholarship on government-led market creation. Mazzucato, in a 2016 paper on innovation policy argues that innovation policies can play a role in solving “socioeconomic-technological challenges” (Mazzucato, 2016, p. 140). In order for innovation policy to be challenge-driven, Mazzucato (2016) argues that “innovation policies require the traditional *market failure* justifications for policy intervention, and even system failure justifications, to be complemented with a more active *market-creating* framework” (p. 140). Based on extensive research into the role of the public sector in innovation systems, Mazzucato calls for a "more strategic and *mission-oriented* approach" on the part of public sector actors in market-creation (Mazzucato, 2013, 2016, p. 140).[125]

India's drip irrigation subsidy program can be understood as a strategic effort by the central government in market-creation, rather than only as a policy to overcome the problem of high relative costs to end users in the adoption of drip irrigation technology. Viewing India's drip irrigation subsidy program as a strategic effort in market-creation by the central government begs the question: What do the private sector actors who benefit from the government's investments in market-creation owe in return? In particular, how should the risk and rewards of market-creating policies be shared across the public and private sectors and how can the government re-design the institutions structuring incentives under the subsidy policy to ensure the poorest farmers reap greater benefits from drip irrigation technology?

Mazzucato's arguments on the role of government-led innovation policy in market-creation are grounded in the work of Karl Polanyi. Polanyi, an economic historian and sociologist in the mid 20th century, questioned the emerging view of the "free market" as a concept untethered to social and political institutions (Polyani, 2001). In his seminal book, '*The Great Transformation'* Polanyi shows that the free market is not a natural artifact, but rather the product of institutional interventions by the state. His work exposes the myth of state vs market distinctions and allows policy scholars to critically question market-failure logics that undergird so much economic policy. An important modern policy implication of Polanyi's argument is that if markets are always shaped by state policies, then the state ought to play an active role in determining who benefits from state investments in market-creation. In the context of this

[125] Mazzucato's 2013 book, *'The Entrepreneurial State'* metiiculously documents the ways in which government investments in R&D have been essential to the success of many private sector companies. She uses the iPhone as an example and shows how much of the underlying technology was first developed through tax-payer funded research. She then shows how the important role of the government is later ignored in the founding stories of major private sector companies, who often pretend that their products are entirely developed by their company and ignore the contributions of public research. Mazzucato extends this emprical study to its implications for public policy: if publically funded research contributed so much to the development of Apple's iPhone, why is apple avoiding the very taxes that fund important public sector research?

chapter, this means that the Indian government should consider who benefits from their drip irrigation subsidy program. This chapter concludes with policy recoemndations for how the Indian government can restructure the drip irrigation subsidy program to ensture the poorest farmers realize greater benefits from the technology.

4.2.2 Data: A Comparative Qualitative Analysis

The data for this chapter was collected between July 2013 and April 2015. I gathered data through qualitative interviews across four states, including Andhra Pradesh, Bihar, Gujarat, and Kerala (see map in Figure 4.1), as well as with officials in the central government and other key experts from the research community and the private sector. I also spent four days on the campus of Jain Irrigation Systems Ltd. in the summer of 2013, learning about their company and cutting-edge R&D in the drip irrigation sector.[126]

[126] I am indebted to JAIN Irrigation Systems Ltd. for inviting me to their headquarters and allowing me to learn from so many of their employees. I am particularly indebted to Dr. P. Soman, Senior Vice President of Projects at Jain Irrigation for helping me understand the technical details of drip irrigation as well as helping me navigate street protests and effigy burnings in rural Andhra Pradesh unscathed.

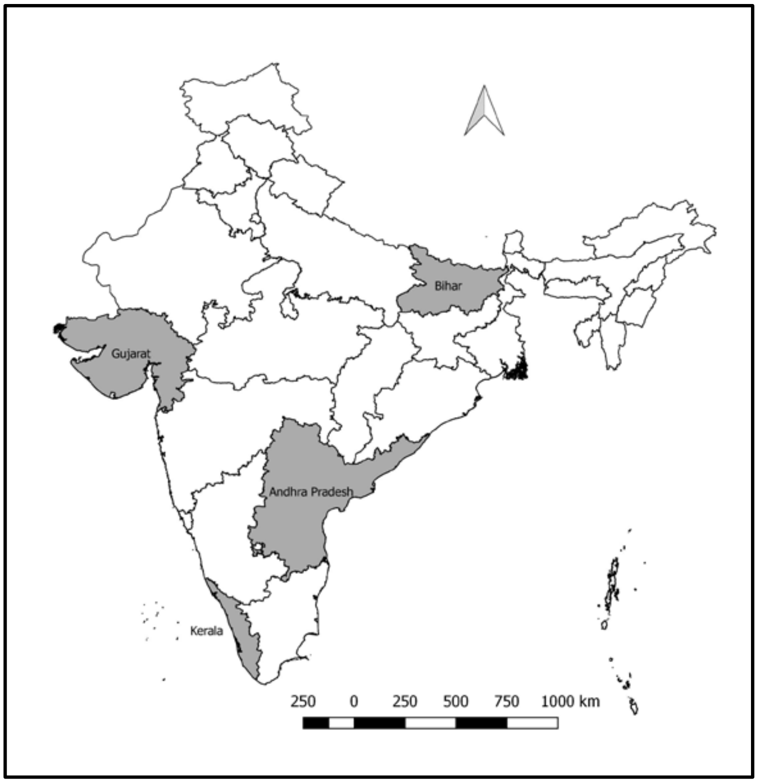

Figure 4.1: Map of India.

The map highlights the four states where I conducted extensive primary fieldwork for this chapter, including Andhra Pradesh, Bihar, Gujarat, and Kerala.

To select case studies, I used a purposive selection methodology common in qualitative research (Seawright and Gerring, 2008).[127] I selected four states, including Andhra Pradesh, Bihar, Gujarat, and Kerala. I purposively selected these four cases for diversity on the following three criteria:

- **First**, I only selected states where the potential area available for drip irrigation is relatively high (over 40% of total cropped area). The potential area available for drip irrigation is

[127] Seawright *et al.* (2008) review a number of case selection methods for qualitative research. In qualitative research, they argue, cases can be selected purposively. Selection methods include typical, diverse, extreme, deviant, influential, most similar, and most different. For this study, I used a diverse case study selection method which is useful for two or more cases that exemplify diverse values for pre-selected criteria. Seawright *et al.* argue that "diverse cases are likely to be representative in the minimal sense of representing the full variation of the population" (p. 297).

calculated by looking both at the types of crops grown, as well as the availability of irrigation infrastructure, such as surface irrigation or borewells.[128] I did not select for diversity on this criterion. Rather, it was a minimum criterion for selection, to ensure that the physical dimensions of drip irrigation are appropriate for enough farmers in the state to make drip irrigation a relevant technology within the state's agricultural innovation system.

- **Second,** I selected states that varied in terms of the extent of drip irrigation adoption. In 2011, Andhra Pradesh had the highest overall area under drip irrigation of any state in India, but Gujarat was quickly catching up. Kerala had a small but not insignificant area under drip irrigation, and Bihar, despite a 90% subsidy for the technology, had almost no area under drip irrigation.
- **Third,** I selected states for variation in the extent of adoption by the poorest farmers (as measured by landholdings). Data collected in 2010, showed that in Kerala approximately 50% of drip irrigation adopters were small and marginal farmers (those with less than two hectares of land). In Andhra Pradesh, small and marginal farmers accounted for approximately 10% of adopters. In Gujarat, small and marginal farmers made up only 2% of adopters. And in Bihar, small and marginal farmers made up less than 1% of adopters (Palanisami and Raman, 2012).

In each of the four states I interviewed a wide variety of actors in the drip irrigation innovation system, including government officials, private sector company representatives (including representatives of Bhumi, JAIN Irrigation Systems, EPC Mahandra, and Netafim), drip irrigation equipment dealers, and farmers (see Table 4.1).

[128]Horticulture crops, sugarcane, and cotton are among the more common crops in India grown with drip irrigation. This may change in the future, as drip irrigation companies are working to demonstrate the value of their technology for rice cultivation. If they succeed, the potential area for drip irrigation in India will expand considerably.

Table 4.1: Overview of fieldwork including interviews conducted and dates.

State	Selection Criteria	Interviews Conducted	Dates
Andhra Pradesh	1. 730k ha potential area. 2. Based on 2010 data, drip had been installed on 50% of potential area. 3. Small and marginal farmers approximately 10% drip adopters.	• Government officials (n=2) • Private sector company staff (n=5) • Equipment dealers (n=3) • Drip adopters interviewed with representatives of drip irrigation companies (n=4) • Drip adopters interviewed independently (n=3) • Non-adopters interviewed (n=3)	July 2013 & March 2015
Bihar	1. 142 thousand ha potential area. 2. Based on 2010 data, drip had been installed on only 0.02% of potential area. 3. Small and marginal farmers approximately 0.5%* drip adopters.	• Government officials (n=3) • Private sector company staff (n=3) • Equipment dealers (n=2) • Drip adopters interviewed with representatives of drip irrigation companies (n=3) • Drip adopters interviewed (n=8)	January / February 2015
Gujarat	1. 1,599 k ha potential area. 2. Based on 2010 data, drip had been installed on 10% of potential area. However, area under irrigation growing rapidly in Gujarat. 2015 data suggests drip irrigation on 26% of potential area in Gujarat. 3. Small and marginal farmers approximately 2% drip adopters.	• Government officials (n=2) • Private sector company staff (n=7) • Equipment dealers (n= 5) • Drip adopters interviewed with representatives of drip irrigation companies (n=6) • Drip adopters interviewed independently (n=7) • Non-adopters interviewed (n=4)	December 2013 / January 2014
Kerala	1. 179k ha potential area for drip irrigation. 2. Based on 2010 data, drip had been installed on only 8% of potential area. 3. Small and marginal farmers approximately 50% drip adopters; 96% all farmers in state.	• Government officials (n=5) • Private sector company staff (n=2) • Equipment dealers (n=2) • Drip adopters visited with companies (n=3) • Drip adopters interviewed with government extension staff (n=5) • Drip adopters interviewed independently (n=3) • Non-adopters interviewed (n=3)	March/April 2015
Other Fieldwork	❖ Spent four days in Maharashtra at Jain Irrigation Systems Ltd. headquarters. ❖ Interviewed government officials in Delhi responsible for subsidy program. ❖ Attended workshops. ❖ Expert Interviews.	• Jain Irrigation Systems Ltd. campus visit (12 interviews with high-level staff, including joint managing director, Ajit B. Jain. • Central government officials in New Delhi (n=2) • Drip irrigation workshops attended (n=2) • Expert interviews (n=4)	Total fieldwork for project conducted between July 2013 and April 2015

While I draw on insights from all of these interviews, the bulk of the analysis draws on my interviews with drip irrigation equipment dealers (n=12), henceforth "dealers". I chose to focus on this data source because the dealers are in a unique position to evaluate the institutional design of the subsidy program in each state, including barriers to overall rates of adoption rates, as well as barriers to adoption by the poorest farmers.

In my first field visits in 2013 to Andhra Pradesh and Maharashtra, I noticed the importance of dealer networks to the spread of drip irrigation. Most of the private sector drip irrigation supply companies, and all of the biggest ones, including JAIN Irrigation and Netafim, work through dealer networks. Dealers are not directly employed by drip irrigation companies, but rather work on a commission basis. Some dealers work exclusively with technology from one company, whereas other dealers work with multiple companies. Dealers are responsible for engaging with farmers throughout the adoption process and are especially important in marketing and outreach. The extent to which dealers are involved with on-site design and installation of drip systems varies by state. However, in many states (like Gujarat), dealers manage almost every step of the process, from initial outreach and marketing, through instillation and after sales service, with limited oversight from engineers at the larger supplier companies (e.g. Jain Irrigation and Netafim), who are ultimately responsible to the government for the performance of the systems installed under the subsidy program.

There are two reasons why dealers offer particularly useful insights into drip irrigation innovation systems in each state. First, dealers work very closely with farmers and understand the opportunities and barriers to drip irrigation adoption, both generally and specifically, for the poorest farmers. Second, larger private sector suppliers are often reticent to share propitiatory information, such as their overall sales in a state, or the number of sales they make to small and marginal. Dealers, in contrast, because they are much smaller companies (with an average of 5.2 employees among the 12 dealers I interviewed) are much less invested in the politics of drip irrigation at the national level and are more willing to share what the larger supplier companies perceive to be sensitive data. Dealers freely shared their context-rich understanding of the nitty gritty details of the functioning of the subsidy program in their state. They were also willing to share what I perceived to be unvarnished accounts of the failures of the subsidy programs. This included both general problems, as well as specific barriers preventing the poorest farmers from benefiting from drip irrigation technology.

In interviews with dealers, I asked about what they saw as the biggest barriers to widespread adoption of drip irrigation in their state, as well as the specific barriers for the poorest farmers. I also asked each dealer to estimate the proportion of small and marginal farmers among their clients. This estimate is useful because I was unable to get data from the government on the distribution of landholding among subsidy recipients and the 2010 data used in the process of case selection is both old and based on a limited sample.[129] Data on the distribution of landholdings served by dealers was a second-best approach to estimating adoption of drip irrigation by small and marginal farmers in each state. In addition to asking dealers about the proportion of their client base in the small and marginal landholding category, I asked them to explain the reasons behind this proportion, which led to rich data on the specific mechanisms preventing small and marginal farmers from benefiting from drip irrigation.[130]

In addition to interviews with dealers, I also interviewed farmers in each state (n=53). Most of these farmers were drip adopters, but I also selected a limited number of non-adopters living in close

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[129] Indeed, based on data provided by the government body responsible for administering the drip irrigation subsidy program in Kerala, I do not believe the central government collects data on landholding or caste of subsidy recipients. The data I collected in Kerala was in standardized reporting format that they sent to the central government on a monthly basis. This data did not include any information about subsidy recipients that would allow for analysis of the socioeconomic profile of drip irrigation adopters. This is interesting in the context of this dissertation because it alludes to the central government's lack of concern with measuring the benefits of this program to the poorest farmers.

[130] I focused on landholding rather than caste as a proxy for well-being, because the relationship between specific caste categories and well-being differs significantly across states and requires nuanced understanding of caste at the state level. In addition, the central government's subsidy program uses landholding rather than caste as the metric for targeting increased subsidies at the poorest farmers, so using landholding as the metric of analysis was also aligned with the policy program. That said, as discussed in the Kerala case study, it turns out that cross-state landholding comparisons as a proxy for well-being also has complications.

proximity to adopters, in order to understand the reasons why they had not adopted the technology. A major drawback of the farmer interview data is that the majority of households I interviewed were not randomly selected.[131] Rather, field visits were conducted with drip irrigation supplier company staff, dealers, and government extension agents. These field visits offered useful insights into the overall processes involved in the spread of drip irrigation in each state, as well as some of the reasons farmers chose to adopt drip irrigation, and the perceived benefits. But, due to the sampling methodology, the data is used with caution.

Despite the drawbacks in the farmer interview data, I believe the robust quality of the interviews with dealers provided robust evidence for studying the causal mechanisms driving adoption of drip irrigation in each state, as well as the main barriers, both across socioeconomic groups of farmers and specifically for the poorest farmers (as measured by landholdings).

4.3 Drip Irrigation: Background and Selection in India

4.3.1 Drip Irrigation: General Physical and Institutional Dimensions

Drip irrigation, in which very small amounts of water are regularly administered to crops, is one of the most efficient irrigation technologies. Drip irrigation is one of three available micro-irrigation technologies (drip, bubbler, and sprinkler). The advantages of drip irrigation are well documented. Drip irrigation significantly decreases on-field water demand, waste, and runoff (Keller and Blisner, 1990; Howell, 2001; Ayars *et al.*, 2007). In addition, drip irrigation improves crop yields relative to traditional irrigation methods, and reduces labor costs (Tiwari *et al.*, 1998; Tiwari, Singh and Mal, 2003; Ibragimov *et al.*, 2007).

[131] In Bihar and Gujarat, I also visited farmers without government or private sector staff as intermediaries. In these two states, I was able to obtain lists of drip irrigation subsidy recipients from the government and randomly selected farmers from these lists. However, the lists were confined to subsidy recipients, limiting broader generalizations from the interviews.

Drip irrigation has another important advantage – it saves water.[132] Because irrigation accounts for nearly 70% of global freshwater withdrawals, finding ways to increase the water use efficiency (WUE) of irrigation is an important sustainable development concern (Postel, Daily and Ehrlich, 1996; Gleick, 2009). A study looking at the use of drip irrigation for growing peppers in India, showed WUE improvements of 38% (Paul *et al.*, 2013). Other experiments with different crops have found WUE improvements between 21% and 103% (Dalvi *et al.*, 1999; Maisiri *et al.*, 2005; Ibragimov *et al.*, 2007). In addition to saving water, drip irrigation's high WUE has many other environmental benefits, including reduced agricultural runoff and the prevention of soil salinity (Hanson and May, 2003).

There has also been a stream of research demonstrating the "pro-poor" potential of drip irrigation. For example, in a study of four villages in West Africa, Burney *et al.* (2010) demonstrated how drip irrigation improved nutrition and food security. Earlier work by Postel *et al.* (2001) estimated that if low cost drip irrigation systems were widely adopted by poor farmers, drip irrigation could "boost annual net income among the rural poor by some US $3 billion per year and inject two or three times this amount into the poorest parts of the developing world's economies" (p. 3). In addition, a 2013 *perspectives* article in PNAS, argued for the need for "distributed irrigation" technologies, including drip irrigation, as a development priority for sub-Saharan Africa (Burney, Naylor and Postel, 2013). Despite the hopeful rhetoric around the potential of drip irrigation to serve as a "pro-poor" technology, there have been few evaluations looking at the extent to which the poorest farmers are benefiting from drip irrigation in countries where the technology has reached relatively widespread use. This study, undertaken in India, provides the opportunity to perform such an evaluation. The conclusions are also policy relevant to the

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[132] Drip irrigation has a higher water use efficiency (WUE) both compared to most traditional flood irrigation methods as well as compared to other micro irrigation methods (bubbler and sprinkler) (Hanson and May, 2003).

development of programs intended to support drip irrigation adoption in sub-Saharan Africa, and other parts of the developing world.

4.3.2 Drip Irrigation Innovation History

Modern drip irrigation methods were invented in Israel in the 1960s and 1970s. The invention of drip irrigation in Israel was not (despite certain poetic creation myths, especially those found in Netafim's promotional materials) the result of a serendipitous discovery, but rather the outcome of institutional incentives and government-funded, goal-oriented research, intended to address the specific needs of the early Israeli State (Sne, 1989). I review Israel's experience with both *invention* and *widespread use* of drip irrigation here, because the institutions Israel developed to support widespread use of the technology, share many commonalities with the institutions developed in the states in India, where drip irrigation has also been widely adopted: namely, strong government support for the technology through a subsidy program, combined with a transparent and efficient regulatory environment.

After the State of Israel was established, the fledgling government had to immediately contend with four very pressing issues: securing the borders of the state in a hostile region; settling a huge influx of new immigrant refugees fleeing Europe; securing the national food supply; and providing a productive economic base for the new state. In response to these pressures, the early Israeli government prioritized agricultural development. Agriculture effectively addressed all four issues at once, by maintaining territorial claims and border security through physical occupation of the land; directly providing food for the burgeoning population and a local economic driver for the state; and encouraging new immigrants to settle in remote portions of the state, helping them to spatially disperse and integrate with local communities (Feitelson, 2013).

Israel's semi-arid tropical climate, however, did not lend itself to intensive agriculture. In order to adequately divide, allocate, and supply limited water resources, Israel adopted a national-scale Integrated

Water Resource Management (IWRM) plan. The IWRM, placed all water in Israel under the ownership of the central government, and gave responsibility for the management and allocation of water resources to the Ministry of Agriculture. Centralizing the water supply and placing allocation responsibilities in a central government agency, effectively 'embedded' water scarcity in the Israeli national consciousness. Israel's IWRM policies also put a price on water, linking farmers' water use to their (subsidized) expenses. Thus, Israeli farmers were financially and institutionally incentivized to conserve water and limit their use of this precious national resource, which belonged not to each farmer, but to the state (Fischhendler, 2008).

In addition to creating cultural and financial institutions to conserve water, the state invested heavily in agricultural research to find technical solutions for growing more with less water (Garb and Friedlander, 2014). Mottes wrote the first-known article on drip irrigation, which appeared in the Israeli agronomic journal *Hasadeh* in February 1962, and proposed a buried system of 0.25 inch plastic lines with vertically inserted drippers at regular intervals (Pasternak, 2008). Drip irrigation's initial purpose was to save water. Because of this, the first drip systems were buried to prevent evaporative water loss and improve water use efficiency as much as possible. Buried drip systems on four test plots however, consistently struggled with blockages from plant roots, and researchers realized that despite some apparent early advantages, the technology could not be scaled-up with that kind of technical inconsistency.

As an accident, drip laterals used additional test plots in 1965/6 that were not buried because the machine for burying the plastic lines arrived too late. The engineer, Simcha Blass, involved in this above-ground drip irrigation trial, realized that above ground drip irrigation overcame many of the original problems with the technology. The yield successes of this new approach, coupled with the elimination of the blockage problems, led to significantly increased interest in surface drip emitters.

After the initial invention of surface drip emitters, Blass conducted many trials with the new technology, both independently and as a researcher with the Israeli Ministry of Agriculture. These early trials presented the first barrier to drip's adoption in Israel because they were never particularly successful. As a result, many Israeli agronomists questioned the technology's utility and scalability. Yehudah Zohar, an Israeli agronomist who believed in the potential of drip technology, especially on marginal soils with saline water, ignored directions from his superiors and continued to pursue research to optimize the use of drip irrigation on poor soils. The results of Zohar's field trials were so successful that other actors in Israel's agricultural research system called the results a 'miracle' (Pasternak, 2008).

As a result of the fact that the first successes with drip irrigation technology had been realized on marginal soils with saline water, it would take many more years before drip irrigation was recognized as an appropriate irrigation technology for general agricultural use. The technology only reached *widespread use* as a direct result of the responses of influential Israeli actors to two external events. First, the World Bank partially funded an initiative to increase water use efficiency in dryland agriculture. The program offered Israeli farmers subsidies, grants, and other direct financial incentives to shift to drip irrigation or other highly efficient water-use irrigation technologies. Second, the Israeli Ministry of Agriculture and Water Commission were forced to respond to an extended drought throughout Israel, with severe cuts to freshwater allocations to agriculture in the Israeli coastal strip. In their efforts to prevent widespread loss of agricultural production, the Ministry of Agriculture developed an extensive extension and subsidy support program to help farmers adopt and then optimize their use of drip irrigation (Sne, 1989).

In 1969, Simcha Blass and his son Yishayahu were awarded the first US patent for a surface drip emitter, on the basis of an earlier Israeli patent. Blass eventually sold his surface-emitter patent to Kibbutz Hatzerim, who founded the drip technology manufacturing company, Netafim, which continues to play a leading role in the global spread of drip irrigation technology (Pasternak, 2008).

The invention and eventual widespread use of drip irrigation in Israel was achieved through government incentives for both invention and widespread used. The government used their authority to both create laws and regulations to promote water conservation, and supported farmers in the adoption of drip irrigation through investments in capacity building and subsidies (Fischhendler, 2008).

As a result of government support for drip irrigation, Israel also has the largest proportion of irrigated land area under drip irrigation, with 73% of total irrigated land area under drip irrigation (ICID, 2005). Israel's high rate of drip adoption enabled a five-fold increase in irrigated land between 1951 and 1986, with only a three-fold increase in water-use. In 1989, it was estimated that productivity per cubic meter of water used in agriculture tripled in Israel between the 1950s to the 1980s (Sne, 1989).

In contrast to the Israeli experience, global drip irrigation adoption has been much slower. In 2012, drip irrigation accounted for less than 5% of total irrigated land area (ICID, 2005). Among the four countries with the largest overall land areas under drip irrigation (see Table 4.2), only Spain has achieved what might be called *widespread* use.

Table 4.2: Drip adoption by country
Source: (ICID, 2012)

Country	Land under drip (ha)	% total irrigated land	Year reporting
India	1,897,280.00	3.1%	2010[133]
China	1,669,270.00	2.8%	2009
Spain	1,658,317.00	47.8%	2011
United States	1,639,676.11	6.6%	2009

Moreover, despite drip's potential benefits for the poorest farmers in developing countries, drip irrigation accounts for less than 1% of the total irrigated land area in most developing countries. In 2012,

[133] Note that adoption of drip irrigation in India has risen sharply since 2010, when this data was collected. A more recent estimate of drip irrigation adoption in India, puts the total area under drip irrigation at 3.3 million hectares or closer to 10% of India's total potential area (Liebrand, 2017).

Morocco, Egypt, South Africa, and Malawi were the only four African countries to report any drip irrigation use (see map in Figure 4.2).

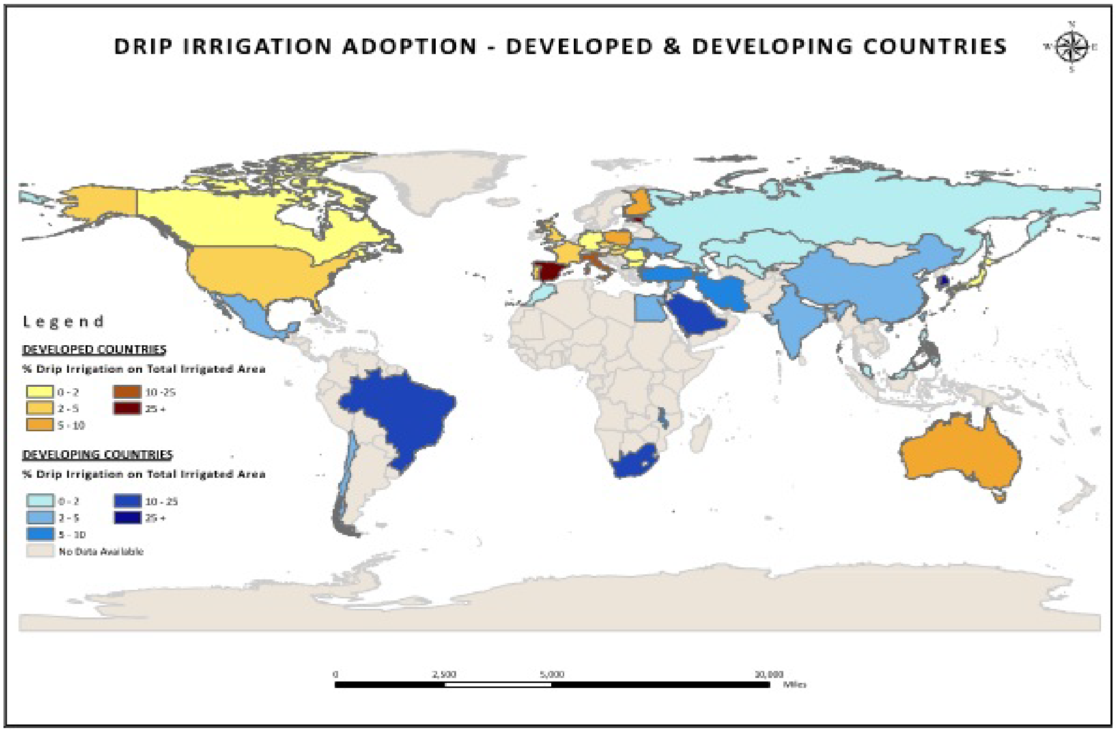

Figure 4.2: Drip Irrigation coverage by country.
Source: (Data from ICID, 2012)

4.3.3 Initial Adoption of Drip Irrigation in India

The first experiments with drip irrigation in India were conducted in a university setting, at the Agriculture University in Coimbatore Tamil Nadu, in the 1970s. Only a year after the first research station experiments had been conducted, drip irrigation was pioneered in a farmer's field in Jodpur village in Madhya Pradesh (Bhamoriya and Mathew, 2014).

The private sector was not far behind the research community in its interest in drip irrigation, and also played a significant role in the selection of drip irrigation in India. Bhavarlal Jain, a businessman and entrepreneur in Maharashtra, attended an agricultural trade show in the United States in the early 1980s, where he learned about drip irrigation. According to the company's founding narrative, Jain saw in drip irrigation, both a business opportunity and an opportunity to address a critical issue facing India's agricultural future – water scarcity. By the late 1980s, his company, Jain Irrigation Systems Ltd., was manufacturing and selling a wide variety of drip irrigation systems (Goldberg, Knoop and Preble, 2011). Today, JAIN Irrigation is one of the largest drip irrigation companies in the world – having purchased Israel's second largest drip irrigation company, NaanDan, in 2013.

In the 1980s and 1990s, despite the efforts of the private sector to promote drip irrigation, adoption rates throughout the country remained low (Liebrand, 2017). Until the 21st century, in fact, drip irrigation in India was virtually synonymous with the state of Maharashtra, where Jain Irrigation had its headquarters. Until 2000, over 60% of drip irrigated area in India was in Maharashtra (Liebrand, 2017).

It was not until drip irrigation was selected more formally by the government, that the adoption of drip irrigation in India began to rise. In 2003, the Chief Minister of Andhra Pradesh, Nara Chandrababu Naidu, faced a challenging upcoming election. Naidu, known for his pro-business stance that had transformed the state's capital, Hyderabad, into an IT hub in India, was in danger of losing the rural vote after a prolonged drought in the state wreaked havoc in the agricultural sector. Eager to both improve his image among rural voters, and to find a solution to overcome the state's water shortages, Naidu appointed a cabinet subcommittee to create policy recommendations for supporting drip irrigation in the state (Praveen Roa, personal interview, Hyderabad, March 5, 2015).

Dr. Praveen Rao, a newly appointed officer in the department of horticulture in Andhra Pradesh was appointed to work with the subcommittee and design the policy recommendations. Rao had recently returned from a post-doctoral fellowship in agronomy in Israel. This experience, along with his in-depth knowledge of Andhra Pradesh's extension system, gave him valuable perspective on the design of a subsidy program for drip irrigation in Andhra Pradesh (Praveen Roa, personal interview, Hyderabad, March 5, 2015).

Roa knew that to be successful, the drip irrigation program would have to align the incentives between farmers, the private sector, and government. Roa's vision was for the institutional design and implementation of the subsidy program to create an incentive compatible structure for all actors in the drip irrigation innovation system, that would spur drip irrigation adoption. One critical aspect of Roa's vision for a drip irrigation subsidy program, was to create an attractive business environment for the private sector, while at the same time, forcing the private sector to reduce the cost of the technology to make it more affordable to farmers. To achieve this goal, Roa used a carrot and stick approach with the private sector, by offering the potential of hugely expanding the market over the long run, in exchange for lower prices, immediately. One way he did this, was by asking all private sector companies to propose a price reduction for their equipment, in order to be eligible for the state's new subsidy scheme. The private sector responded with a 27% reduction, but Roa felt they could cut their prices further. Rao did his own analysis of input and production costs, and eventually convinced the private sector to reduce their component prices by 37% in order to participate in the state's subsidy program. While the private sector was not happy with the price reductions, the long-term growth opportunities that the subsidy program would create, ensured that the private sector did not completely balk.

Roa also carefully selected private sector companies to participate in the subsidy program, to ensure both the quality of their product, but more importantly, their ability to provide quality and timely service to farmers. Roa knew that if farmers developed a negative perception of drip irrigation due to substandard technology or poor after sale service, it could ultimately doom the long-term success of drip irrigation in the state (Praveen Roa, personal interview, Hyderabad, March 5, 2015).

Despite Chief Minister Naidu's support for the proposed subsidy program, there was some dissent in the government, with respect to subsidies for agricultural development. Not only were agricultural subsidies out of favor with the international community, but subsidies for electricity, which were responsible for dwindling groundwater supplies in western India, had become politically impossible to repeal based on the strength of farmer lobbies in these states (Mukherji, 2006). This experience, among others, created feelings of uneasiness towards agricultural subsidies on the part of many policy makers (Praveen Roa, personal interview, Hyderabad, March 5, 2015).

Ultimately, the subcommittee recommended that the CM establish an independent body within the Ministry of Horticulture to administer the subsidy, known as the Andhra Pradesh Micro Irrigation Project (APMIP). APMIP's target was to cover an additional 10,000 hectares per year under micro irrigation. This goal was very ambitious, given that prior to 2003, annual adoption of micro irrigation in India was around 75,000 across the entire country and almost none of this was in Andhra Pradesh. While the CM accepted the committee's recommendation, the realities of funding a subsidy program at this scale set in. International donor agencies balked at the program Ultimately, however, the National Bank Agriculture Development (NABARD) agreed to fund the first year of the program at a 6% interest rate, with future funding contingent on meeting the 10,000-hectare goal. In the first year, APMIP surpassed their goal and NABARD extended their funding (Reddy and Satyanarayana, 2010). The success of the program also served as a model for a national framework to support drip irrigation.

4.3.3 Selection of Drip on a National Scale: The National Mission on Micro Irrigation (NMMI)

Encouraged by Andhra Pradesh's success in meeting its targets for FY2003-2004, the Government of India (GoI) set up a National Task Force on Micro Irrigation in 2004. The Task Force which was asked to evaluate the design of APMIP and create a national policy for micro irrigation that would encourage widespread use across India. This process resulted in the Centrally Sponsored Scheme for Micro Irrigation, which was introduced nationally in January 2006. The scheme was updated in November 2010 and renamed the National Mission on Micro Irrigation (NMMI). The two schemes were very similar in design. The 2006 scheme, provided a 40% subsidy from the central government and mandated that states provide an additional 10% subsidy. The 2010 scheme increased the central government's contribution from 40% to 50%, while maintaining a 10% contribution from the states. For the purposes of brevity, I refer comprehensively to the subsidy program between 2006 and 2015 as the NMMI subsidy, since the general framework of the subsidy program changed very little over this period, despite the change in name (Government of India, 2010).

The NMMI program was intended by its creators to catalyze widespread adoption of drip irrigation across India (Official NCPAH, personal interview, March 3, 2015). The government argued that drip irrigation was necessary for both conserving India's dwindling water reserves, and raising yields and incomes for farmers (Government of India, 2010). While many subsidy programs in India for agricultural equipment such as tractors, borewells and solar pumps are quantity limited, so that only a limited number of subsidies are available at the local level (thereby limiting costs), the drip irrigation subsidy program was intended to be available to all who applied. Subsidizing 40% of the cost of drip irrigation equipment for any farmer who applied was a very large investment on the part of the central government.

Total spending on NMMI since 2006 has not been published by the government. While it is difficult to estimate exactly how much money has been spent on the drip irrigation subsidy program in India since its inception, data from 2013-2014 can be extrapolated for a rough estimate. In 2013-2014, the central government allocated $260 million to the NMMI subsidy program for a single year (Government of India, 2014). Given that the subsidy program has been ongoing since 2006 and even assuming that the allocation in 2013-2014 was higher than previous years, it is likely that between 2006 and 2014, the central government spent well over a billion dollars on the subsidy program to stimulate the drip irrigation industry in the country.[134]

The public policy justification given for the NMMI subsidy program was the "harnessing maximum benefits from available water resources." The first goal of the subsidy program was to

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[134] This is in addition to the money spent by state governments which varies significantly between states depending on how much additional subsidy the state offers.

“increase the area under micro irrigation through improved technologies” and the second goal was to “enhance the water use efficiency in the country” (Government of India, 2010, p. 3). Despite the significant text devoted to justifying the subsidy program in terms of water savings and other positive economic and environmental outcomes in the text of the NMMI guidelines, the guidelines do not address why public intervention is required to promote adoption of the technology. However, all actors involved in the NMMI implementation I interviewed said that the reason for the NMMI subsidy program is that capital costs of drip irrigation are too high for farmers to pay for themselves and without a subsidy program, drip irrigation would never reach *widespread use*.

The justification for the NMMI subsidy program rests on weak data. While drip irrigation almost unquestionable has the potential to increase water use efficiency at the plot level, the degree to which the technology saves water at the basin level is debated (Berbel *et al.*, 2015; Fishman, Devineni and Raman, 2015; Liebrand, 2017). It is likely that a significant proportion of the water that drip irrigation saves at the plot scale is not actually saved at the basin or aquifer scale. This is because water that is not used by the crop often percolates to shallow aquifers where it is used by other farmers. The amount of water lost to evapotranspiration differs by climate and crop, but in the context of a human environment like West Bengal, drip irrigation likely results in no net water savings at the aquifer scale. At the same time, evidence from India and Spain suggests that farmers who save water by using drip irrigation on one plot, often choose to expand their area under irrigation, reducing the total water savings from the adoption of drip irrigation.

Given this data, the ‘public good’ justification for subsidizing the adoption of drip irrigation for its water saving and environmental benefits is hard to defend. The other justification given for the NMMI subsidy policy are the benefits realized by the individual adopters who are able to increase yields, reduce labor costs and (depending on local circumstances) save money on the cost of irrigation. Policies that support increased agriculture productivity are not unique to the NMMI subsidy program. Much the public policy undergirding the Green Revolution in the 1970s and 1980s came in the form of government support to farmers in order to raise their yields (Chopra, 1985). The allocation of public money to support the Green Revolution was justified as an effort to secure the India's food security, prevent famine and alleviate poverty (Chopra, 1985). Today, India is largely food secure and already has the capacity to address localized famines through and extensive network of food reserves. The only remaining justification for spending public money on the NMMI subsidy program is poverty alleviation. But for this to be achieved, the NMMI subsidy program would have to benefit the poorest farmers. This I demonstrate in the Section 4.4 is not the case.

4.3.4 Implementation of NMMI at the State Level

While the central government set up the subsidy program in 2006, they left implementation largely to the states. States were given substantial independence to design their own implementation plans. States were asked to submit Annual Action Plans to the NMMI Executive Committee, and to send monthly data on subsidy disbursement to the National Committee on Plasticulture Applications in Horticulture (NCPAH), a small committee loosely affiliated with the Ministry of Horticulture, which was tasked with coordinating and monitoring the subsidy program.

Two key aspects of the NMMI program were standardized at the national level. The first aspect aimed to ensure that small and marginal farmers (those farmers with less than two hectares of land; 5 acres) benefited from the NMMI subsidy program, by allocating an additional 10% subsidy from the central government (Government of India, 2010). Many states also allocated their own additional subsidies to small and marginal farmers –often adding an additional 5% to the central government's 10% or running special limited time programs with added incentives for small and marginal farmers, to try to target this group.

The second aspect of the NMMI program, which was standardized at the national level, had to do with the physical design of the technology itself. Based on experience in AP, the government wanted to ensure that drip irrigation companies did not inflate their costs over market value. The concern was that with such a large percentage of the cost of the technology being paid for by the government, that "free-market" competition mechanisms would be ineffective at ensuring that private companies charged fair prices for their technology (Krish Iyengar, Executive Director NCPAH, personal interview, New Delhi, March 4, 2015). In order to ensure that companies neither inflated costs, nor skimped on system design and quality, the NMMI subsidy program outlined specific standards and prices for any drip irrigation equipment eligible for the subsidy program.

States began implementing the NMMI subsidy program in 2006. States varied markedly in their implementation plans. While Andhra Pradesh continued with its strategy under APMIP, which housed the drip irrigation subsidy program within an independent branch of the horticultural department, many subsidy programs were run with much less independence, often within existing programs in the states' agricultural or horticultural departments. Gujarat followed Andhra Pradesh's lead and set up an independent implementation agency, or special purpose vehicle, called the Gujarat Green Revolution Council (GGRC) (Pullabhotla, Kumar and Verma, 2012) . The GGRC differed from APMIP in that it was not housed within a government department, but rather was set up as a public company. This gave the implementing agency considerable independence and authority. The Chief Minister of Gujarat at the time, Narendra Modi (now India's Prime Minister), was deeply invested in the success of the GGRC subsidy program, believing that a more business-oriented subsidy delivery model would help his state improve agricultural productivity in the face of declining groundwater tables (Shyamal Tikadar, joint managing director GGRC, personal interview, December 26th, 2013). In order to make GGRC a success, Modi personally recruited a retiring senior officer from the prestigious Indian Foreign Service to serve as joint managing director, in order to set up GGRC, and ensure that the organization ran smoothly and cut through red tape (Liebrand, 2017).

Apart from variation in the institutional design of NMMI subsidy programs at the state level, the states also differed markedly in the amount of subsidy they allocated to the subsidy. States like Gujarat and Kerala kept their subsidy in-line with the NMMI's bassline policy of 50% (40% from the central government and 10% from the state), whereas states like Andhra Pradesh and Bihar, decided to add additional funding to the program, subsidizing drip irrigation for their farmers to the tune of 90% – even 100% at times in Bihar, for small and marginal farmers.

Interestingly, data collected in 2011 showed no correlation between the size of the drip irrigation subsidy provided by a state and the extent of drip irrigation adoption in the state (see Figure 4.3). Some states with lower subsidies, such as Maharashtra, had adoption levels as high as 25% of potential area. While other states, such as Bihar, who had 90% subsidies, had less than 1% adoption rates.

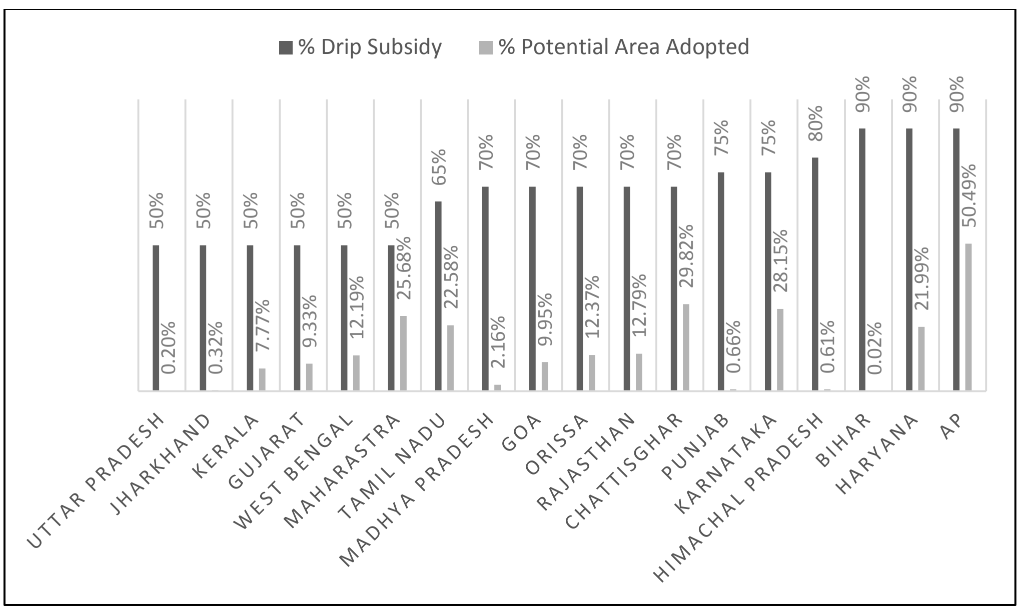

Figure 4.3: Percent subsidy for drip irrigation and percent potential area adopted by state in 2010
Source: (Compiled from Palanisami et al., 2011; Data provided by state governments)

The lack of correlation between size of the subsidy and overall adoption of drip irrigation across states, presents something of an empirical puzzle from a market economics perspective. Why were farmers in states that had 90% subsidies, like Bihar, adopting drip irrigation at such low rates, whereas farmers in states with only 50% subsidies were adopting drip irrigation much more widely?

Certainly, the answer lies in both the institutional design of the subsidy program, as well as in local characteristics of each state. But understanding exactly what institutional mechanisms and local characteristics favored the widespread use of drip irrigation technology is a useful empirical question. The first goal of the cross-state comparison in this paper (Section 4.4) is to better understand the factors behind the divergent rates of adoption of drip irrigation in India.

The second goal of the empirical design of the case studies, was to understand what institutional factors allowed for small and marginal farmers to adopt drip irrigation in some states more than others. Data from 2010 (Palanisami *et al.*, 2011) showed that in most states, adoption of drip irrigation by small and marginal farmers was below 20% of all adopters in the state – despite the additional 10% the NMMI subsidy targeted at this group (see Figure 4.4).

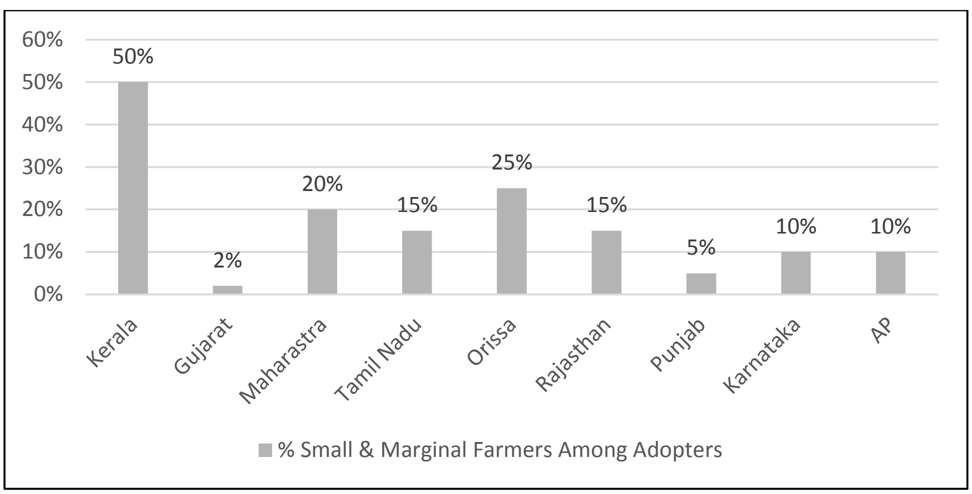

Figure 4.4: Percent small and marginal farmers among drip irrigation adopters by state in 2010. Sources: (Palanisami et al., 2011; Some data provided by state governments)

The lack of small and marginal farmers amongst drip irrigation subsidy recipients in most states is even more stark than appears from Table 4.4. This is because in most states in India, small and marginal farmers account for considerably more than 50% of farming households. Thus, if the benefits of the subsidy program were distributed evenly across socioeconomic groups, small and marginal farmers would make up the greatest share of drip irrigation subsidy recipients.

Clearly, benefits of the NMMI subsidy program are skewed toward wealthier farmers. My research question asked whether any state had begun to solve the problem, by designing mechanisms beyond the additional 10% subsidy, that would give small and marginal farmers greater access to the subsidy program. I selected Kerala, as the state with the greatest number of small and marginal farmers adopting drip irrigation, for a case study on one end of the spectrum, and Bihar and Gujarat, as states with low rates of adoption among small and marginal farmers (0.5% and 2% respectively). Andhra Pradesh, at 10% of small and marginal farmers among adopters, came in somewhere in the middle of the pack.

4.4 Analysis: Implementation of NMMI in Four States

4.4.1 Andhra Pradesh

Andhra Pradesh was the first state to develop a drip irrigation subsidy program (APMIP). Data from 2011 indicates that more than 50% of potential area in Andhra Pradesh is irrigated by drip irrigation technology. It was clear during field my fieldwork in the state that drip irrigation is in *widespread*, and that even farmers who have not adopted drip irrigation are still very well versed in the technology. This included both the physical and institutional dimensions of the technology (e.g. the availability of the subsidy program, the types of crops where drip irrigation is used, benefits associated with yield and labor).

Interviews with private sector drip irrigation companies suggest that the biggest barrier to increased adoption of drip irrigation in Andhra Pradesh is actually deteriorated performance of APMIP itself. One of the important institutional dimensions of APMIP that led to the initial success of the program was the decision for APMIP to pay subsidy money directly to the private sector drip irrigation companies based on proof of successful instillation of the drip system. This decision reduced upfront costs for farmers who under more typical subsidy programs would have to pay for the full cost of the system, submit paperwork to the government and then wait to be reimbursed for the proportion of the cost covered by the subsidy. Instead, under APMIP the private sector companies took on responsibility for ensuring the paperwork for the subsidy application was in order and they were able to charge farmers only the price of their drip system minus the subsidy amount. The government would then give the subsidy money directly to the drip irrigation companies' accounts after verifying that the drip irrigation system had been installed.

Initially APMIPs institutional design was very effective, and in interviews with the private sector officials in Andhra Pradesh, they credit the decision to pay subsidy money directly to the private sector with the rapid adoption of drip irrigation by farmers who did not have to come up with capital to pay for the full cost of the system, while waiting for the subsidy. However, starting around 2010, the government began to release the subsidy funds to the private sector companies far more slowly than they did in the early years of the APMIP scheme. This left the private sector companies with large accounts due from the government, which were often behind by as much as two years and several million dollars. In response, private sector companies began to slow down their growth in Andhra Pradesh to avoid ballooning their accounts payable to their own creditors. Due to the slowdown in reimbursements under the APMIP program, many private sector companies chose to focus their growth in other states, especially Gujarat.

In Andhra Pradesh, farmers felt that the biggest benefits of drip irrigation were increased yields and water savings. Water savings in Andhra Pradesh were important to many farmers who relied on diesel for irrigation and were able to cut their irrigation costs by using drip irrigation. However, the biggest benefit all adopters cited was increased and higher quality yields.

The biggest barrier to adoption of drip irrigation cited by non-adopters in Andhra Pradesh is the cropping cycle for farmers whose land is flooded during monsoon. The only crop that can be cultivated on low-lying land during monsoon is rice, which is not a crop that is grown with drip irrigation.[135] Farmers with low-lying land felt that they could not use drip irrigation in the other two seasons because removing, storing and then reinstalling the drip irrigation system during monsoon was prohibitive, both in terms of time and expertise required to reinstall the system.

A second barrier cited by non-adopters was access to the technology. One small farmer I interviewed said that he had inquired about drip irrigation but was told by the dealer that there was a back-log in applications for the subsidy and that he would have to wait at least a year. In interviews with the private sector and equipment dealers, I learnt that the back-log was not due to a waitlist for the APMIP subsidy scheme itself, but due to the intentional slowing-down of business on the part of the private sector suppliers, who were waiting for APMIP to reimburse them for earlier work.

The biggest barrier to adoption of drip irrigation in Andhra Pradesh by small and marginal farmers was the lack of incentives for equipment dealers to work with small and marginal farmers. This was confirmed by all three dealers I interviewed in the state. Instead, equipment dealers prefer to work with larger farmers because they earn a much larger commission working with larger farmers, not only because the size of the drip system is usually larger, but also because working with small and marginal farmers is usually more time consuming. One dealer explained, "I don't spend more time convincing a large farmer to buy drip irrigation, rather I spend more time explaining the system to a small farmer. This means that I save time if I work mainly with larger farmers and because they are often buying a larger drip system, I get a larger commission as compared to the time I spent selling the system." Poorer farmers, drip equipment dealers explained, require more hand-holding through the entire application process and more

[135] Some agronomists including scientists at JAIN irrigation have demonstrated benefits of drip irrigation in rice cultivation, but using drip on rice was not in widespread use at the time of fieldwork.

training on how to use the equipment. All three equipment suppliers said that they targeted their outreach and marketing toward medium and large landholders and only worked with small and marginal farmers when the small and marginal farmers directly approached the dealers. Of the three equipment dealers I interviewed, two estimated that small and marginal farmers made up less than 10% of their business. One equipment dealer estimated that small and marginal farmers made up 25% of his business because he worked in an area of the state where the majority of landholders were smaller. He also said the percentage of his client base made up of small farmers had grown over the years as most of the medium and large farmers had already adopted drip irrigation on their land. He also said that while small farmers made up 25% of his clients, very few of his clients were marginal farmers with less than 1 hectare of land.

4.4.2 Bihar

My own survey of 498 households in Bihar found only one farmer who had adopted drip irrigation. This finding supports other estimates of drip irrigation adoption in Bihar being less than 1% of land area in the state. Overall, Bihar is a case of both very low overall adoption and close to no adoption by small and marginal farmers. In fact, one equipment dealer I interviewed told me that except for a few NGO-led projects he was unaware of any marginal farmers in the state who had received the NMMI subsidy. Moreover, 80-90% of his clients are large farmers with more than 10 hectares of land, which means that few medium sized farmers in the state are not benefiting from the NMMI subsidy program.

My first visit to the office responsible for implementing the NMMI scheme in Bihar helped explain these empirical findings. While most government departments I visited in Bihar were chaotic and stacked with paper records, the chaos was active and one got the sense that things were getting done even if not always efficiently. The department responsible for implementing the drip irrigation subsidy program was not like this. It was dark, musty, and the lone computer looked like it had been purchased before the turn of the millennium. In total, only three government employees work on Bihar's NMMI program when I visited and only one of the three was capable of working with a computer.

The management of the NMMI program by the government of Bihar is the biggest barrier to growth of the subsidy program in Bihar according to three different private sector company officials I interviewed. One major challenge the private sector faces is long delays getting the government to verify instillation of the drip irrigations systems so that subsidy funds can be released. In addition, subsidy funds are released to the farmers themselves and not to the private sector companies. That means that farmers either have to pay the full cost of the system up front and wait to be reimbursed by the government which can take over a year, or the private sector agrees to wait until the farmer has received the subsidy to take full payment for the system from the farmer. While private sector companies do not like to do this because it raises transaction costs and opportunities for farmers to attempt to avoid payment, dealers say that most farmers will not adopt drip if they have to pay the full cost of the system upfront.

The main mechanisms through which the poor implementation of the subsidy program in Bihar hampers adoption of drip irrigation is private sector avoidance of the market altogether. What made the APMIP program successful is that the private sector took the responsibility for outreach and marketing to farmers, which spurred adoption in the Andhra Pradesh. In Bihar, Jain Irrigation's office in the capital of Bihar had only eight employees when I visited in 2015. This stood in stark contrast to their operation in Gujarat which had over fifty employees in the central office in addition to multiple satellite offices. This example is reflective of other private sector drip irrigation companies in Bihar who mostly only have a few employees in the state focused on larger clients.

Adopters of drip irrigation in Bihar are happy with their investments. In fact, many farmers had managed to bypass the rules of the subsidy program by applying in the name of more than one household member and had received the subsidy package more than once. Farmers cited increased yields, decreased labor costs and decreased costs of irrigation as the main benefits to adoption. Farmers who irrigated using high-cost diesel, rather than low-cost electricity were the happiest with drip irrigation because it significantly reduced their costs. One farmer estimated that he would recoup his investment in less than half a season.

While in theory, there might be many barriers to adoption of drip irrigation by small and marginal farmers in Bihar, such as lack of well-ownership, in practice, the limiting barrier is simply that small and marginal farmers have never heard of drip irrigation. In the survey of 498 households in Bihar, only 15% of all farmers had even heard of drip irrigation or knew what it was. Moreover, only 11% of small and marginal farmers said they had heard of drip irrigation.

4.4.3 Gujarat

My first visit to the implementing agency responsible for the NMMI program in Gujarat, the Gujarat Green Revolution Council (GGRC), was impressive. The GGRC offices took up perhaps a city block, were immaculate, and had no stacks of paper or clutter because all records were digitized. GGRC had even hired their own external evaluators, and shared their reports with me when I arrived. They also shared all of their raw data including GPS coordinates of the subsidy recipients as well as copious details about each farmer who had adopted drip irrigation through the GGRC system. I was most impressed on the following day, when I used the list they sent me to randomly visit villages and track down farmers in their data set. Out of the seven farmers I interviewed, who I randomly selected from the GGRC data, all seven of them were actively using the drip irrigation systems they had received through the GGRC subsidy in their fields. Some of these households had drip irrigation systems older than five years (n=2) that were still functioning well. This finding stood in contrast to published journal articles on adoption of drip irrigation in the developing world, which showed high rates of disadoption among farmers (Friedlander, Tal and Lazarovitch, 2013).

While 2011 data showed Gujarat significantly behind AP in terms of percent of potential area under drip, estimates from 2015 showed that the GGRC program had the highest annual rate of adoption of any state in India (Liebrand, 2017). Private sector companies explained that the business environment in Gujarat was the best of all states in India. The GGRC program had built on the success of APMIP, but by making GGRC an autonomous organization, the bureaucratic red tape the companies were used to dealing with in other states, was practically non-existent in Gujarat. While the subsidy application process required a lot of paperwork, the paperwork was streamlined, could be entirely completed by equipment dealers and supplier company staff and was always processed efficiently by the GGRC.[136] Most importantly, the GGRC reimbursed private sector suppliers within three to four months. Simply put, the cost of doing business in Gujarat was low and this incentivized private sector companies to hire more staff and build more capacity in the state.

The 13 farmers who I interviewed that had adopted drip irrigation all cited increased yields and decreased labor costs as the main benefits of the technology. Only one household was interested in the water-saving characteristics of drip irrigation and this was not because of the high cost of water (he paid a monthly flat rate for electricity) but rather because he was intrinsically concerned with the declining groundwater in the state and wanted to do his part to concern water.

Two major barriers to adoption of drip irrigation were identified both by the farmers I interviewed and the staff of GGRC. Both barriers had to do with water access. First, in areas where farmers own their own wells, growth in drip irrigation adoption was high. But in regions where farmers use large communal wells and were thus uncertain about when they would be able to access water, using drip irrigation technology proved more difficult and adoption rates were significantly lower. A second major barrier for

[136] One interesting proposal discussed by GGRC staff was their efforts to include iris-scanning in the subsidy application process as part of their effort to prevent the same farmer from receiving the subsidy more than once in a 10-year period. To an American, this idea struck me as invasive of privacy, but did show the lengths GGRC would go to foster transparency in the subsidy program.

many farmers in Gujarat is land fragmentation – the more individual pieces of land a farmer owns the more difficult it was to adopt drip irrigation due to fixed costs associated with each individual plot of land.

Overall, out of the five equipment dealers I interviewed, one said that about 15% of his client base are small and marginal farmers; three equipment dealers said that small and marginal farmers made approximately 10% of their clients; and one said that he only worked with large farmers because "I have more business than I can handle only working with large farmers, so why would I do anything else?". However, given that Gujarat has a much smaller overall proportion of small and marginal farmers (25%) the ratio of adoption among this group is higher than in any other state. When I asked dealers about this, they said that like in Andhra Pradesh, they had less incentive to market to small and marginal farmers because their profit margins are lower. However, because the GGRC often implements short-term additional subsidies for small and marginal farmers that they advertise widely through radio, small and marginal farmers approach the dealers themselves after seeing drip irrigation in their neighbor's fields and hearing on the radio that there is additional subsidy available for them. The dealers even said that they thought the short-term subsidy offerings were useful in spurring interest by small and marginal farmers because the limited time window served to overcame inertia on the part of farmers.[137]

Dealers said that while their profit margins were lower when working with small and marginal farmers, they thought the main limiting factor preventing small and marginal farmers from adopting the technology was water access. Small and marginal farmers they said faced the greatest barriers adopting drip irrigation because they are also usually water-buyers. Borewells in Gujarat are expensive to build because the water table is very low (often 500-700 feet). Small and marginal farmers cannot afford the

[137] This is a very interesting finding that merits further exploration through the lens of behavioral economics. It also is supported by findings from Kenya, that behavioral incentives can encourage farmers to buy fertilizer when they otherwise might now (Duflo, Kremer and Robinson, 2011).

capital investments for a borewell and buy water from other farmers. As water-buyers, they have less certainty over when they will be able to access water from their neighbor. They are thus unable to use drip irrigation technology which requires a high degree of control over timing of irrigation.[138]

4.4.4 Kerala

I originally selected Kerala because it was one of the few states that had high rates of small and marginal farmer adoption of drip irrigation – indeed small and marginal farmers make up 50% of farmers adopting drip irrigation in the state. What quickly became apparent during my fieldwork, was that in the case of Kerala, small and marginal farmers did not serve as a good proxy for the "poorest" farmers. Indeed, many of the households I interviewed, despite having landholdings under two hectares, were wealthy households whose members had often returned from working in the Gulf states or who had children working in high-tech industries in the United States.[139] Only four out of the 11 households who had adopted drip irrigation saw agriculture as their primary source of income. For seven households, agriculture was largely a retirement activity. Moreover, the two equipment dealers I interviewed both said that about 85% of their clients have landholdings in the small and marginal range.

The primary reason for adopting drip irrigation amongst farmers in Kerala was labor costs. Because Kerala's labor force is highly educated with many opportunities outside the state, hiring daily labor for agriculture is expensive, and the main value drip adopters saw from the technology was the ability to reduce either their labor costs or their own labor field. One farmer, with one and a half acres of

[138] Note: This is a feature of all field-level water conservation technologies including the system of rice intensification. In order for a farmer to irrigate her field less on one day, she must be confident she will have access to irrigation on day 2 when she needs it to keep her crop sufficiently irrigated. If she is uncertain about when she will next be able to access water, she is better off using traditional irrigation methods which ensures residual water is available to the plant between irrigations.

[139] In fact, out of the 11 households I interviewed who had adopted drip irrigation, six of the households had immediate family members who either currently worked or used to work as high-income professionals in Gulf countries or in the United States as doctors, nurses and data scientists. A seventh household was a retired professor at the Indian Airforce Academy in New Delhi and his large home garden for which he had received a subsidized drip irrigations system was his retirement hobby.

land, said that because the cost of hired labor was just over $9 USD per day, he mostly watered his field himself, spending five to six hours a day watering his vegetable crop. With drip, his time investment is now under 15 minutes. He said drip irrigation had significantly improved his well-being because now "I have more time to grow plantains near the house and more time to spend with the children which my wife appreciates."

Out of the 11 households I interviewed who had adopted drip irrigation, 11 cited labor costs as the primary reason for adopting the technology and nine also cited increased yields. Only two households mentioned water savings as a reason for adopting drip irrigation and in both cases, this was a secondary benefit to the labor saving dimensions of the technology.

Most of the households I interviewed had learnt about the drip irrigation subsidy after being approached by drip irrigation dealers in their district. Out of the 11 households, eight had decided to adopt drip irrigation after a dealer visited their home; two learnt about drip irrigation from their local government extension officer, who had then put them in touch with a drip irrigation dealer; and one had read about the subsidy in a newspaper advertisement paid for by a local drip irrigation dealer and then approached the dealer directly.

Based on interviews with three farmers who had not adopted drip irrigation in Kerala, as well as with two equipment dealers and two representatives of drip manufacturers, a major barrier to adoption of drip irrigation in Kerala is a result of the design of NMMI and local characteristics of agriculture in the state. Many farmers who practice agriculture as their primary income source, lease land from wealthier households who have moved out of agriculture into other careers (many outside the state). Because they are leasing their land, they are ineligible for the NMMI subsidy. Moreover, they are uninterested in making long-term capital investments in the land they lease. This barrier was raised by two farmers, two dealers, one private sector official, and one government extension officer.

Another factor slowing the rate of growth of drip irrigation adoption in Kerala is lack of private sector participation. One of the private sector companies said that because landholdings in Kerala are small, their own profit margins in the state are also lower, so they have less incentive to invest in growth. This private sector official suggested that in states with smaller farmers, the private sector should be given greater incentives to do business. In addition, the design of the subsidy program in Kerala sends the subsidy money to the farmer rather than the drip irrigation company which also limits growth in the state.

4.4.4 Comparing NMMI Across Four States

Looking across the four states, the variation in overall success of the NMMI subsidy program is driven by the design and implementation of the subsidy programs at the state level. It is not driven by the percent subsidy provided to farmers in each state. This is initially counter intuitive from a purely economic incentive perspective and underscores the importance of institutions in the functioning of innovation systems.

Adoption in both Andhra Pradesh and Gujarat is far higher as a percentage of potential land area than in either Bihar or Kerala. And while Gujarat was behind Andhra Pradesh, the state is quickly catching up. The reason for these differences in overall adoption rates is the institutional design of the subsidy implementing agencies. In both the case of Andhra Pradesh and Gujarat, the chief ministers of both states took a personal interest in the implementing of the drip irrigation subsidy program and appointed directors of the programs with the necessary authority and resources to create an effective implementing agency.

In the case of Andhra Pradesh, the chief minister established APMIP before even the national scheme had been developed and convened a Task Force of high-level officials to think through an effective institutional design for APMIP that would create the right incentives for the private sector to do the "last mile" extension work connecting farmers with drip irrigation.

In the case of Gujarat, the chief minister at the time the GGRC implementing agency was established was Narendra Modi who is now the Prime Minister of India. To ensure that GGRC had both an effective institutional design as well as the authority to implement the program, Modi hired a retired foreign service officer (a coveted and highly sought after position in India that only the brightest students achieve) to design and implement the GGRC program. He also ensured that GGRC controlled a large fund that allowed GGRC to repay private sector companies quickly, thereby reducing risk to the private sector and making Gujarat that most attractive state for private sector retailers to focus their growth and hire dealers to market their products to farmers.

In contrast, the offices responsible for implementing the subsidy program both in Bihar and Kerala sit within larger ministries and are only one piece of their minister's overall prevue. The individuals tasked with implementing the subsidy program in both states have very little authority or control over their own budgets.

One important institutional innovation of both the APMIP and GGRC programs was to give the subsidy money directly to the private sector rather than passing it through the hands of the farmers. This substantially improved the overall functioning of the subsidy system and also incentivized the private sector to take over responsibility for farmer outreach and marketing.

In Bihar and to some extent Kerala, where the NMMI subsidy program is not run through a separate implementing body and where the subsidy is given directly to farmers, the private sector has found the business environment less stable and has not invested in growth and marketing in the state.

Only Gujarat has succeeded in designing institutional incentives to promote drip irrigation among the poorest farmers (with the caveat that almost all farmers in Kerala are small and marginal and that landholding size is not a good proxy for assets in the state). Gujarat, by advertising short term additional subsidies directly to small and marginal farmers has spurred interest in the technology for the poorest farmers. They have also overcome the private sector and equipment dealers' reluctance to work with smaller farmers by finding ways to get small and marginal farmers to approach the private sector.

In all states, the equipment dealers highlighted the smaller profit margins they receive when working with small and marginal farmers. This suggests that the NMMI design, which targets additional funds towards small and marginal farmers, has not aligned incentives structures appropriately to achieve the goal of increased adoption by small and marginal farmers. Instead of offering small and marginal farmers themselves increased subsidy, it may make more sense to provide additional incentives to equipment dealers and the private sector more broadly to work with this group. I summarize the findings from the four states below (see Table 4.3).

Table 4.3: Comparison of performance of NMMI across four states.

State	Ave % of small and marginal farmers in dealers' client base	# of Dealers Interviewed	Summary of Key Findings by State
Andhra Pradesh	15%	3	• Equipment dealers and private sector concerned about management of APMIP. Slow re-payment from government. • Barriers to increased overall adoption include institutional incentives for private sector and agroecological conditions. • 80% of farmers in the state are small and marginal. • Small and marginal farmers originally made up a small percent of subsidy recipients, now that most medium and large farmers who are interested having adopted drip, some dealers are targeting small farmers more.
Bihar	3.5%	2	• Equipment dealers in Bihar say that over 85% of their clients are medium and large farmers with over 10 acres of land. • In Bihar, 97% of farmers are small and marginal. Less than 2% of farmers in Bihar have landholdings above 10 acres. At the same time, the two equipment dealers estimate that less than 5% of their clients are small farmers, and none are marginal farmers. • Neither equipment dealer recalled selling drip irrigation to marginal farmers through the NMMI program. • Only project where marginal farmers in Bihar have drip irrigation are through NGOs, and very few small farmer adopters.
Gujarat	9%	5	• GGRC subsidy program very effective. Private sector companies focusing growth in Gujarat because of design and stability of GGRC program, which creates good business environment. • Small and marginal farmers make up approximately 25% of farmers in the state, which means that proportionally Gujarat is also doing better than Andhra Pradesh in reaching this group. • Gujarat has designed effective incentives to target small and marginal farmers through short-term additional subsidies for this group. The GGRC advertises these short-term subsidies through radio. • Major barrier to adoption by poorest is lack of well-ownership.
Kerala	85%	2	• The majority of farmers in Kerala who buy drip irrigation through the subsidy program belong to the small and marginal category. • 96% of farmers in the state are small and marginal • Landholding size in Kerala is not well correlated with overall assets. • Major barrier to adoption is high rates of land-leasing amongst Kerala's farmers who lease from wealthier households who have moved out of agriculture.

4.5 Findings: NMMI Delivers Mixed Results

4.5.1 NMMI at the National Level

There are also two major barriers preventing the poorest farmers from benefiting from drip irrigation at the national level.

Data Collection: The NMMI scheme is centrally managed in Delhi. Despite the large overall budget under NMMI, management of the scheme at the national level is relatively small. The office responsible for collecting data on the states' implementation of the subsidy program (NCPAH) has a modest staff, who do not work full time on the NMMI scheme, but rather focus on multiple schemes and programs related to the use of plastics in agriculture. While I was unable to convince NCPAH to share their data with me, I was able to obtain the monthly reports sent to NCPAH from the implementing agency in Kerala. If the reports that NCPAH collects from Kerala are similar to those used in other states (and it appears to be a standard form) then NCPAH receives no socioeconomic data about subsidy beneficiaries from the states. Kerala did not send demographic data such as caste, religion, income or total landholdings of subsidy recipients to NCPAH. Failure to collect socioeconomic data on the part of NMMI calls into question the strength of the programs commitment to ensure benefits of the technology are realized by small and marginal farmers.

Design Standards: The NMMI subsidy program set technical standards for all drip irrigation equipment covered by the subsidy. The original intention of these standards was to ensure that the private sector did not sell sub-par equipment under the subsidy scheme. This was a significant concern because with such a large percentage of the overall cost of the system provided by the public sector, it could limit incentives for individual buyers to ensure they were getting the best product, especially in areas with limited competition between drip irrigation sellers. However, the technical standards had an unintended effect in that they excluded low-cost drip irrigation designs from the subsidy program. For example, NMMI mandates that the minimum thickness of pipes used for drip irrigation should be no less than 600 microns. The thickness of the pipes is a major component of the entire system cost, and because of low-cost systems all have pipes that are below 600 microns, this standard excludes low-cost systems from the NMMI subsidy program (Sarah Huber, DripTech India, personal interview, March 23, 2015).

Low-cost drip irrigation designs are often more appropriate for small and marginal farmers. For example, they are easier to install and uninstall, which means that small and marginal farmers can easily store them in monsoon season during their paddy crop and then use them again in winter and summer for vegetable crops. However, due to the exclusion of low-cost systems from NMMI's design standards, low cost drip irrigation companies have a difficult time competing in India and have mostly focused their efforts on other countries. This limits availability of low cost drip irrigation systems on the market in India. DripTech, a low-cost drip irrigation provider in India says that in most states their systems are "costed out" by the NMMI subsidy. Because of this, they focus their business growth in states with low overall subsidies and where the subsidy program is poorly implemented, so that farmers often choose to purchase drip irrigation without the NMMI subsidy (Sarah Huber, DripTech India, personal interview, March 23, 2015).

4.5.2 Success of NMMI: Public Incentives for Private Extensions

Measured against drip irrigation adoption, the NMMI program has been a qualified success. Many states in India have succeeded in spurring *widespread* adoption of drip irrigation. Moreover, farmers who have adopted drip irrigation through the NMMI program, report positive benefits and cost recovery periods of under two years (and often as little as six months).

Supporters of the NMMI subsidy policy in India claim that the main mechanism that has moved drip irrigation into *widespread use* is decreased prices to end users as a result of the subsidy program. While this is partly true, the four cases analyzed in this chapter demonstrate that decreasing prices to end users alone is not enough to encourage *widespread use* of the technology. If it were, Bihar with a 90% subsidy should have higher rates of drip irrigation adoption than Gujarat with a 50% subsidy. Instead, the results of the case studies demonstrate that the institutional design of subsidy implementation programs is important in explaining overall adoption across states.

The APMIP and GGRC programs aligned incentives between actors in the public and private sector. Under the APMIP and GGRC subsidy programs, the states created institutions that created stable and attractive business environments for the private sector. This required providing a subsidy to decrease costs to end users, but more importantly it required ensuring that the subsidy program functioned efficiently. Under these conditions, the private sector focused on growth in Andhra Pradesh and Gujarat, and took over responsibility for "last mile" technology marketing and delivery. In Bihar and to some extent Kerala, the states failed to create institutions that assured the private sector of stability and growth and the private sector in turn did not provide "last mile" technology delivery to the same extent as in Gujarat and Andhra Pradesh.

4.5.3 Subsidies for Whom? Failure of the NMMI Program to Benefit the Poorest Farmers

Despite the success of the NMMI subsidy program in spurring widespread use of drip irrigation in several states in India, the program has been much less successful in benefiting small and marginal farmers. There are two primary reasons for this.

First, the Task Force that designed the NMMI program wanted to ensure that small and marginal farmers also benefited from the subsidy scheme. To do this, they designated an additional 10% subsidy for small and marginal farmers. However, this additional 10% was largely ineffective because the equipment dealers responsible for "last mile" extension of drip irrigation face higher transaction costs when working with small and marginal farmers, with no extra benefit. Discussions with equipment dealers led me to believe that if the dealers received a higher commission for working with small and marginal farmers, their incentive structure would change and adoption amongst this group might rise. The extra subsidy currently targeted at small and marginal farmers under the current NMMI guidelines could be split between marginal farmers and dealers or additional subsidy funds could be allocated for dealers. Alternatively, the quantity of subsidies given to larger farmers could be decreased, especially given limited evidence of public benefits (such as aquifer-scale water savings) from drip irrigation and these funds could be reallocated towards small and marginal farmers and equipment dealers.

Second, the standards set by the NMMI subsidy program exclude low-cost drip irrigation systems, which are often most appropriate to the needs of small and marginal farmers. This has caused low-cost drip irrigation systems to disappear from the market in many states in India. This may be changing, as states such as Karnataka consider ways to include low-cost drip irrigation in their subsidy programs (GGGI, 2015). It is likely that discussions in Karnataka about low-cost drip irrigation and even inquiries from researchers like myself have prompted interest in how NMMI can be re-designed to include low-cost system drip irrigation systems and better meet the needs of small and marginal farmers. What is more, larger drip irritations companies may be sensing change on the horizon – JAIN irrigation decided to invest in low-cost drip irrigation technology by buying DripTech, in late 2015.

4.6 Discussion: Public Led Market-Creation for Public Benefit?

The successful spread of drip irrigation in India sheds light on the strengths of the private sector in "last mile" technology delivery. Successful implementation of the NMMI subsidy program in some states has placed India among the top markets for drip irrigation globally (Research Nester, 2017).[140] It has also helped India's home-grown drip irrigation company, JAIN Irrigation Systems Ltd, become one of the largest players in the business with 980 million USD in revenue in 2014-2015 . At the same time, the

[140] My guess is that India is the leader in drip irrigation sales, but I would have to pay over 2,000 USD for access to the market research to confirm this (Research Nester, 2017).

failure of the program to encourage adoption by small and marginal farmers, shows that relying on the private sector for "last mile" technology delivery can easily exclude the poorest farmers.

The states that were the most successful in realizing widespread use of drip irrigation in India aligned incentives between public sector goals and private sector profits. The states focused on creating a stable and high growth business environment for the private sector. Understood this way, the NMMI subsidy program is not only as a tool for decreasing the required capital expenditure on the part of farmers to adopt the technology, but rather is a tool for catalyzing an entire innovation system through government-led "market-creation" (Mazzucato, 2016). The NMMI subsidy program can be scrutinized as a large-scale effort to support the emergence of a new market and industry. From a policy perspective, given the size of the publicly funded investment in market-creation, the government should demand more from the private sector in return for its investment.

The failure of drip irrigation in India to benefit the poorest farmers is a result of decisions made in the design of the subsidy program, including failure to add additional incentives for the private sector to work with small and marginal farmers. These decisions also included those made about technology standards that excluded low-cost drip irrigation, alternatives which are more appropriate for the needs of small and marginal farmers. Future iterations of the NMMI subsidy program should focus on realigning incentives for the private sector so that the poorest farmers realize more of the benefits from the NMMI subsidy program. The government can do this by offering specific financial incentives to the private sector equipment dealers for working with the poorest farmers, by marketing specific subsidies directly to the poorest farmers (like in Gujarat), and by limiting the availability of the subsidy for medium and larger farmers.

Appendices

Appendix 1. A note on caste categories, monetary conversions, and translations.

Caste Categories

Caste is at once a central concern of any research project on poverty in India and at the same time a complicated social construction for which there is a great deal of scholarship. For the purposes of this dissertation, a lengthy discussion of caste and caste politics would take use too far afield. I will use the terminology in common use in Bihar to refer to different caste groupings and occasionally refer to specific castes (*e.g. Yadavs*) with reference to the larger category they are generally categorized in (*e.g. Yadavs* in Bihar belong to the OBC category).

The caste groupings include:

1. "upper castes" (UC). These castes have traditionally formed India's elite. In Bihar, the major forward castes have traditionally controlled the vast majority of agriculture land.
2. The lower castes are grouped into several categories. The first, known as "other backward castes" or OBCs are generally the most socially and economically empowered of the lower castes.
3. Scheduled Castes and Scheduled Tribes (SCs and STs) are a level below OBCs in terms of the social and economic empowerment.

Caste categories are officially recognized in legislation and are eligible for affirmative action programs known as reservations. This in turn has led to extreme politicization of the classification process with different castes groups jockeying to be classified in a lower category, eligible for greater reservations from the State.

It is also worth noting, that the most common way to refer to the three caste categories is to use acronyms to describe OBC and SC/ST castes, but to use the full words when describing UC castes (upper castes). I find this discrepancy unfairly biased and use acronyms in most cases to describe all three groups. I sometimes continue to use the full spelled out version when the use of the caste category is meant as an adjective rather than a noun (*e.g.* upper caste hegemony; lower caste empowerment).

Monetary Conversions

In this dissertation, monetary values are usually important in a relative context within the agriculture systems I study. I have therefore used a single exchange rate to convert from *rupees* to dollars of 65 to 1. Over the course of my fieldwork, the exchange rate fluctuated between 60 and 70 to 1. This midpoint seemed like the best choice for consistency sake. Results are never dependent on the exact conversion. I chose to mostly work in dollars rather than rupees because it is more straightforward for most readers.

Translations

In an effort to make this dissertation as easily readable as possible, I have limited my use of Hindi to a few key words which I always used in *italicized* lettering. I explain the meaning of all Hindi words on first use in the text. Below is a list of Hindi words used with their translations.

- *Kranti:* Revolution

- *rupee:* Indian currency
- *Sri-vidhee:* Sri in Hindi means respected. In Bihar, the technology SRI is often called *Sri-vidhee* so that Hindi speakers translate the term as respected method.
- *tola:* Hindi word to describe a sub-unit of a village or hamlet.
- -*walla:* Hindi expression often used to create a rhyming or musical cadence. Used in the context of rubber pipes, which all farmers refer to as rubber-*walla* pipes. The *walla* serves no linguistic purpose other than to embellish the name.
- *ryotwari:* Revenue collection system put in place by the British Colonial Government in other parts of India (i.e. not Bihar).
- *zamindar (n) (zamindars (pl); zamindari (adj):* landlord or large landholder. In Bihar, under British colonial rule, the *zamindars* were responsible for revenue collection. Today the word is still used at times to refer to large landholders.

Appendix 2. Additional figures and tables for Chapter 2

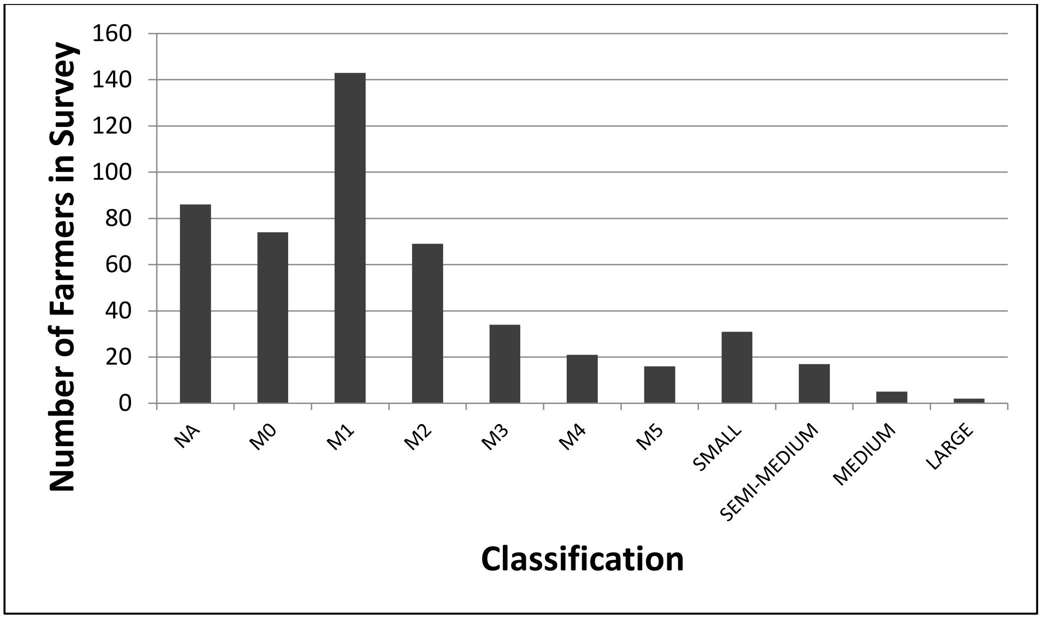

Figure A1: Distribution of farmers in survey by landholding classification.

In India, standard classifications run from marginal to large, but in Bihar, so many farmers fall within the marginal classification, that I have further subdivided the marginal category into six sub-classifications (M0-M6). M0 means that farmers have no land, but practice agriculture either on a sharecropping basis or less frequently by leasing land from other farmers. M1 are farmers that have up to 0.5 acres of land. M2 farmers have between 0.5 and 1 acres. M3 farmers have 1 to 1.5 acres. M4 farmers have 1.5 to 2 acres. M5 farmer have 2-2.5 acres. Small farmers have 2.5 to 5 acres. Semi-medium farmers have 5 to 10 acres. Medium farmers have 10-25 acres. Large farmers have 25 acres or more.

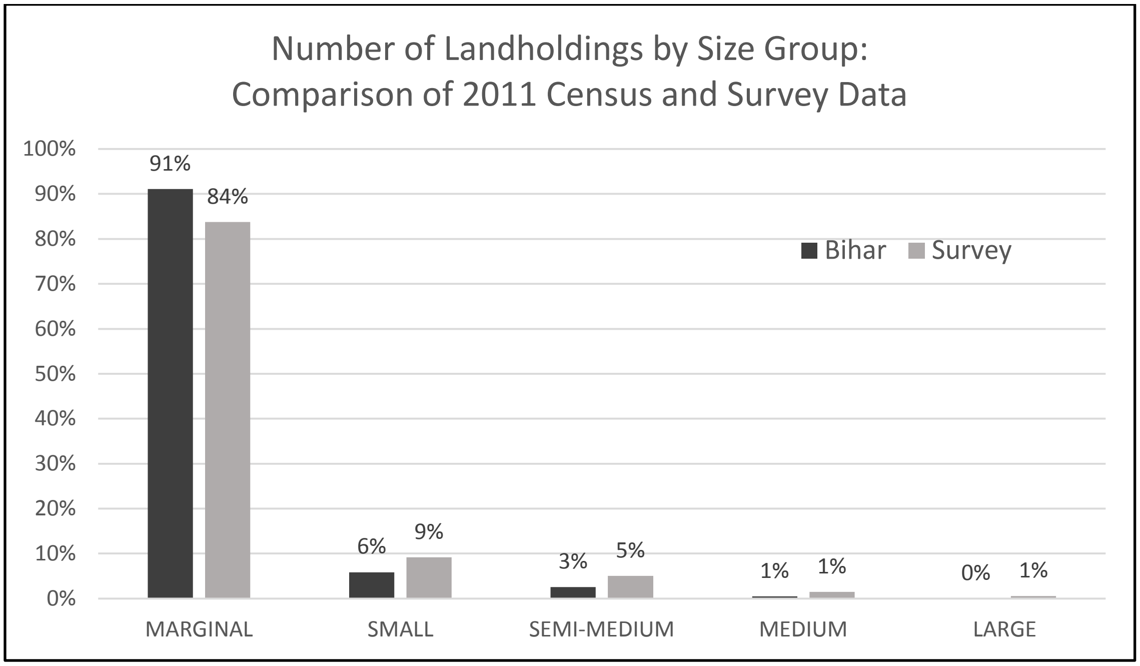

Figure A2: Comparison of survey data and distribution of size classes of farmers in 2011 Census.

In order to have sufficient data on larger classes of farmers, small, semi-medium, medium and large farmers were all slightly oversampled in survey. This was done by ensuring that all tolas in each village we surveyed were randomly sampled (rather than randomly sampling at the village level). Because there is usually caste (and wealth) based stratification at the unit of the tola, sampling at the tola unit, ensured greater representation in the data set of larger farmers than background rates. As we are interested in within-group technology adoption rates, this improved the quality of our data for larger farmer's without skewing the findings

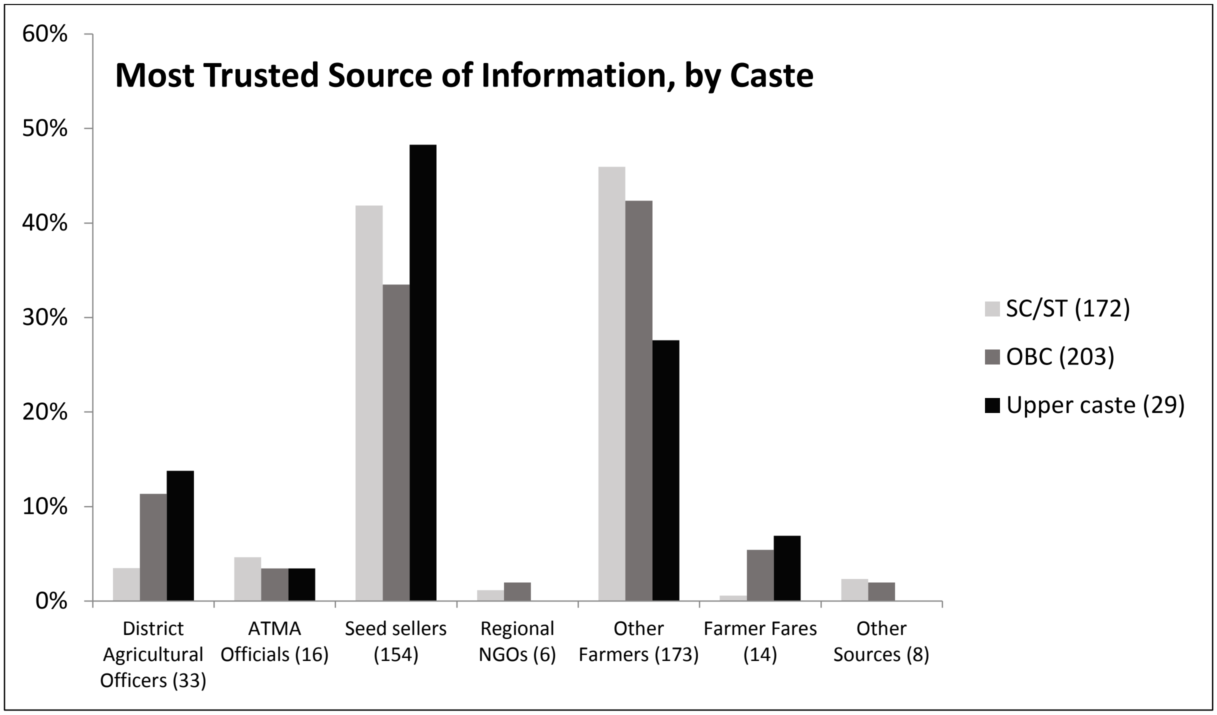

Figure A3: When farmers were asked from a multiple-choice list what was their most trusted source of information, the majority across castes answered either other farmers or seed sellers. Other farmers are the most trusted sources for OBC and SC/ST farmers followed closely by seed sellers. For UC farmers, seed sellers are the most trusted source followed by other farmers and district agriculture officers.

Table A1: 2008 Agricultural Road Map financial outlay (USD Million) overview.

Source: (Compiled by author based on data from 2008 Agriculture Road Map)

Name of scheme	2008-09	2009-10	2010-11	2011-12	Total	Percent of Total
Seed plan	10.2	10.8	11.6	11.6	44.1	8.3%
Soil health management	11.7	16.0	20.7	22.6	71.0	13.4%
Crop protection	5.9	5.8	5.0	1.0	17.8	3.3%
Farm mechanization	12.2	13.7	13.8	15.4	55.1	10.4%
Transfer of technology	6.0	6.6	7.2	7.6	27.4	5.2%
Financial implications for para extension workers	7.8	7.8	-	-	15.6	2.9%
Agricultural extension (E- Kisan Bhavan)	7.5	6.3	6.3	-	20.1	3.8%
Integrated farming model	0.1	0.2	0.5	0.7	1.5	0.3%
Soil & water conservation	1.8	1.8	1.8	1.4	6.9	1.3%
Micro irrigation	8.8	16.3	25.2	26.0	76.2	14.3%
Agricultural marketing development	62.3	48.0	42.7	42.7	195.7	36.8%
Total Agricultural Budget	134.4	133.4	134.7	129.1	531.5	100.0%
Source: Compiled from Government of Bihar 2008 Agriculture Road Map. All rupee to dollar conversions have been done using a 65 to 1 exchange rate.						

Table A2: 2012 Agriculture Road Map financial outlay (USD Million) overview.

Source: (Compiled by author based on data from 2012 Agriculture Road Map)

Name of scheme	2012-13	2013-14	2014-15	2015-16	2016-17	Total	Percent of Total
Integrated seed village and crash seed programs	4.6	3.1	3.2	3.4	3.5	17.8	1%
Seed subsidy program	17.9	20.3	23.2	26.9	30.5	118.8	6%
Soil fertility management	63.4	70.6	79.4	86.8	99.2	399.3	22%
Establishment of quality control laboratory	7.6	5.4	6.3	5.6	5.1	30.0	2%
Agriculture mechanization	58.4	87.1	122.4	148.9	185.9	602.7	33%
Agriculture extension	86.7	105.3	131.3	153.6	155.3	632.1	34%
Integrated watershed development	6.1	6.7	6.6	7.2	6.1	32.6	2%
Total Agricultural Budget	245	298	372	432	485	1,833	100%
Source: Compiled from Government of Bihar 2012 Agriculture Road Map. All rupee to dollar conversions have been done using a 65 to 1 exchange rate							

Table A3: 12-village household survey descriptive data.

A total of 12 villages were surveyed evenly divided across three districts including Gaya and Jehanabad districts in south Bihar and Madhubani district in north Bihar.

Village (District)	**UC**		**OBC**		**SC/ST**	
	HH Surveyed	**Average Land per HH (Acres)**	**HH Surveyed**	**Average Land per HH (Acres)**	**HH Surveyed**	**Average Land per HH (Acres)**
Village 1 (Gaya)	0	NA	63	1.0	98	0.3
Village 2 (Gaya)	3	1.2	9	0.8	26	0.3
Village 3 (Gaya)	0	NA	7	1.0	8	0.3
Village 4 (Gaya)	2	26.3	4	3.6	20	0.4
Village 5 (Jehanabad)	0	NA	16	1.4	6	0.2
Village 6 (Jehanabad)	0	NA	14	1.0	6	1.2
Village 7 (Jehanabad)	1	0.2	6	4.1	11	0.7
Village 8 (Jehanabad)	6	5.7	12	0.7	11	0.0
Village 9 (Madhubani)	0	NA	9	3.6	7	1.1
Village 10 (Madhubani)	2	2.8	9	1.4	4	0.4
Village 11 (Madhubani)	13	3.0	13	1.1	19	0.7
Village 12 (Madhubani)	0	NA	19	0.7	8	0.2
Total	**27**	**6.5**	**181**	**1.7**	**224**	**0.48**

Table A4: Factor by which poorest farmers are less likely to use a technology than wealthier farmers. This table is based on data from the 12-village survey

Category and Number of Farmers →	**Caste Category Upper Caste (OBC and UC) - 248; Lower Caste (SC/ST) - 250**		**Landholding Size Marginal (M1 through M5) - 283; Non-Marginal (Small, Semi-medium, Medium, Large) - 55**	
Technology	**Factor by which a lower caste farmer is less likely to use a technology compared to an upper caste farmer**	**Chi-Square Test P-value to Compare Difference Between UC/OBC and SC/ST Farmers**	**Factor by which a marginal farmer is less likely to use a technology than a non-marginal farmer**	**Chi-Square Test P-value to Compare Difference Between Marginal and Non-Marginal Farmers**
Rubber pipes	0.89	0.002*	0.93	0.137
Tractor	0.98	0.453	0.95	0.321
Improved seeds	0.93	0.134	0.92	0.225
Diesel engine	1.01	0.903	1.16	0.107
Introduced new crop	0.52	0.004*	0.93	0.861
SRI	0.34	0.000*	0.34	0.000*
Started intercropping	0.58	0.115	0.67	0.337
Electrical motor	0.63	0.391	1.23	0.794
Vermi-compost	0.69	0.490	0.31	0.011*
Drip	(Count = 1)	NA	(Count = 1)	NA
Solar irrigation pumps	(Count = 0)	NA	(Count = 0)	NA

* $p < 0.05$; I am interested in technologies whether or not $p < 0.05$. The chi-square test p-value gives important information about the data, but should not be interpreted in a way that makes some cases interesting and others not. For some technologies like improved seed varieties (ISV), $p>0.05$ because the factor difference between poor and wealthy farmers' likelihood of use is low. In other words, ISVs are a technology that "raises all boats" and the p-value signifies this. The p-value is also greater than 0.05 for technologies with limited data because overall use across socio-economic groups in Bihar is low. This is true for intercropping for example.

To select cases, I used a purposive selection methodology and included cases where the factors and p-values showed that there are large differences in likelihood of use between socioeconomic groups, as well as cases where there are small differences in likelihood of use between socioeconomic groups. I also selected cases of technologies where the technology is in widespread use, as well as technologies in limited use. I selected technologies in limited use to look at whether the technologies in limited use were the "missing" pro-poor technologies.

Table A5: Variance in technology use by household landholding.

This table shows the percent of farmers in the dataset that have used each of the 11 technologies for more than 1 year by landholding category.

Standard classification for landholding sizes based on the Indian Census are used (marginal, small, semi-medium, medium and large). However, due to a very large proportion of the data set falling within the marginal landholding category (which is representative of landholding patterns across Bihar), I further classify marginal farmers into five categories (M1-M5). In addition, M0 represents farmers who do not own their own land, but practice sharecropping or lease land from other farmers.

# Farmers	NA	74	143	69	34	21	16	31	17	5	2
Technology	**Avg**	**Land-less**	**Marginal**					**Small**	**Semi-medium**	**Med-ium**	**La-rge**
		M0	**M1**	**M2**	**M3**	**M4**	**M5**				
Rubber pipes	87%	92%	72%	96%	94%	95%	94%	100%	94%	80%	100 %
Tractor	86%	91%	78%	90%	85%	86%	88%	100%	88%	100%	50%
Improved seeds	80%	81%	76%	77%	85%	67%	100%	97%	88%	80%	50%
Diesel engine	76%	86%	69%	87%	76%	67%	69%	74%	76%	20%	50%
Introduced new crop	19%	5%	19%	28%	26%	24%	19%	26%	18%	20%	NA
SRI	17%	11%	7%	14%	24%	19%	38%	55%	24%	20%	50%
Started intercropping	8%	3%	8%	6%	12%	10%	6%	16%	6%	20%	NA
Electrical motor	5%	NA	3%	1%	12%	5%	44%	6%	NA	20%	NA
Vermi-compost	5%	1%	3%	4%	6%	5%	NA	16%	6%	40%	NA
Drip	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Cou nt=1
Solar irrigation pumps	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table A6: Variance in technology use by household caste

In Bihar and much of India, castes groups are generally divided into three categories: Upper Castes (UC), Other Backward Castes (OBC), and Scheduled Castes & Scheduled Tribes (SC/ST). The reason the sample size in this data table is larger than in table 2.9 is because it includes households that do not own their own land but use technology when sharecropping on others land. The farthest column to the right shows the gap between the weighted average of UC / OBC farmers and SC/ST farmers.

Technology	Percent all farmers using technology (n=412)	Upper Castes (UC) (n=28)	Other Backward Castes (OBC) (n=207)	Scheduled Castes and Tribes (SC/ST) (n=177)
SRI	17%	14%	24%	8%
Rubber pipes	87%	93%	93%	80%
Improved seeds	82%	86%	85%	77%
Tractor	88%	93%	91%	84%
Vermi-compost	5%	18%	4%	4%
Intercropping	9%	4%	12%	6%
Drip irrigation	0%	4%	0%	0%
Solar irrigation pump	0%	0%	0%	0%
Introduced new crop	20%	29%	25%	13%
Electrical motor	5%	7%	6%	4%
Diesel engine	76%	64%	80%	75%

Table A7: Data from 12-village survey showing the relationship between caste and well-ownership.

In this table, open wells and borewells are treated equally.

Household Caste	Count of Farmers that do not own a well	Count of Farmers that own a well	Total Number of Farmers	Percentage of Farmers that own a well
OBC	207	12	219	5%
SC/ST	240	10	250	4%
UC	22	7	29	24%
Total (# farmers) or Average (percentage)	469	29	498	6%

Table A8: Farmers with land title by caste from 12 village survey (excludes landless HH)

Caste	Number of Farmers having Land Ownership Documents	Total Number of Farmers in Sample	Percent Farmers Having Land Ownership Documents
OBC	166	179	93%
SC/ST	109	131	83%
UC	27	28	96%
Grand Total	**302**	**338**	**89%**

Table A9: Farmers with land title by landholding (excluding landless HH)

Landholding Category	Number of Farmers having Land Ownership Documents	Total Number of Farmers in Sample	Percent Farmers Having Land Ownership Documents
M1	123	143	86%
M2	61	69	88%
M3	31	34	91%
M4	19	21	90%
M5	16	16	100%
Small	29	31	94%
Semi-medium	16	17	94%
Medium	5	5	100%
Large	2	2	100%
Total (or Average)	**302**	**338**	**89%**

Appendix 3. Annotated bibliography of supporting literature for STCMs

STCM 1: Lack of financial assets

- Banerjee *et al*. 2014. "Understanding biophysical and socioeconomic determinants of maize (*Zea mays* L.) yield variability in eastern India." *NJAS - Wageningen Journal of Life Sciences.*
    - Banerjee *et al*. (2014) found that a lack of capital can lead to reduced yields of maize for farmers in eastern India because they invest in fewer inputs and other technologies in the maize cultivation process. A farmer's income determines his/her ability to take risks and invest capital in farming practices. In addition, farmers who lack capital sometimes do off-farm work. The authors of the study believe that there is a negative relationship between off-farm work and crop yields.

- Dao *et al.* 2015. "Identifying farmers' preferences and constraints to maize production in two agro-ecological zones in Burkina Faso." *Agriculture & Food Security*.
    - Dao *et al*. (2015) looked at constraints to maize production in Burkina Faso. The results showed that the biggest constraint to increased maize production was poor cash flow, which made the high costs of seeds and fertilizer unaffordable. Small-scale farmers were unable to afford the inputs needed to prevent crop destruction from a root parasite called *Striga hermonthica*. As a result of financial constraints, the study showed that many poor farmers do not use enough pesticides or fertilizer, which hampers yields compared to wealthier farmers.

- Duflo *et al*. 2011. "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya." *The American Economic Review.*
    - Duflo *et al*. (2011) found that it is not a lack of financial assets per se that hampered farmer investments in fertilizer in Kenya. Rather it seems that the crux of the challenge is that farmers do not save money from the time of harvest for their last crop to invest in fertilizer during the next season when it is needed. This is the case, despite the fact that fertilizer is a relatively low cost technology investment which is shown to greatly increase yields. Through an experimental design, the authors found that by offering farmers a small time-limited discount at the time of Harvest (when they have cash on hand) encourages fertilizer adoption. This implies that lumpiness in farmers' cash flow can impact technology investments even when overall farmers are not overly cash constrained to make a specific investment.

- Kishore, Avinash. 2004. "Understanding Agrarian Impasse in Bihar." *Political and Economic Weekly*
    - This study by Kishore (2004)looks specifically at the causes of low yields in Bihar. While he notes a wide variety of challenges including failure of land reform and expensive irrigation, his overall analysis is that intensive agriculture production is simply not remunerative enough in Bihar for farmers to pursue higher yields. Prices for everything from fertilizer to irrigation has risen, and farm gate food prices have declined. Because of these factors Kishore argues, farmers in Bihar tend to practice "cost covering agriculture" which maximizes neither yields nor profits, but is a safe strategy under such unfavorable factor to output price ratios. *Notes: This argument is more nuanced than a simple lack of financial assets argument because it speaks to a different type of incentive structure. It's not that farmers can't afford a specific input at a specific time, rather, they see no point given the ratio of input costs to sale price to use the input. It would seem that this type of STCM 1 would impact both the poorest and wealthier farmers equally. However, there may also be ways for different socioeconomic groups to gain advantage in factor prices on the one hand, or to gain access to better sale prices on the other. Indeed, use of family labor (for the poorest) and exclusive access to government procurement programs through caste networks (for wealthier farmers) were two ways I observed farmers in Bihar influencing this ratio.*

- Yengoh. 2012. "Determinants of yield differences in small-scale food crop farming systems in Cameroon." *Agriculture & Food Security.*
    - Yengoh (2012) found that a lack of capital is a main factor in the inability of 61% of Cameroon farmers to meet their fertilizer needs. Household needs unrelated to farming often use up the resources that were originally allocated for fertilizer investments. The study concluded that the inability to afford fertilizer is the main reason smallholder farmers do use enough (or any) fertilizer. A lack of capital also makes it difficult for small-scale farmers to afford resources such as fuel and transportation.

STCM 2: Inappropriate technology design

- Chekene & Chancellor. 2015. "Factors affecting the adoption of improved rice varieties in Borno State, Nigeria." *Journal of Agricultural Extension*.
    - Chekene and Chancellor (2015) study the factors affecting Nigerian farmers' adoption of improved rice varieties. The authors used purposive and random sampling to gather data. Twelve farmer groups and 120 respondents from the southern part of Borno State, Nigeria were part of the study. The study found that two of the reasons farmers prefer to use older improved varieties or local varieties is that the new improved varieties mature too quickly. Although the early maturing varieties have high yield potential, they mature before the rainy season ends. This makes it difficult to dry the crop when harvested, which in turn makes threshing more challenging. In addition, harvesting during the rainy season increases susceptibility to mold and fungi while in storage. Many farmers continue to use an improved variety from the 1990's because it matures later than the newer improved versions.

- Timu *et al.* 2014. "The role of varietal attributes on adoption of improved seed varieties: The case of sorghum in Kenya." *Agriculture and Food Security*.
    - Timu *et al.* (2014) evaluate the factors that determine whether farmers in Kenya adopt improved varieties of sorghum or continue to grow local varieties. Data was collected through random sampling of 140 farmers. The study found that of the five improved varieties available, only two were widely adopted. The improved varieties matured earlier, produced higher yields, and yielded premium market prices. However, the local varieties had better drought tolerance, *Striga* resistance, brewing qualities, and taste. Overall, the improved varieties were superior for selling but the local varieties had more desirable consumption attributes and better drought tolerance. Many farmers preferred the local variety partly because of its superior attributes in terms of production and consumption. Notably, farmers who did adopt one improved variety were likely to adopt a second.

STCM 3: Missing market linkages

- Jagwe, Machethe, & Ouma. 2010. "Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda, and the Democratic Republic of Congo." (Doctoral dissertation).
    - Jagwe *et al.* (2010) use the Heckman procedure to analyze how transaction costs influence smallholder farmers' participation in banana markets in the Great Lakes region of central Africa. The data was collected through purposive sampling and by interviewing 2,666 households of smallholder farmers in Rwanda, Burundi, and the DRC (North Kivu, South Kivu, and Bas-Congo). The secondary data was obtained from the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA). One of the main factors in smallholder farmers' decision to participate in markets is fixed transaction costs. Fixed transaction costs are mainly dependent on farmers' proximity to markets, access to information, and geographical location.

Access to market information is crucial for market participation. Farmers who have no access to market information or are limited to information passed along by their neighbors are unlikely to participate in banana markets. Farmers in Gitega, Kirundo, and North Kivu Provinces were very unlikely to participate in markets due to poor infrastructure, relatively low economic activity, and political conflicts.

- Jayne, Mather, and Mghenyi. 2010. "Principal challenges confronting smallholder agriculture in Sub-Saharan Africa." *World Development*.
  - This study (Jayne, Mather and Mghenyi, 2010) used survey data on small farms in Ethiopia, Kenya, Malawi, Mozambique, and Zambia. The data was collected mainly by national statistical services. Michigan State University and local partners also contributed data. One of the findings of the study was that low crop productivity and inequality in productive assets has to be taken into account when trying to connect African farmers with markets. As a result of these factors, farmers do not have much surplus to sell. This inhibits the development of markets, which creates a negative cycle since a lack of markets means that smallholders are limited in their ability to sustainably use productive farm technologies. This then further reinforces farmers' inability to produce enough crops to have a surplus to sell. Inelastic product demand at local markets is also a problem. When local markets are unable to absorb seasons of so called bumper crops or high output, prices drop significantly. This then means that it is risky for farmers to increase their crop production, since they may not be able to sell their surplus for enough to cover the money they put into increasing their crop production. The authors believe that these price drops due to overproduction for local markets are major causes in the subsequent dis-adoption of new technology by farmers.

- Markelova *et al.* 2009. "Collective action for smallholder market access." *Food policy.*
  - This study (Markelova *et al.*, 2009) argues that smallholders need access to local, regional, and even international markets in order to raise their incomes. There are currently multiple factors hindering poor farmers' ability to participate in new marketing opportunities, including lack of information on prices and technology, high transaction costs, and credit constraints. Of these factors, high transaction costs are the largest obstacle. In addition, new procurement systems favor large farmers because they can provide larger supply volumes. Marketing perishables is especially difficult for smallholders because of the sophisticated and costly storage transportation facilities required. Similarly, cash crops require processing equipment that most smallholders cannot afford. Therefore, they are forced to sell to larger farmers or agribusinesses who can afford the equipment. Longer marketing chains present greater disadvantages for smallholders. The lack of rural infrastructure, extension services, credit markets, and accessible relevant information need to be addressed in order to lower the costs for farmers to participate in markets.

- Pradhan *et al*. 2015. "Closing yield gaps: How sustainable can we be?" *PloS one*.
  - This article (Pradhan *et al.*, 2015) looked at causes for yield gaps around the world using data from the Global Agro-ecological Zones. In addition to biophysical factors they analyzed socioeconomic factors. They found that travel time to the nearest market is a significant factor in productivity. This is because farmers who do not have easy access to markets have limited access to agricultural inputs such as fertilizer and high quality seeds. It also impedes the farmers' ability to sell their produce. In addition, these farmers often have little access to current farming information from extension services. The study found that a long travel time (over six hours) to the nearest market was a common problem for farmers in Africa, South-East Asia, and Central Asia.

STCM 4: Lack of access to credit

- Olagunju & Ajiboye. 2010. "Agricultural lending decision: A tobit regression analysis." *African Journal of Food Agriculture Nutrition and Development*.
    - Olagunju & Ajiboye (2010) argue that lack of access to credit means that small farmers cannot finance the purchase of fertilizer, better seeds, additional labor, etc. Therefore, investment in agriculture technology is hindered by an inadequate supply of institutional credit. This study looked at the factors that two Nigerian banks used when deciding which farmers to give loans to. Farmers with very small farms were very unlikely to be approved for a loan from either bank. This is likely because a large farm can be used as collateral. A large household size made farmers more likely to be approved for loans because they had more laborers available to cultivate large areas of land. A higher net farm income also made loan approval more likely because a wealthier farmer would be better equipped to absorb the cost of failure. The major significant variable for both banks was a good credit record—an asset many poor farmers lack. Another important conclusion from this study was that a delay in loan disbursements reduces farmers' abilities to repay the loans. Loans that arrive after the time period for which they were most needed often get spent on less productive or completely unproductive activities.

- Ololade & Olagunju. 2013. "Determinants of access to credit among rural farmers in Oyo State, Nigeria." *Global Journal of Science Frontier Research Agriculture and Veterinary Services*.
    - Ololade & Olagunju (2013) found that farmers in Oyo State, Nigeria listed lack of collateral security, lack of guarantor, and high interest rates as the biggest obstacles to acquiring credit. Mode of repayment was also said to be a problem by 28.6% of farmers, and 23.8% said that a lack of information about available credit was a challenge. Unmarried farmers and female farmers were significantly less likely to have access to credit.

- Phillip *et al*. 2009. "Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6)." *International Food Policy Research Institute*.
    - Phillip *et al.* (2009) findings are based on preliminary material and research results from the IFPRI and its partners in Nigeria. The authors state that limited access to credit is a major issue in Nigeria's farming systems. One of the main reasons for this is that banks with large loan funds are difficult for farmers to access. In addition, smallholder farmers often do not qualify for loans due to issues of collateral. High interest rates are another significant barrier for smallholder farmers. Agricultural loans are often not compatible with annual cropping because they are short term and have fixed repayment periods. Another problem is that the loan release date does not always coordinate with growing cycles.

- Kochar. 1997. "Does Lack of Access to Formal Credit Constrain Agricultural Production? Evidence from the Land Tenancy Market in Rural India." *Amer. J. Agr. Econ.*
    - In contrast to the three papers above which all use data from Nigeria, Kochar (1997) finds that in India, lack of access to formal credit has little impact on farmer investment decisions. Rather, farmers rely on informal credit from family and friends, rather than turning to formal credit markets.

STCM 5: Missing Infrastructure

- Gajigo & Lukoma. 2011. "Infrastructure and agricultural productivity in Africa." *African Development Bank Marketing Brief.*
    - Gajigo and Lukoma (2011) in a briefing paper prepared for the African Development Bank argue that missing infrastructure plays a strong role in depressing yields and reducing productivity in sub-Saharan Africa. The paper argues that poor roads, inadequate irrigation infrastructure and inadequate food storage facilities are the main infrastructural challenges hampering agriculture on

the continent. Poor roads and inefficient transport links increase the cost of inputs and decreases farmers' access to markets. Poor roads also make it more difficult for smallholder farmers to access credit. Long distances for professionals to reach farmers' fields increases the administrative costs of lending, monitoring, and loan recovery, which results in higher intermediation costs. A lack of irrigation infrastructure also reduces productivity in Africa. Farmers who are entirely dependent on rainfall experience significant fluctuations in output, since rainfall is very unpredictable. This increases risk for farmers. Inadequate storage facilities result in produce losses due to pests and weather-related decay. This is an especially significant problem in Sub-Saharan countries, where 30-50% of perishable agro-commodities and 15-25% of grains are lost post-harvest. The challenge of storing perishable commodities leads to reductions in the food supply, which in turn increases prices. This creates high temporal price variations, in addition to the spatial price variations caused by poor roads. A lack of proper storage facilities also hinders the development of high-value agri-business industries that specialize in horticulture or other perishable products. In contrast, good infrastructure increases output per capita and output per unit of land.

- O.E. & D.G. 2009. "Effect of road infrastructure on agricultural output and income of rural households in Delta State, Nigeria." *Agricultura Tropica et Subtropica*.
    - O.E. and D.G.(2009) gathered data through multi-stage random sampling in three agricultural zones of Delta North, Delta Central, and Delta South in Nigeria. The study found that poor roads negatively impact output. Road quality had the greatest effect on output compared to the other independent variables (land area cultivated, value of other assets, distance to market, education, and household size). The study found that a 10% increase in road quality will result in a 12% increase in output. Well-paved roads would guarantee that farmers could transport produce to markets year-round, providing greater incentive to invest in increased production through technological inputs such as improved seeds and fertilizer.

- Narayanamoorthy & Hanjra. 2006. "Rural infrastructure and agricultural output linkages: A study of 256 Indian districts." *Indian Journal of Agricultural Economics*.
    - Narayanamoorthy and Hanjra (2006) used data from the *Indian Agricultural Statistics* journal published by India's Ministry of Agriculture among other sources to study the impact of rural infrastructure on agriculture output. Their results show that a lack of rural infrastructure can reduce yields. The Indian districts with lower agricultural outputs were the ones with less infrastructure including roads, irrigation, schools, electricity, etc. Irrigations, roads, and literacy were the three most significant factors affecting agricultural output.

- Tunde & Adeniyi. 2012. "Impact of road transport on agricultural development: A Nigerian example." *Ethiopian Journal of Environmental Studies and Management.*
    - Tunde and Adeniyi (2012) used questionnaires and focus group discussions to gather data on the impact of roads on agriculture development in Nigeria. The study found that poor road conditions have a large impact on farmers' production because they increase the cost of transporting produce from farms to markets. The results of the study showed that farmers spend a significant portion of their income on transportation. Transport costs depend on the type of produce being transported, the efficiency of the transport, and the distance being traveled. The high cost of transport means that farmers need to increase their selling price in order to recoup that money. However, if their prices are higher than other farmers the customers will not buy their produce. This can result in farmers having to sell at a loss. Transportation costs therefore limit production levels. When asked about transportation problems, farmers listed bad roads, high cost of transportation, irregular and insufficient vehicles, insufficient means of transportation, and long distances from their houses to their farms and from farms to markets. Interviews with transporters revealed that they were reluctant to provide transport for farms that were only accessible through bad roads because it was too rough on their vehicles.

STCM 6. Ineffective extension services

- Baloch & Thapa. 2016. "The effect of agricultural extension services: Date farmers' case in Balochistan, Pakistan." *Journal of the Saudi Society of Agricultural Sciences.*
    - Baloch & Thapa (2016) study the impact extension services have had on farmers in Pakistan. The data was gathered through a questionnaire survey of 200 date palm farming households, group discussions, and surveys of key informants in Pakistan. The study found that farmers who had access to extension services had higher yields than farmers who did not have access. Small-scale farmers who used extension services had higher yields than medium- and large-scale farmers. Farmers who used extension-recommended land preparation methods experienced a positive change in date palm yields by 17.73 kg. However, in general the extension officials gave advice that the farmers could not apply. For example, the farmers could not follow the recommendation to irrigate their farms daily, since they didn't even have enough water to irrigate twice a week. They also could not afford the specific pesticides the extension officials suggested they use. Nor did they have the equipment needed to properly use the pesticides. Although the extension services did have a positive impact on yields, the inadequate number of extension agents and their lack of knowledge about the specific challenges facing the resource poor farmers they worked with left most farmers dissatisfied with the extension services.

- Davis *et al.* 2010. "Impact of farmer field schools on agricultural productivity and poverty in East Africa." *World Development.*
    - Davis *et al.* (2012) used a longitudinal impact evaluation to assess the efficacy of farmer field schools (FFS) in East Africa. They collected data by analyzing documents, interviewing informants, and analyzing primary and secondary survey data. The study found that FFSs positively impact productivity. Kenyan farmers who participated in FFSs saw an 80% increase in the value of crop productivity per acre. In Tanzania, the increase was 23%. FFSs did not significantly impact crop productivity in Uganda. This may be because a National Agricultural Advisory Services program was already present in Uganda. Participation in FFSs especially benefited the productivity of female farmers. This is important to note, since female farmers contribute the most in agricultural production in Sub-Saharan Africa. It is important to note for the purposes of this study that FFSs actually had a negative, although nonsignificant, impact on the productivity of farmers with small land areas (the poorest farmers as measured by landholding). The authors hypothesized that this was because the smallholder farmers were resource-poor and could not follow the FFS recommendations about technology investments.

- Zhang *et al*. 2016. "Closing yield gaps in China by empowering smallholder farmers." *Nature*.
    - Zhang *et al.* (2016) showed how effective extension services can increase yields. The study looked at the impact the Network of Science and Technology Backyards (STB) program had in China. The STB program has agricultural scientists live in farming villages in order to help farmers learn more advanced and efficient farming practices. Data was gathered from the Quzhou Experimental Station, farmer surveys, and experiments carried out by leading farmers who had been under the instruction of STB staff. By living near and working closely with farmers, the STB staff were able to do extended trainings, farming schools, and field demonstrations. They were able to effectively pass information on to the farmers because they formed relationships with them and took farmers' feedback into account. On-site advice and real-time reminders were also beneficial. Farmers from STB villages had better agronomic knowledge, higher adoptions of extension recommendations, and higher yields, nutrient and water-use efficiencies, and economic returns. These effects even spread to neighboring villages since they had better access to extension events and information than distant villages. The STB staff also started a farmer co-operative system of combining the land of 30-40 farmers in order to use management practices that are more effective on large areas of land. The farmers benefit from these practices and then harvest their lands individually. The importance of this paper to the issues explored in this dissertation is that the study demonstrates

what quality extension services can do when effectively administered. Where quality extension services are lacking, farmers lose. This is especially problematic from the perspective of this study when access to extension services is less available for poorer farmers.

STCM 7. Lack of individual farmer capacity

- Alene & Manyong. 2007. "The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: An endogenous switching regression analysis." *Empirical Economics*.
    - Alene and Manyong (2007) found that a farmer's education level has a more significant effect on agricultural systems using modern technologies than in traditional agricultural systems. Both education and extension services enhance productivity to a greater extent when improved technology is being used rather than traditional technology. For example, the effects of farmer education on cowpea production were greater among farmers who have adopted improved cowpea varieties than on those who were using traditional varieties. Cowpea production increased by 25.6% as a result of four years of education *and* the use of improved technology, but showed no increase as a result of the same amount of education when traditional technology was being used. The main reason for this is that new technology creates instability and changing circumstances which require farmers to develop new skills and knowledge. Better-educated farmers are better equipped to meet this challenge.

- Croppenstedt & Muller. 2000. “The impact of farmer’s health and nutritional status on their productivity and efficiency.” *Economic Development and Cultural Change.*
    - Croppenstedt and Muller (2000) demonstrate a link between the health and nutritional status of farmers and their agricultural productivity amongst Ethiopian peasant farmers. This finding underscores the importance of STCM 7 because it shows how factors leading to poor health in rural farming households, such as food insecurity and poor nutrition, can reduce agricultural productivity and rural wages when peasant farmers are employed by larger landowners.

- Mani *et al*. 2013. “Poverty impedes cognitive function”. *Science.*
    - Mani *et al.* (2013) demonstrate how the very stress of being poor irrespective of its impact on actual consumption, reduces the cognitive capacity of farmers thereby decreasing the individual capacity of the poorest farmers more than other farmers. This finding has implications for the design of agriculture policies: For example, complex extension interventions are best timed toward the end of harvest seasons and long and complex forms for programs targeting the poor should be minimized (e.g. a subsidy application). This causal mechanism leading to low yields affects poorer farmers more than other farmers because they are most likely to suffer from the cognitive stress due to poverty.

- Narayanamoorthy & Hanjra. 2006. "Rural infrastructure and agricultural output linkages: A study of 256 Indian districts." *Indian Journal of Agricultural Economics*.
    - Narayanamoorthy & Hanjra (2006) used data from the *Indian Agricultural Statistics* journal published by India’s Ministry of Agriculture, a study by Bhalla and Singh (2001), and the *Census of India*. The conclusions about how infrastructure affects yields were based on cross-sectional data for 256 Indian districts in 13 states during the time periods of 1970-71, 1980-80, and 1990-91. The authors used both descriptive and regression analyses to study the relationship between rural infrastructure development and agricultural productivity. The results of these analyses were that a lack of rural infrastructure can reduce yields. The Indian districts with lower agricultural outputs were the ones with less infrastructure including roads, irrigation, **schools**, electricity, etc. Irrigations, roads, and **literacy** were the three most significant factors affecting agricultural output. The study found that the impact of irrigation on agricultural output has been increasing since the 1970’s. It’s interesting that education was included as a variable in a study on infrastructure.

- Yengoh. 2012. "Determinants of yield differences in small-scale food crop farming systems in Cameroon." *Agriculture & Food Security*.
  - Yengoh (2012) found minimal effect on yields comparing a post-secondary school level education and an elementary-level education. However, there is a significant effect on yields when comparing A-level and no education. There is also a considerable difference between no education and an elementary-level education. The study hypothesized that the causal pathway undergirding this finding is that education enables farmers to better understand and use information on the potential pros and cons of new technology in their decision-making. In addition, farmers who have received some education are also usually more willing to test and adopt new technology.

STCM 8. Weak capacity for collective action

- Jagwe, Machethe, & Ouma. 2010. "Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda, and the Democratic Republic of Congo." (Doctoral dissertation).
  - Jagwe, Machethe, and Ouma (2010) used the Heckman procedure to analyze how transaction costs influence smallholder farmers' participation in banana markets in the Great Lakes region of central Africa. The data was collected through purposive sampling and by interviewing 2,666 households of smallholder farmers in Rwanda, Burundi, and the DRC. The secondary data was obtained from the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA). The study found that collective action is beneficial in improving market access for smallholder farmers. The study results showed that when someone in the farm household was a member of a farmer group they were more likely to sell their bananas at markets. The researchers confirmed that farmer groups are a good way for farmers to exchange information. Farmer groups also reduce the transaction costs of market participation by enabling the farmers to link to buyers at a reduced cost.

- Markelova *et al*. 2009. "Collective action for smallholder market access". *Food Policy.*
  - Markelova *et al*. (2009) in the introduction to a special feature in the journal of *Food Policy* begin with the insight that research in other sectors has shown that voluntary collective action is advantageous for technology adoption. The special feature looks at the importance of collective action in agriculture systems. The special feature argues that cooperation is crucial for poor smallholders to overcome challenges created by unfavorable policies and markets and to create sustainable livelihoods. Collective action can enable small holders to solve transportation and storage issues, acquire technologies and certificates to comply with required quality standards, and reach the necessary scale to supply the desired quantity of their products. This will then allow the smallholders to reach larger domestic, urban, regional, and international markets that they are unable to reach individually.

- Otieno. 2012. "Impact of farmer groups on crop enterprise productivity and economic welfare of smallholder farmers in South Kivu territories, Democratic Republic of Congo." (Doctoral dissertation).
  - Otieno (2012) collected data for this study through structured interviews and multi-stage sampling techniques. The study found that farmers who were members of a group had higher values of production and economic gains. This may have been the result of an increase in the use of fertilizers, organic manure, and new varieties and technologies among group member farmers. The study also found that group members were able to borrow more money than non-group members. This may be because financial institutions prefer group lending over lending to individuals. Group members may also have been better informed about the availability of funds thanks to group meetings and extension programs. In addition, group members adopted more technology than individual farmers. This may be because they had gained knowledge about technologies through the group meetings. The non-group members used more planting fertilizer and top-dressing fertilizer than group member farmers. The group members used more organic fertilizer, possibly

because it was all they could afford (the groups were mostly made up of poor farmers). The study also found that interventions in the area had encouraged the group members to use organic fertilizer. Group members adopted more new varieties and technologies. They also had increasing numbers of extension contacts, whereas non-group members had decreasing numbers of both extension contacts and lower rates of adoptions of technology.

- Thorp *et al*. 2005. "When and How Far is Group Formation a Route Out of Chronic Poverty?" *World Development.*
    - Thorp *et al* (2005) look at the conditions under which group formation is a route out of chronic poverty. They find that when the poor form groups, they often exclude even poorer groups. This is especially true for groups formed around market functions. They also find that the specific political function of groups is important in determining success in helping to overcome marginalization and social exclusion experienced by the poorest.

STCM 9: Structure of land tenure regimes

- Banerjee *et al*. 2014. "Understanding biophysical and socioeconomic determinants of maize (Zea mays L.) yield variability in eastern India." *NJAS - Wageningen Journal of Life Sciences.*
    - Banerjee *et al.* (2014) found that poor land tenure systems negatively affect the yields of tribal farmers in eastern India. Tenant farmers tend to exploit the land and use short-term farming practices that eventually degrade the land resources. These unsustainable practices then result in lower yields. In addition, land owners often lease less-fertile land to tenant farmers and keep the better-quality land for themselves. Land owners in this study had higher mean yields than tenant farmers.

- Donkor & Owusu. 2014. "Effects of land tenure systems on resource-use productivity and efficiency in Ghana's rice industry." *African Journal of Agricultural and Resource Economics*.
    - Donkor & Owusu (2014) looked at the effects of land tenure systems on resource-use productivity and efficiency in the Upper East region of Ghana. The authors sourced data from the country's Agricultural Production survey (GAPS) and conducted a stochastic frontier model. The GAPS data was obtained by surveying 470 rice farmers in Ghana. The study examined farmers' resource-use productivity and efficiency for three land tenure systems: individual land ownership, fixed-rent tenancy and sharecropper tenure. The results showed that land ownership positively influenced technical efficiency because land owners were in a position to undertake both short-term and long-term measures to promote their farm outputs. Tenant farmers generally only made short-term improvements to the land since they likely wouldn't benefit from long-term investments. Tenant farmers who rent land are more likely to use inputs than sharecroppers. Sharecroppers had the lowest technical efficiency. The authors concluded that owners are more efficient than either fixed-rent tenant farmers or sharecroppers.

- Henao & Baanante. 2006. "Agricultural production and soil mining in Africa: Implications for resource conservation and policy development." *IFDC*.
    - Henao and Baanante (2006)began the study by estimating soil nutrient balances. They did this by accounting for the effects of inputs, nitrogen fixation, and sedimentation, and then subtracting the effects of leaching, erosion, crop uptake, and volatilization. They used geographic information systems to complete spatial analyses that analyzed crop production and predicted leaching, erosion, and nutrient mining. They evaluated soil nutrient losses, current yields, and potential future yields with simulated modeling and transfer functions. The study found that poor land tenure systems can lead to nutrient mining. Tenant farmers in sub-Saharan Africa view soil mining as the least expensive source of plant nutrients. Because tenant farmers will probably not farm the land for more than a few years, they do not care about the long-term health of the soil or long term

impacts on yields. This is especially true when tenant farmers practice shifting cultivation. In contrast, famers who have well-established property rights or land tenure arrangements internalize the eventual costs of nutrient mining.

- Phillip *et al*. 2009. “Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6).” *International Food Policy Research Institute (IFPRI).*
    - Phillip *et al.* (2009) findings are based on preliminary material and research results from the International Food Policy Research Institute and its partners in Nigeria. The authors state that the communal system of land ownership in Nigeria is a problem for agricultural productivity. Communal land ownership provides little incentive for individual farmers to invest in improving the land or make long-term investments in land management. The farmers do not have the ability to use other farmlands, so they continue to use the communal lands. These lands become depleted and suffer from soil degradation. The lack of clear titles to the land and the inability to sell it make it impossible to use the land as collateral. This then hinders farmers’ access to credit and impedes the development of a rural credit market.

- Place & Otsuka. 2002. "Land tenure systems and their impacts on agricultural investments and productivity in Uganda.” *Journal of Development Studies*.
    - Place and Otsuka (2002) study how land rights affect production in two sites in Uganda. The authors interviewed 47-50 households in each area. The study included farmers who owned land and tenant farmers. Because of the ever-changing politics in Uganda, even those who "owned" land felt uncertain about their future rights to the land. The study found that both owners and tenant farmers used short-term investment strategies for prolonged periods of time and had few long-term improvement plans.

STCM 10: Misaligned incentives

- McCullough & Matson. 2012. “Linking knowledge with action for sustainable development: A case study of change and effectiveness.” In *Seeds of Sustainability.*
    - McCullough and Matson (2012) write in a long-term mixed methods study of the Yaqui Valley in Sonora, Mexico that farmer’s in the region failed to adopt best management practices for fertilizer application, which cost farmers money and also led to environmental pollution (McCullough and Matson, 2012). The research team found that the reasons farmers continued to over-apply fertilizer were complex, but one of the reasons was due to misaligned incentives between farmers, scientists and local credit unions. In the Yaqui Valley, large farmers received inputs such as seeds and fertilizer, but also crop insurance, post-harvest storage, marketing and technical assistance through their local credit unions. After the research team identified and published best management practices to reduce fertilizer use, the credit unions discouraged farmers from following the new guidelines. Rather the credit unions encouraged farmers to continue to apply the time-tested quantities of fertilizer to mitigate risks to farmers (who they ensured) but also likely because the credit unions profited from the sale of fertilizer. Interestingly, small farmers in the region who were ineligible to be members of local credit unions were more likely to adopt the new best management practices. While this example, does not demonstrate misaligned incentives leading to reduced yields, they likely led to reduced farmer profits over the long run.

- Mukherji, Aditi. 2006. “Political ecology of groundwater: the contrasting case of water-abundant West Bengal and water-scarce Gujarat, India.” *Hydrogeology Journal.*
    - In this study, Mukherji (2006) looks at groundwater and electricity policy in two states in India: West Bengal and Gujarat. The author shows that groundwater-related policies in India have very little to do with scarcity, depletion or quality of groundwater, and more to do with rural politics manifested in the strengths and interests of the farmers’ lobbies in the two states. In West Bengal, where the farmers’ lobby is in general weak compared to the political influence of the urban

educated elite and even when the farmer's lobby is active, its interests are split because it represents the interests of the poorest farmers, larger landholders and rural non-farming households (three groups that have distinctly different needs). Because of this, the farm lobby has failed to demand electricity infrastructure for the agriculture sector to decrease the costs of pumping groundwater for irrigation (when electricity is unavailable farmers are forced to irrigate with more expensive diesel or not at all). Moreover, out of unfounded concerns about groundwater depletion the state government has limited the availability of electric pump connections. This has slowed the growth of groundwater markets and led to negative impacts on water buyers who are mostly small farmers.

- Phillip *et al.* 2009. "Constraints to increasing agricultural productivity in Nigeria: A review. (No. 6)." *International Food Policy Research Institute (IFPRI)*.
    - Phillip *et al.* (2009) findings are based on preliminary material and research results from the International Food Policy Research Institute and its partners in Nigeria. Presidential initiatives were introduced in Nigeria to support the production of cassava, rice, vegetable oil, tree crops, livestock, and aquaculture products. However, these initiatives have not worked as well as hoped. The Presidential Initiative on Cassava (PIOC), and the Presidential Initiative on Rice (PIOR), have been hindered by inadequate and delayed release of funds, a lack of funds to buy the necessary processing equipment, a lack of implementation committees as state and local levels. The PIOC has especially suffered from external trade constraints as a result of the absence of storage facilities, railway systems, and ports equipped to handle agricultural exports. The presidential initiative for vegetable oil has been hindered by old and inefficient processing equipment, high costs of inputs and new machinery, inability to compete with cheaper imported vegetable oil products, inadequate funding, and delays in certifications for projects.

- Songco. 2002. "Do rural infrastructure investments benefit the poor? Evaluating linkages: A global view, a focus on Vietnam." *World Bank Publications.*
    - Songco (2002) studies the impact of infrastructure investment on the poor through a wide review of published reports and literature. Of particular interest, the author notes that a 1994 World Bank report found that the use of electric pumps in India led to increased agricultural productivity through greater land use, decreased reliance on rainfall, and a move to higher-yield crops. Rural electrification had similar effects in Bangladesh. However, Songco's review found that in several countries, rural electrification (RE) had little or no impact on agricultural productivity. In these countries, constraints to RE included prohibitively expensive connection costs, unclear land-use rights, extremely low income levels, limited access to credit, and/or existing agricultural patterns or low potential for irrigation improvements. This article supports SCTM 10 *misaligned incentives* rather than STCM 2 *inappropriate technology design* because it shows that the challenge is often not the physical dimensions of the technology itself but rather the institutional dimensions of the technology.

STCM 11. Corruption

- Anik, Breustedt, and Bauer. 2011. "The impact of corruption on farmers' efficiency in rice production: A natural experiment from Bangladesh. "*EAAE 2011 Congress Change and Uncertainty. Zurich, Switzerland: EAAE*.
    - Anik *et al.* (2011) looked at the effects of corruption on Bangladesh rice production during two growing seasons. During the Aman season there is sufficient rainfall to compensate for a lack of irrigation. During the Boro season, the decreased rainfall and increased use of HYV seeds require irrigation and fertilizer for maximum yields. Farmers have to bribe officials in order to receive subsidies that are supposed to cover a portion of their electricity bill that was used for irrigation. In the Aman season, farmers often have to pay a bribe to get the slip needed to collect fertilizer from the retailers. The authors used data from a 2008 Aman season in which the fertilizer market was

quantity-restricted, leading to increased corruption. The subsequent Boro season had less corruption because the quantity-constraints had been resolved, but the farmers had more capital-constraints since this season requires more fertilizer and irrigation. The results of the study were that a 1% higher cost of corruption actually increases technical efficiency by 1.5% during the Aman season since farmers could afford to pay the bribes. However, it decreased technical efficiency during the Boro season by 0.5% because farmers were capital-constrained and could not afford the bribes. Bribe payers are "more efficient" because they received adequate fertilizer and/or irrigation to achieve improved yields. The likely implications for from this study for the poorest farmers is that poor farmers who are less likely to be able to afford the bribe will suffer more than wealthier farmers from this underlying causal mechanism.

- Bromley & Foltz. (2011). "Sustainability under siege: Transport costs and corruption on West Africa's trade corridors." *Natural Resources Forum*.
    - Bromley and Foltz (2011) use data from a review of transport costs in Africa done by other researchers, and data from the Transport Study Project done by the West African Trade Hub (WATH). The researchers used a spatial model of institutional incoherence to connect corruption with farmers' enterprise choices. The study used an Integrated Road Transport Group (IRTG) report to find that corruption costs make up 15-20% of the total cost of transportation for shea from Mali and cashews from Ghana when the products are transported in legal trucks. The percentage rises to almost 30% when illegal trucks are included. The researchers believe that a 10% reduction in total transportation costs would result in price increases of 12-13% for onions, 2% for cashews, and 7% for shea. Based on their study, the researchers conclude that corruption is a factor in undermining the net profitability of the crops. This leads to farmers postponing investments or not making them at all. As a result, yields fall and net returns decrease. Farmers begin a cycle of falling productivity, reduced tradable products, and potentially higher shipping costs.

- Fulginiti *et al*. 2004. Institutions and agricultural productivity in Sub-Saharan Africa. *Agricultural Economics.*
    - Fulginiti *et al*. (2004) study agricultural productivity in 41 sub-Saharan African countries from 1960 to 1999 focusing on the rate of productivity change in agriculture systems across countries. They measure a significant reduction in productivity during political conflicts and wars, and significant increase in productivity among countries with higher levels of political rights and civil liberties.

- Mandemaker *et al*. 2011. "The Role of Governance in Agricultural Expansion and Intensification: A Global Study of Arable Agriculture." *Ecology and Society.*
    - Mandemaker *et al*. (2011) studied the empirical relationships between agricultural production dynamics and six quantitative World Bank governance indicators for 173 countries between 1975 and 2007. They found that countries with higher quality governance are more likely to achieve yield gains by intensification of yields on existing land. In contrast, countries with poor governance are more likely to achieve agriculture production gains via extensification of agriculture onto new lands. *Note: The World Bank indicators included both values for corruption as well as rule of law and political stability, two issues which improved after the election of Nitish Kumar in Bihar.*

- Ministry of Agriculture. 2006. "Agriculture governance in Bangladesh: A survey of six *thanas*." Agriculture Sector Review, Ministry of Agriculture, Government of Bangladesh, Dhaka.
    - This review of agricultural governance (Government of Bangladesh, 2006) in Bangladesh was done by the Government of Bangladesh' Ministry of Agriculture. The survey was conducted 36 villages in Bangladesh. The data about the effects of agriculture governance on crops was based on the survey responses from fifty farm households of different sizes in each of the 36 villages.

The surveys found that there is corruption among Bangladesh Chemical Industries Corporation appointed fertilizer dealers. BCIC dealers are supposed to sell the fertilizer directly to the local farmers. Instead, they sell it to retailers across the country, who then sell it to farmers after adding in their contingency costs and profit margins. The majority of farmers purchase their fertilizer from the local market rather than BCIC dealers. There is also corruption in the government's fertilizer and electricity subsidy programs. The surveys found that the subsidies for imported fertilizer had had no effect on price. This is likely because importers and dealers took advantage of the subsidy. The subsidy intended to lower the costs of irrigation was also fraught with corruption. The majority of deep borewell (DTW) operators received the subsidy but did not lower the costs of irrigation water for the farmers. The study did not look at the impact of the corruption on yields or across socioeconomic groups, though the assumption is that corruption negatively impacts farmer well-being when they fail to receive government benefits due to corrupt practices of bureaucrats and the private sector.

Appendix 4. World Bank SRI toolkit: Transcription of interviews

In response to the controversy over SRI, the World Bank Institute developed a toolkit to explain SRI technology. Instead of avoiding the controversies around the technology, the World Bank addressed them directly by interviewing farmers, researchers, practitioners and development agency staff about their views on SRI. These videos were at one time online, but the website is no longer available. Fortunately, I transcribed these interviews while they were still available, and I felt the text was worth including in the dissertation as useful data for the study of boundary work (Gieryn, 1983) in innovation systems.

Farmers

Farmer 1 – Singadavardan

Normally I would need 30 Kilos of seed to be used for 1 acre of land. But with this new process, I use 3 Kilos of seed for 1 acre of land. Labor wise it has been very economical. I can further reduce from 3 Kilos to 2.5 Kilos. Considering the results, the neighbors may want to try. I used to have 20 laborers, now I use only 10. To develop a nursery for planting it used to cost at least a 1000 rupees per acre, now it costs me less than 200 rupees per acre with seed reduction. Planting is cheaper and other advantage is that planting is easier as well using the marker. People who experimented with this say they are getting 38-40 bags of paddy per acre but with old method they were only getting 25-30 bags per acre. I believe this was a good venture.

Framer 2 – Uma

Less labor is required because I am using a weeder. The weeder also makes it easier to eliminate weeds and because of this I also get more yield. With the old method, the yield was 20-25 bags for one acre and with the new method I get more than 30 bags.

Farmer 3 – Santhalingam

The fertilizer was the same as the old method but the yield went up to 35-42 bags and previously it was only 25 bags. Main difference is that I am using less water and less labor.

Framer 4 – Murgan

Now with this method, planting is done with 13 day old seedlings. I am using only about 3 Kilos of seed breaker versus 30 Kilos breaker with the old method. As a result, I am only using 10 percent of the seeds and growth is very robust. Old method produced 20 tillers but only 10 were healthy. Now, the new method results in 45-50 tillers per plant all healthy and as a result the yield is increasing. In each of the tillers I used to get 130-150 grains, now I get about 250-300 grains per tiller. Wider spacing results in healthier plants. Previously I used to use 30 laborers, now I only use 9 laborers.

Researchers

Dr. Norman T. Uphoff

Why is there resistance to the acceptance of SRI?

Well, I think it's a good question why there has been as much resistance to SRI as we have encountered. I think it comes on to the fact this is really a paradigm shift from an earlier understanding of how we can get the most out of rice crops or wheat crops or other crops. The Green Revolution was very successful and had a very simple paradigm which was you improve the genetic potential of the crop and then you add extra inputs, more fertilizers, more water, more agrichemicals and so forth. And it works. Reason it took me 3 years to understand and accept SRI was that it didn't do either of that. Didn't do anything to improve the genes, took whatever varieties farmers were already using and didn't add extra inputs, it reduced them. And so was very hard for me to understand it first time. So this alternative paradigm is one where you change the manners of the plants, the soil, the water and the nutrients to get a better phenotype from any genotype. And so it's a whole different approach to the way in which we can nurture and benefit from the crops. And I think it's very hard for a lot of people to understand and accept. And I say it took me 3 years and I am sympathetic with skepticism about this but I have decided that we should follow the motto – "Skepticism is the very good but it should be optimized, not maximized". And so I would hope that more and more scientist as see the evidence accumulating would be willing to shift their concept (1:29) of how you do things. And don't depend upon genetic change, don't depend upon external inputs but really capitalize upon the symbiosis between the plants and the soil organisms. We are still learning about the SRIs. I mean that I keep emphasizing that this is a work in progress, we are not finished with it yet. The changes and innovations are coming all the time, mostly from farmers but also from researchers, NGOs, retired school teachers who get involved with this and just find it really exciting to work with this potential in the plant, that one little rice seed.

What are the benefits of applying SRI, especially in relation to climate change?

Well I think we know already that 21st century is going to be very different from 20th century for agriculture. We are going to have to deal with less land per capita as population keeps growing and some line gets degraded and goes out of production. We are going to deal with less water and it's going to be less reliable water so we have to have production price at a very economic(0:12) with our water. Energy cost are going to keep going up I am afraid so that the kind of highly mechanized production large scale is going to become less and less economic. And I think the climate change then just adds a whole different set of problems on top of that where we have more pests and diseases to deal with, more draught, more storm damage. We find that once you have used these SRI practices with the rice plant for example, it can withstand draught much better than other plants because it has developed a large and deep and a healthy root system. We have had incredible pictures sent in of crops where the typhoon has gone over and blown the whole normal crop down and yet the SRI plants are all standing upright, vigorous. As one farmer where I visited several times in Xinjiang province in China who actually got a 12 ton SRI yield in 2004 which was the highest yield in the whole province that year. Next year this area had 3 typhoons, all within six weeks of each other yet he still harvested a crop of 11.15 tons per hectare according to the China National Rice Research Institute researchers working with him. Whereas his neighbor's crops were very badly affected. So the rice plants with SRI methods are more vigorous, they have stronger tillers, stronger root systems, they can resist pest disease damage which is going to be more serious with climate change.

Is there a relation between SRI and energy?

Our present modern day issues develop when petroleum crosses 10-20 dollars per barrel. We are now talking about petroleum crossing 110-120 dollars per barrel. So we have to rethink the energy relationship. Things that were not economic 10-20 years ago are going to start being economic now in the next 10 and 20 years. So I think energy is going to figure very prominently. We have to capitalize as much as we can upon natural sources of nutrients, of water. Rather than transporting water large distances for this big irrigation. I think how do we get green water, how do we maximally capture and utilize water in-situ in the places where plants are growing.

Is SRI labor-intensive?

When we first started working with SRI, we were working in Madagascar where farmers found the methods to be fairly labor intensive requiring more work per hectare to get their results. So we accepted that this is a labor intensive technology but that is the price you pay to save water, to save seeds, to higher yields and so forth. That seemed to make sense, then farmers in Suyaka few (could not understand the name) in Madagascar started telling me that actually after the second or third season it started saving them labor. It took me a while to absorb that, I think. But we had a study done by GTZ team in Cambodia in 2004. 500 farmers in 5 provinces chosen randomly. 4 of them were SRI users and 100 were controls in the same villages who did not use SRI. They found that this was labor neutral. In fact there was not more labor per hectare for SRI with about 75 percent more yield. It turns out that if you look at the SRI farmers, some are new farmers some are experienced farmers. And the new farmers they take 10-20 percent more labor per hectare for their results. But once farmers get used to the methods and techniques and acquire both skill and confidence, it's less labor. We have studies done in India by International Water Management Institute(IWMI), by Tamil Nadu Agriculture University both of which said it is 8 percent less labor per hectare with SRI. In China, there is one village in Sichuan province where it was studied by China Agriculture University researchers because they were told that this is very unusual village. In 2003 they had 7 farmers use SRI next year they had 398, 50 times more farmers "what's going on?" And they interviewed these farmers, these farmers got 45 percent more yield 40 plus percent less water but the thing I liked the most SRI is it that saved them labor. In China labor is a big constraint. So you have to acquire both techniques and confidence and use them quickly and skillfully. When I was in Xinjiang province in Eastern China last August where they have over 110000 hectare of SRI rice that season. The extension agents told me the reason why this is moving so quickly and why if that is popular among large farmers and small farmers is because it is labor saving as well as water saving, seed saving and cost saving. There is an article published in the American Journal of Agriculture Economics, 2004 based on 108 farmers who are doing both practices were studied very carefully. So by year four it was 4 percent less labor and by year five it was 10 percent less labor. So I think once farmers realized they can save not just cost and water and seed but also labor then I am very confident it's going to catch on very widely. So we are having to change our thinking. I am afraid some of the skeptics haven't caught up to the data, from IWMI, from GTZ, from the different universities, from NIP and COY(3:01). In fact the intensification is really management not necessarily even more labor per hectare once you learn how to do this. There is always a learning cost, there is a learning curve we have to climb up on.

What are the leading constraints in disseminating SRI?

The leading constraints I think are mostly mental. It's just the idea that you can get more production with less inputs, it goes against all our intuition, experience. We can explain this in scientific terms. How and why, less water, less plants, wider spacing gives you those results. There is objectively the limitation that if you don't have any water control, if you can't keep the soil in mostly aerated conditions you won't see these results. And so good water control which is a combination of hardware and software, that's subjective. If you want to go the organic route and use organic fertilization, you need to have enough biomass. Rice straw is of course the basis for this but you want other kinds of grasses, leaves, manure any kind of other material to decompose to enrich the soil biologically. In some places we have had some pest control problems. The most unusual was one on the edge of the Amazon jungle in Peru in Pucallpa where they tried SRI on an acre of land just using instruction they got from a drilling article and they got 8 ton yield instead of 2 tons. And one thing they really liked was that for the last month normally they have to be out scaring the birds away from the jungle with SRI the pinnacles are heavy enough that they hung down, the birds could not get them so they saved that labor of bird scaring and got 8 ton yield. Other constraints to get the best results you need to use a push wheel which will aerate the soil and at the same time removes weeds. At some places the farmers don't have the access to or don't have the credit. Yet they don't cost much 10-20 dollars that's all. You can pay that back easily with the increased yield but you got to have the money upfront. I think the biggest constraint still is the mental one. My wife and I were in the Tripura state of India last August. Just village to village, in some village farmers were like "it's so easy it almost recreational, this weeder were so fast and easy" other would say "this weeder is so much work and difficult". So there are very different human reactions. We do find most of the times once you get past that first month. I mean another thing I think I should mention is that for the first month the field looks terrible. These tiny little seedlings widely spaced not flooded, you don't see much green. There is no water to reflect the blue sky and give you a nice blue color to your planted field. This looks muddy. We had wives leave their husband for the first four five six weeks. Said "you fool you have ruined our families food supply". The Cambodian farmer told us at a workshop that after the six weeks when it started the tillerings she came back and when we harvested these we were pretty good friends again. I remember in Cuba, a farmer said that his Father in law was embarrassed and said that I have been transplanting more seedlings at night so that the field won't look so embarrassed so naked. So it does take a certain amount of courage and audacity just to be the first farmer in your area to try this. Once you have seen this crop cycle and seen the crop by the end of the season then those kinds of apprehensions and fears pretty much go away.

SRI demands good irrigation infrastructure. Is this a major constraint?

Water control is as I said is part of the most objective requirement for SRI results. So that you have to ensure that soil is not continuously flooded, not hypoxic, not suffocating the plant roots and the soil organisms. Once you passed the first month once those roots are going down, the plant is pretty tolerant and pretty forgiving. If you start flooding the plant from the really beginning of the roots they become deformed degenerated. Then if you water stress they are finished, they can't survive. The water requirement is kind of a time frame. It's the first month which is very critical to get enough water but not too much.

What role can governments play in disseminating SRI?

One of the characterizations of the SRI we view is that it is a civil society innovation, it comes really from the community, it hasn't come through the standard channels of the researchers then extensions going to the farmers to tell them what to do. Initially it was mostly NGOs, universities and others that were interested in this. But in several countries it was government agents who picked up on this. In Nepal, in the Indian state of Tripura the leadership has really come from extension, agriculture government civil servants. So we are really pleased to see this is a coalition of Government, NGO, university, research institutes, private sector participants. Governments has got a key role to play. At this point where we have got we can demonstrate this. We can show people the results but for a large scale impact its going to require governments to get involved. In the state of Tripura, this one government researcher started on his own with SRI in 2000. He tried it for 2 years to adapt it to their very rainy conditions there. In 2002 he got 44 farmers to try it, next year 88, next year he got 440 (five times more) then he got 880. But that year he got the Chief Minister of the state, the Minister of Agriculture, the Finance Minister to come and see it and talk to farmers. And they said fine we got to reach this target of self-sufficiency by the year 2010, you can have one-third of the state's agriculture budget. So in 2 years' time it went from under a 1000 to over 70000. But all the state institutions worked with them. The local government institutions got very much involved. They gave subsidies for the weeders so that you can do that aeration with weed control. They gave them some subsidies for organic fertilizations, certain bio fertilizers and so forth. One interesting thing that any farmer growing SRI got a yellow flag on a stick that he put in his field. They are very proud to show this yellow flag in their fields. That was a nice visual reinforcement. I think that it's not a matter of giving free seeds. It's not a matter of giving subsidies or I call them often bribes. It does mean working with the irrigation department to make sure that they can deliver the water in a reliable way. Not more water but reliable water, that's an important thing governments can do. If they can facilitate farmer to farmer meetings or visits that's probably the suo most important to spread SRI. Extension play the important role. They are the planners, facilitators and help answer the scientific questions. But they are not out there to sell the innovation to the farmers rather to facilitate farmers learnings from peers. So if I was designing a program I would say that this superior extension is probably the most important thing. Having access to weeders, roller markers and so for(3:11). Not to give them out as zzzzzz(3:12) but may be to make them easy to purchase, keeping the price low ensuring availability. Working on the irrigation to make that those are probably the 3 most important things for this to spread.

Could SRI be the future of irrigated rice?

Well, some may think that SRI could be seen as the future of irrigated rice agriculture. We found that SRI methods and concepts work for unirrigated rain fed rice cultivation as well. So I wouldn't want to limit it just to irrigation but I think it is going to change the way in which we do irrigated rice. I think we can make our rice so productive that farmers can get both better incomes and we can have much lower price for consumers.

What are some downsides to SRI?

Well when we started we were sure that there had to be some downsides to this. I mean I have worked in the development for 40 years and nothing is ultimately as good as it appears at first. At first as I said we thought that labor intensive is going to be a sticking point but that has not proved to be the case. At some point if our productivity gains really hold up we are going to have a negative effect upon price. That of course is a good for the poor especially and for the consumer. What we want to do is to encourage diversification of agriculture. In Cambodia our NGO partners are already working with farmers who even as small as half hectare. When they will go from 1 or even 0.9 ton per hectare yield or 3 or 4 SRI then they will go back and take half of their time out of rice because they can get more than enough food than on just half of their rice land. And then they will have fish ponds, fruits, vegetables, legumes, poultries over. So they diversify and intensify their whole farming system. I just think we have to figure out of how do we solve the problem of this intensification, diversification and higher productivity. If we can put less of our land, less of our labor, less of our water, less of our money into rice production for our staple foods, we are going to be able to improve both our household economies and our national economies. I have been looking for the negatives, we are not afraid of them. First of all we have got so many positives that we can certainly absorb some negatives but I just haven't seen them. We even get 15 percent more outturn of milled rice per bushel of unmilled paddy. That was something of a bonus on top our paddy yields we get 15 percent more milled rice because there are less breakage of grains and less chaff, that's the unfilled grains in the paddy. So see that's really quite a nice bonus. We find that the crops mature 1 to even 3 weeks sooner which means we use less water for irrigation and we also have land freed up for vegetable and other crops.

Final comments?

We didn't demonstrate outside Madagascar anywhere before 2000. Now 8 years later we are up to 30 countries where we have been able to demonstrate this. Without any major donor support. Little support from Rockefeller foundation, little from GGSIT(0:15), little from World Vision, little from AI but basically it has been done by people of different countries who are interested, who care about farmers, who care about the environment and want to help the consumers. We really welcome whatever support we get then from the World Bank, from the major donors, from the foundations, from national governments. I think national governments should probably pick this up before the others because they have the most immediate needs to be able to use water more efficiently and more productively and SRI is one of the ways in which we can help to get higher water productivity.

Dr. Amir Kassam

What are the benefits of applying SRI, especially in relation to climate change?

SRI offers you immediate advantage in terms of addressing the water scarcity problem. SRI is a production system which offers you at least double the yield with half the water. That is water saving as well as a cost saving advantage. But more importantly it offers you double the productivity. In terms of climate change SRI is a much more robust system and it has characteristics which can tolerate variability much better than the conventional system and certainly during drought period it can stand up to water shortages much better.

Why is SRI controversial?

SRI to some people appears controversial. I think that the main reason is that it offers a new way of looking at agriculture. It offers a paradigm which is more agro-ecologically based, it is more closer to nature and it offers for the first time an ability to pay special attention to environmental issues. SRI in one sweep offers you increase in productivity, offers you better environmental services and it is less costly. I think that these features make some people believe that it is not true and therefore they question the validity of SRI. But I would say to those people "go to the field and see the evidence for yourself". There is now close to million hectares under SRI and that cannot be regarded as a delusion. It is real.

What is the implication of SRI to irrigation investments?

Investing in irrigation without specifying the way the water will be used for production is not the best way of managing investment. Policymakers and decision makers should always insist that SRI approach would be an integral part of irrigation investment.

Comments on SRI's agro-ecological aspects?

Agro-ecological principles have been ignored over the last 2-3 decades and we have followed a very simple approach, the so called Green Revolution approach which relies heavily on agro-chemicals but SRI shows that we can produce more using less but rely more on agro-ecological resources. SRI is an example of what future agriculture would be like.

Dr. Achim Dobermann

Can you share the reservations of IRRI on SRI?

I think it is important to understand first what SRI means. It is essentially a set of management practices, nothing else. Many of which one way or another have either been known for a long time. In some cases where they make most sense in terms of adaptation to a particular environment or cropping system, they are already recommended best management practices. So scientifically speaking I do not believe there is any miracle in these practices or any sort of unexplained synergistic miracles by the combination of these different practices. I think we have strong scientific understanding of most of these things. Now the situation is basically such that whenever people independently and with scientific methods have evaluated the SRI practices as they have been proposed then the results have usually been quite different from what has been reported from one formula ideations (1:24) conducted by NGOs and other who are promoting it. In other words, many scientists have had great difficulties to replicate those observations or have failed completely. That's one thing. But I think the more important one is what do you compare against this. What I have often seen in these reports is SRIs being compared in farmers' fields against something that is called conventional management. What is called conventional management has nothing to do or very little to do to with what we would consider being a best management practice. What I am trying to say is that "Yes", if you implement these practices very carefully you will get pretty good rice yield but we know we can achieve that. We know we can achieve this with management practices that are by and large much more readily adoptable by farmers than many of the techniques that are being promoted under SRI. So, we have strong reservations scientifically about the claims that are being made. But what is probably more important is that we have strong reservations in terms of the claims being made about the general applicability of SRI. Because it is a very labor intensive practice, it is very knowledge intensive. It is in my opinion in many ways going against the socioeconomic transfer that we see in rice farming where labor is becoming less available or more expensive. Where the trend is more generally towards more mechanized forms of production, more labor efficient forms of production. So, I think that is a complicating factor. There are many rice cropping systems in the world where it will be next to impossible to convince farmers to use management practices of the labor-intensive kind that the SRI represents. Go to small fields and small farms where plenty of labor is available then that is normally not a constraint.

How do you explain reports of higher yields from some farmers adopting SRI?

If you compare SRI with what we would promote as a best management practice is no significant difference. But I think the more important thing is that there has been a lot of confusion about what means adoption of SRI. If some states like Tamil Nadu claims half a million hectare or like it has always been reported from Zhejiang province (0:26) in China 1 million hectares. If you look very carefully what those practices that farmers use are you will notice two things. One is that lot of the practices that are now called SRI have been around there for long time and have actually been standard management practice e.g. alternative wetting and drying instead of flood irrigation has been the standard recommended management practice in Chinese hyperdry (0:56) systems for 20 years. There is nothing new there. Or the fact that planting younger seedlings gives higher yield has been the standard management practice zzzzzz (1:09) of 30 years. It is basically just good management in general. One important piece of research that needs to be done is actually clarify what has been adopted where in terms of the practices and in terms of the modifications of those that have been made compared to what has originally been thought to be the SRI. I think we have lot of confusion out there.

Why have some SRI trials by scientists failed?

Whenever this has happened and this happened quite frequently, the proponents of SRI usually say well that is because you haven't done it right or because it takes some time to learn how to do it right or they will say it takes some time, overtime, even years until the new positive effects become implemented or in terms of benefits or soil fertility or things like that. But I think these are fairly poor excuses because if scientists can't do that easily and replicate it or really verify it properly, I think it's very risky to go out and recommend things to farmers that aren't really explained properly. So whether there is any clear explanation for that failure is an interesting question.

Are you saying that SRI is simply a set of good management practices?

That basically what I look at it those management practices some of them are the same as we recommend, some of them I think are unnecessary or are very difficult to implement by farmers so but it is basically a set of management practices. We don't call it SRI we call it good management practices or best management practices or recommended management practices. But the goal is in the end the same to optimize the management of the crop in the given environment and given cropping season.

Explain why some farmers get better yields compared to scientific trials?

No they, Ok let's define failure, they have followed these practices very closely as they had been recommended but the yields that they were getting were not better or even less in some cases than what they were getting with what we already recommend as known good management practices. There was no difference. You have to look at the baseline for the comparison. If what is called the common practice or conventional practice yields very low, 1 ton or 2 tons, there is something wrong with it. There is obviously something fundamentally wrong. If you then with better management achieve 4 tons, you have doubled the yield but you are still far away from what the optimal yield should be. So I don't like these kinds of comparisons unless it is very clear also in terms of measurements and characterization what the common or conventional practice is. I don't question you can achieve this if you follow these management practices to the point. Any time you come there with improved management practices you are going to increase the yield so this not something that will only happen with SRI.

Comment on the plans for joint research by IRRI, Cornell, and Wageningen?

We have developed a first draft of proposal that will be led by Wageningen University in Netherlands with IRRI and Cornell University as partners. The proposal has essentially two major purposes. One is to really document, that goes back to my first answer, what is really actually happening out there in areas where there have been claims of adoption of SRI. So that's basically a surveying activity that we will conduct together but led by an independent institution who has not been directly involved in this debate so far. Second major component is to address scientifically some of the roots or the fundamental hypothesis on the zzzzzz SRI(1:01). So we propose to conduct jointly a set of very carefully designed experiments in a number of key locations across Asia. I would expect that we have results in about 3-4 years that will hopefully clarify a lot of the uncertainties that currently exist there and also the confusion that exists.

<u>Practitioners</u>

<u>Mr. Shuichi Sato</u>

What has been the constraints to disseminating SRI to farmers in Indonesia?

Biggest constraint is confidence. Financially not problem because SRI no increase external inputs. Main constraint is because of drastic change of the way of doing. Most of course farmer difficult to understand or afraid and question a lot more. So first we must prepare some demonstration farm. Most important point is first knowledge information. So we prepare material like pamphlet, vinyl (0:36). Also very important point is government side understanding and their cooperation. Structured practice (0:43) on the field. Only knowledge in the classroom not enough. Practice is important.

Why do you differentiate organic SRI from non- organic SRI?

I say basic SRI and organic SRI. Organic approach was commonly understood that part of important aspect of SRI but difficulty also exist. Many countries due to organic approach dissemination is very slow. Most farmer faced difficulty of organic approach because the organic mean for example consists of (0:27) compost need big energy but real effect come out not first year but second or third year. If market is not variable or organic rice cannot sell in higher price what's the return for them for their effort, this is question. So, in my project 5 years ago when we start we follow the original idea basic SRI only without using organic material and very great success already. But now after 5 years we gradually disseminate organic approach now. We are now proposing phased approach First basic SRI then come to organic approach. Step by step this is realistic. But of course, some farmer like West Java start from the organic SRI directly because market ability or farmer level everything is good. So, we must be flexible how to do. There are many choices.

Are there differences in the quality and price of SRI rice?

SRI rice quality is better than conventional system even same variety. One is taste is good. Second after cooking one or two or three days later, SRI rice no quality change still delicious. But conventional rice after one day stale smell come out, not delicious. This really happens and also very big difference is milling quality is different. It means SRI rice is much better reducing the broken rice after milling. SRI rice is much better price. In Indonesia SRI rice, but not organic, may be 20 percent higher than conventional rice but organic SRI rice 2 times or 2.5 times so benefit of farmers are very high.

Mr. Carlos Salazar

What has been the reaction of farmers in your area to SRI?

In the Philippines, farmers still believe that if we could achieve what really happened they don't tend to agree. They want to see it first for them to follow. That's why I am recommending demonstration farm will be established nationwide. This is the best way to convince farmers. Actually, many were surprised after seeing that specially in the intermittent method of water application because farmers in the Philippines practice flooding method with continuous water but when they saw that with intermittent method of water application even to the extent of soil cracking (0:49) produced more tillers, that's why they were surprised and many are now convinced to adopt the system of farming.

From your experience, does SRI require more labor?

I agree that increase application of organic fertilizer will increase labor because zzzzz (0:09) we are recommending something like 20 zzzzz (0:12) or bags of organic fertilizer not like chemical fertilizer that we are only recommending 3-5 bags per hectare so there is accordingly an increase of labor requirement. But as we go on applying organic fertilizer, the trend is reducing. May be in 3-4 years no organic fertilizer will be applied because soil will already become fertile, ideal for rice farming. So no more application of organic fertilizer or chemical fertilizer. So the idea that there is that increase in labor if we go on organic farming is not true.

Development Agencies

Dr. Willem Janssen

How did you see the potential of SRI in project preparation?

This project was very novel in the way that it tried to combine agriculture and irrigation which to most outsiders seems pretty logical but in many projects is done separately. And SRI came up that is one of the best options for actually kind of let's say economizing water and getting higher yield. And so it brought together the two main things that we wanted to do in this project, get agriculture to become more productive and to be more effective with water resources available. Up to now it's been living up to that promise. We really have been more efficient with water use. Farmers are because of that able to plant higher areas in rice because water is very scarce in the state and they are getting rice of good quality.

Some of the reasons why we were very willing to go forward at that state is that the project was being developed by a very competent group of people. University of Tamil Nadu which is recognized in the country, is probably the best Agriculture University of the country. And we also were aware of the fact that the SRI system had been functioning quite well in other places. Often at somewhat smaller scales but we felt that it was quite ok to try to scale it up at another level. Some other reasons why we felt it was a very good component in this project was that we would be able to reduce and produce. We would be able to reduce the use of fertilizer and also the use of herbicides. And since these are very major cost elements that was very essential to make farming more profitable to farmers. All those things together made us decide that it was a very wise and good move to try out SRI and to try it out on a big scale.

How was the idea of SRI introduced in the project?

It was certainly not the World Bank that introduced the technology to India. India has a very vibrant kind of scientific community both in the Indian Council of Agriculture Research and in the State Agriculture Universities and I believe that some of those have been in kind of touch very early on with the System of Rice Intensification. And those were the ones that actually started to push it. I think what the bank did is we picked up on it and we picked up on it not so much because we had a specific interest in rice but we had a specific interest in combining improved economy with improved irrigation. SRI was just in the middle of it.

What is needed for scaling up SRI?

One of the main elements for scaling up will be that the technology is going to be adapted to specific conditions. And the specific conditions can be agro-biological conditions like the type of soil, like when the water is available, like the planting months. But they may also be socioeconomic conditions like when there is labor available and that is a point where SRI system needs to be adapted with care. Because the labor peaks change through the cropping cycle towards let's say more at the early start of the crop. Other than that an important change in many irrigations systems is that the water must come at different moments and that might be one of the more difficult things to manage. Many irrigation systems in India work with quite big bulk delivery of water. So at a certain moment the canal opens up, the water starts coming out. Farmers have water for a day or two and then it stops again in the gravity systems. An important would be in these SRI systems that the amount of water that the arrives at the farm is going to be smaller, it might need to come a bit more often and with the surplus water that is not required any more, the additional land will be irrigated. And those are let's say relatively substantial changes. And those are the changes that go beyond the management of the field into the management of irrigation system.

Do you view SRI expansion as a bottom up approach?

In the 70s of the last century, we became very used to a type of model of technological change where all the change was coming out of the research organizations. So, change started with a scientist having a bright idea and then further developing that. And one of the interesting things that we see occurring now in the last 10-15 years is that the change increasingly comes up from the bottom. SRI is a very typical example of that and it's an example that in retrospect merits a lot of study. Understanding why it was able to mushroom in quite so many places? What were the key success factors? And in the retrospect, it has also been seen occasionally as a challenge for the small traditional technological change models which tend to start withresearch organizations. There is no reason to be concerned there as there is a lot of follow up work to be done once the technology arrives in order to put in place, in order to understand how you make it work best. And so, there is certainly more work even than before for scientists.

What is the role of the World Bank in response to paradigm shifts like SRI?

SRI really is a paradigm shift. It's a system of producing rice in which basically everything that we knew about rice is going to be turned around and the surprising thing is that it actually yields higher. I think the first thing that the bank should do with respect to paradigms is we should be very careful with adopting them. We have had a lot of bad experiences with being hooked on to paradigms too strongly. We must be very let's say sober about what is possible, what can be funded, what can be done. Then the next thing that we need to do is we need to look at the evidence. We are not scientists so for the bank what counts is the bottom-line. We need to make sure we come out with technologies that were better for the people that we have to deal with. The point that we need to make sure is that we really are evidence based and we are practical. The bank is not about proving or disproving scientific paradigms. And one of the main reasons why we went forward with the System of Rice Intensification in India is basically because it had worked at substantial scales, it was backed by a good team and under those conditions we could just try it. At the same time, we also need to be careful and we need to listen. We should not do things basically because somebody believes in it. We should make sure that there is a group of people that is able to understand why it works and why it comes about. It's also very important to understand that increasingly innovation is based not on very big changes. It's based on many small changes in many different places and if we do that we can also avoid that we get locked into let's say paradigms that afterwards turn out not to be valid.

Appendix 5. SRI songs from Bihar

The text of these songs was provided by PRAN. I also have recordings of PRAN SRI farmers singing these songs before the beginning of meetings and at district-wide agricultural fairs. When PRAN expands to a new area, it brings female farmers from other villages all wearing yellow saris to sing these songs. As the women sing, other women are curious and gather to hear the songs which describe the techniques and benefits of SRI in detail.

Song No. 1

Sisters, spread your knowledge to each and everyone,
SRI method is very great. (Twice)

We will adopt Sri method,
We will facilitate our girls' study,
Sisters, our daughters would become pride for our village.
SRI method is very great. (Twice)

We will use weeders on 15th day,
We will repeat it on 30th day,
Then the plants would become healthy,
SRI method is very great. (Twice)

We will prepare manures on our own,
We will prepare pesticides on our own,
Sisters, we will not give our command to the market,
SRI method is very great. (Twice)

We will prepare SRI Pranamrit (plant energizer),
We will repel urea and DAP,
We will repel chemicals as it is our pride,
SRI method is very great. (Twice)

We will practice SRI method,
We will propagate it to every person,
Sisters, we will collectively develop the world,
SRI method is very great. (Twice)

We will enhance our knowledge on PRAN (spirit of life),
We will keep going on the path of truth,
Sisters, God will be found in every people,
SRI method is very great. (Twice)

We will construct the temple of SRI method,
We will also keep SRI method in our minds,

Then our sons and daughters may become great,
SRI method is very great. (Twice)

Song No. 2

Transplantation of paddy seedlings through SRI method is pleasant.
Transplant it slowly, sister; Transplant it slowly, aunty, (twice)
Paddy plants look nice when transplanted in rows,
Transplantation of paddy seedlings through SRI method is pleasant.

Less seed is needed for SRI method,
It will also consume less labor,
You will find its transplantation pleasant and nice,
Transplantation of paddy seedlings through SRI method is pleasant.

Do use the weeders on 15th day,
Do repeat it on 30th day,
Then double will be yield of paddy and pleasant,
Transplantation of paddy seedlings through SRI method is pleasant.

It may yield three maunds[141] a Kattha[142],
It may yield four maunds a Kattha,
Leave the practice of growing one maund a Kattha, it is pleasant,
Transplantation of paddy seedlings through SRI method is pleasant.

Purify and treat the seeds at first,
Only then develop the nursery,
Sow the seeds after germination,
Mulch them using paddy straw,
Do the watering and go to check it every day,
You will fill in with joy to see, it is pleasant,
Transplantation of paddy seedlings through SRI method is pleasant. (Twice)

Song No. 3
He introduced the SRI method village to village,
My brother is knowledgeable.

My brother is knowledgeable; my sister is knowledgeable, (twice)
He introduced the SRI method village to village,
My brother is knowledgeable.

Receiving the training from PRAN office,
He became VRP[143] of SRI method,
He visited and convinced village to village,
My brother is knowledgeable.

He facilitated us grow paddy, wheat, vegetables, finger millet,
He introduced the technique of SRI method,
He lit candles in the houses of the poor,
My brother is knowledgeable,
He introduced the SRI method village to village,
My brother is knowledgeable.

Brother from PRAN is sailor for the poor,
Facilitator of farming on the farms of the poor,
He eradicated the feeling of superior and inferior (people),
My brother is knowledgeable.

He extended the method locally and abroad,
He extended it to the oppressed and backwards,
He enhanced the yield farm by farm,
He caused it to grow three maunds a Kattha,
My brother is knowledgeable.

My brother is knowledgeable; my sister is knowledgeable, (twice)
He introduced the SRI method village to village,
My brother is knowledgeable.

Song No. 4
Grow SRI method paddy, grow my sisters.
Grow SRI method paddy, grow my sisters.

SRI method consumes less water,
It consumes less seeds, less labor,
Adopt it farm to farm, adopt it my sisters,
Grow SRI method paddy, grow my sisters. (twice)

Brother from PRAN is sailor for the poor,
Coordination with Government, growth promoter for farmers,
Prevent him from enemies, prevent my sisters,
Grow SRI method paddy, grow my sisters.

Sisters stay hungry at homes; they do not get their meals,
Adopt it house to house, adopt my sisters,
Grow SRI method paddy, grow my sisters.

Honorable Minister is sentry for poor,
Welcome him with garlands,
Put on him garlands; put not my sisters,
Grow SRI method paddy, grow my sisters.

Song No. 5
Come brothers and sisters,
We visited here to extend you the knowledge,
To enhance the knowledge of farming through SRI method.

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141 A measurement of weight (forty seers).

142 A measurement of land.

143 Village resource person

Transplant the seedlings very young,
Do not use seedlings more than one,
The farms will be prosperous,
The crops will yield limitless, dear sisters.

PRAN visited to tell all of us,
To use weeders only on 15th day,
To grow green manures in the fields,
Then, it will grow, bunches will grow again and again, dear sisters.
PRAN visited to tell all of us,
Come brothers and sisters ….

Less crop will yield more,
Sons and daughters will go to read,
The family will be well to do, dear sisters.
PRAN visited to tell all of us,
Come brothers and sisters,
We visited here to extend you the knowledge,
To enhance the knowledge of farming through SRI method.

Song No. 6

We will enhance awareness for SRI method, we will change the world.
We will ….

We will transplant paddy field by field using SRI method,
We will change the minds of every family towards SRI method,
We will turn every village into heaven, we will change the world.
We will …

We will also prepare manure and pesticides (twice)
We will not buy chemical poison from market (twice)
We will repel the diseases from every family, we will change the world.
We will ….

We have learnt farming through SRI method,
I will be beloved of parents and all,
We will facilitate the children be great, we will change the world.
We will….

We have turned the views of society,
We have enhanced the capacities through SRI method,
We will flow the Ganges of knowledge, we will change the world.
We will….

We will adopt the lesson of five 'S' in our families,
We will extend our respect to the elders,
We will bow before them in our families,
We will get the well wishes of the elders,
We will enlighten house to house, we will change the world.
We will….

We will turn the earth into heaven with five 'J',
We will improve water, forest, animals, land, (twice)
We will turn every person into true human being,
We will change the world.
We will ….

The demons polluted the earth (twice)
Spread poison in air and water, (twice)
We will enhance the knowledge of PRAN, we will change the world.

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