Essays in Development Economics

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Essays in Development Economics

A dissertation presented
by

Jack Willis

to

The Department of Economics
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy
in the subject of
Economics

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Abstract

This dissertation consists of four chapters, in two halves. The common, broad theme is the importance of time in problems which we often analyze statically.

In the first half, we consider the role of time in insurance. The gains from insurance arise from the transfer of income across states. Yet, by requiring that the premium be paid upfront, standard insurance products also transfer income across time. We consider the theoretical implications of this transfer across time in Chapter 2, and test them empirically in Chapter 1. We show that the intertemporal transfer can help explain low insurance demand, especially among the poor, and in a randomized control trial in Kenya we test a crop insurance product which removes it. The product is interlinked with a contract farming scheme: as with other inputs, the buyer of the crop offers the insurance and deducts the premium from farmer revenues at harvest time. The take-up rate is 72%, compared to 5% for the standard upfront contract, and take-up is highest among poorer farmers. Additional experiments and outcomes indicate that liquidity constraints, present bias, and counterparty risk are all important constraints on the demand for standard insurance.

In the second half, we consider the implications of time for policies on investments in durables. Such investment decisions are forward looking, so expectations over future policies matter. In Chapter 3 we argue public infrastructure often substitutes for, or complements, private durables. In such cases, private investment in durables depends on expectations over future public infrastructure. In turn, private investment affects future demand for, and hence investment in, public infrastructure. This creates a dynamic coordination game which can
have multiple equilibria. If governments can commit early to future public infrastructure, they may do so. If they cannot, they may be driven to second best policies, such as early construction of public infrastructure. In Chapter 4 we consider Pigouvian taxation of durables. Dynamically and statically optimal Pigouvian subsidies on durables will differ in a growing economy. For durables with positive externalities, statically optimal subsidies will typically grow, whereas dynamically optimal policies may commit to eventually reducing subsidies.
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To my parents, Stan and Cherry
Introduction

This dissertation consists of four chapters, in two halves. The common, broad theme is the importance of time in problems which we often analyze statically.

In the first half of the dissertation, co-authored with Lorenzo Casaburi, we consider the role of time in insurance. The gains from insurance arise from the transfer of income across states. Yet, by requiring that the premium be paid upfront, standard insurance products also transfer income across time. We consider the theoretical implications of this transfer across time in Chapter 2, and test them empirically in Chapter 1.

In Chapter 2, we develop a model of insurance which incorporates the transfer across time, and layout several implications for insurance demand. First, demand for insurance does not just depend on preferences for redistribution across states, but also for preferences for redistribution across time. Second, insurance may make consumption paths less smooth, if inappropriately timed. Third, the transfer across time reduces demand for insurance precisely when self-insurance is hard, and hence when the gains from risk reduction are largest. Finally, the transfer across time may be particularly costly for the poor, providing an explanation for why they typically demand less insurance. Having considered the implications for demand, we next turn to insurance supply, showing that imperfect contract enforcement may explain why premiums are paid upfront, before discussing the policy implications and potential ways in which the transfer across time could be removed in practice. Finally, motivated by the theoretical framework, we discuss how preferences over time and state are mixed together in standard preference elicitation, and propose an experimental design to separate and compare preferences over time and risk over both
money and consumption.

In Chapter 1, directed by the above theory, we present empirical evidence for effect of the transfer across time in insurance products. Namely, in a randomized control trial in Kenya, we test a crop insurance product which removes it. The product is interlinked with a contract farming scheme: as with other inputs, the buyer of the crop offers the insurance and deducts the premium from farmer revenues at harvest time. The take-up rate is 72%, compared to 5% for the standard upfront contract, and take-up is highest among poorer farmers. Additional experiments and outcomes indicate that liquidity constraints, present bias, and counterparty risk are all important constraints on the demand for standard insurance. Finally, evidence from a natural experiment in the United States, exploiting a change in the timing of the premium payment for Federal Crop Insurance, shows that the transfer across time also affects insurance adoption in developed countries.

In the second half of the dissertation, co-authored with Michael Kremer, we consider the role of time in public policy towards investments in durables. Investment decisions for durables are forward looking, hence expectations of future policies matter. We consider the implications for two different policy problems, and show that there may be multiple equilibria, and so an important role for government commitment to future policies, and for second-best policies when such commitment is not possible.

In Chapter 3, we consider investments in public infrastructure. Public infrastructure often substitutes for, or complements, private durables. Sewage connections substitute for latrines, electric grid connections for generators; subway stations complement surrounding housing. In such cases, private investment in durables depends on expectations over future public infrastructure. In turn, private investment affects future demand for, and hence investment in, public infrastructure. This creates a dynamic coordination game which can have multiple equilibria. If governments can commit early to future public infrastructure, they may do so. If governments cannot commit, they may be driven to second best policies, such as early construction of public infrastructure or the taxation of private durables. We consider these interactions in a generalized setup in a growing economy, and focus on what
affects the ensuing equilibria and whether efficient outcomes are attained. The technical efficiency of the two solutions and the natural catchment area of public infrastructure are obviously important, but so too are the level of inequality, the growth rate of the economy, the institutions and the ability to commit. Many of the conditions which can lead to inefficient outcomes are widespread in the developing world, suggesting an important role for second-best policies in their current rapid growth in infrastructure.

Finally, in Chapter 4, we consider Pigouvian taxation. Dynamically and statically optimal Pigouvian subsidies on durables will differ in a growing economy. For durables with positive externalities, such as sanitation, statically optimal subsidies will typically grow. However, in a dynamic game, governments can most cheaply induce optimal purchasing time by committing to eventually reduce subsidies. If governments cannot commit, there may be multiple, Pareto-ranked equilibria. The presence of multiple subsidizing bodies, including foreign donors, makes commitment more difficult. As a result, consumers may actually delay purchase, rationally anticipating growing subsidies. In the extreme, the benefits of foreign subsidies for durables that create positive externalities may be more than fully offset by such delays in private investment. For durables with negative externalities, such as guns, delays between the announcement and implementation of taxes or regulation may bring forward purchase, potentially causing policymakers who would otherwise prefer such policies to abandon them. Political actors may also be able to shape others’ policy preferences by changing private expectations. For example, a political party that announces an intent to redistribute land may reduce current owners’ investment incentives, thus reducing the benefits of maintaining existing property rights and making land reform more attractive to the median voter.
Chapter 1

Time vs. State in Insurance: Empirical Evidence from Contract Farming in Kenya

1.1 Introduction

The welfare gains of insurance come from the transfer of income across states of the world, from good states to bad. In practice, however, most insurance products also transfer income across time: the premium is paid upfront with certainty, and any payouts are made in the future, if a bad state occurs. This paper provides experimental evidence on the consequences of this transfer across time in insurance, by evaluating a crop insurance product which eliminates it.

Crop insurance offers large potential welfare gains in developing countries, as farmers face risky incomes and have little savings to self-insure. Yet demand for crop insurance has remained persistently low, in spite of heavy subsidies, product innovation, and marketing campaigns (Cole et al. 2013a). The transfer across time is a potential explanation. Farmers face highly cyclical incomes which they struggle to smooth across time, and insurance

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1Co-authored with Lorenzo Casaburi, University of Zurich
makes doing so harder: premiums are due at planting, when farmers are investing, while any payouts are made at harvest, when farmers receive their yields.

The insurance product we study eliminates the transfer across time by charging the premium at harvest, rather than upfront. We work in partnership with a Kenyan contract farming company, one of the largest agri-businesses in East Africa, which contracts around 80,000 small-holder farmers to grow sugarcane. As is standard in contract farming, the company provides inputs to the farmers on credit, deducting the costs from farmers’ revenues at harvest time. We tie an insurance contract to the production contract and use the same mechanism to enforce premium payment: the company offers the insurance product and deducts the premium (plus interest) at harvest.

Our first experiment shows that delaying the premium payment until harvest time results in a large increase in insurance demand. In the experiment we offered insurance to 605 of the farmers contracting with the company and randomized the timing of the premium payment. Take-up of the standard, upfront insurance was 5%: low, but not out of line with results for other “actuarially-fair” insurance products in similar settings. In contrast, when the premium was due at harvest (including interest at 1% per month, the rate which the company charges on loans for inputs), take-up was 72%, among the highest take-up rates seen for agricultural insurance in similar settings. To benchmark this difference, in a third treatment arm we offered a 30% price discount on the upfront insurance premium. Take-up among this third group was 6%, not significantly different from take-up under the full-price upfront premium. Taken together, these results show that farmers do have high demand for insurance, but they have a low willingness to pay for it upfront.

To help identify the channels, guided by the model in Casaburi and Willis (2017b),

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2Further, while farmers can often reduce their idiosyncratic income risk through informal risk sharing (Townsend 1994), similar mechanisms are less effective for reducing seasonal variation in income, since it is aggregate.

3The insurance product has a double-trigger design (Elabed et al. 2013), providing partial yield insurance, conditional on both plot yield and local area yield being below given thresholds, and on harvesting with the company.

4The experiment was registered before baseline at the AEA RCT registry, ID AEARCTR-0000486, https://www.socialscienceregistry.org/trials/486
we consider heterogeneous treatment effects in the above experiment and two additional experiments. Heterogeneous treatment effects by proxies for wealth and liquidity constraints show that, in line with the predictions in Casaburi and Willis (2017b), the transfer across time reduces demand more among the poor and the liquidity constrained, and they actually show higher demand for Pay-At-Harvest insurance.

In the first experiment on channels, we dig deeper into the role of liquidity constraints. Not having cash was the most common reason given by farmers who did not buy pay-upfront insurance in the main experiment. To test this, in this experiment we gave a subset of farmers cash, before offering them insurance later in the same meeting (similar to Cole et al. 2013a). The cash gift, being slightly larger than the cost of the premium, ensured that farmers did have liquidity to purchase the insurance if they wished to. However, as acknowledged by Cole et al. (2013a), it may also have induced reciprocity. To address this, we cross-cut the cash treatment with a pay-upfront vs pay-at-harvest treatment. The difference-in-differences effect of the cash was 8%, small and not significant, showing that pay-upfront insurance was not the marginal expenditure, and ruling out the explanation that farmers simply did not have cash. However, because the cash gift may not have completely removed liquidity constraints (farmers may still have wanted to borrow), two possible explanations remain: farmers were not liquidity constrained to begin with, or farmers were very liquidity constrained and hence had other uses for cash. The next experiment helps separate the two: it should only find an effect in the latter case.

In the second experiment on channels, we consider the effect of a small delay in the premium payment, such that payment is not due immediately at sign-up. The design targets present bias, which has important implications for optimal contract design and for welfare interpretations. In the experiment, we compare insurance take-up across two groups. In both groups, during the visit, farmers had to choose between a cash payment, equal to

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5Barring reciprocity, if anything we would expect demand for pay-at-harvest insurance to fall slightly with a cash drop, hence the diff-in-diffs should be an upper bound on the effect on upfront take-up, net of reciprocity.

6Such delays have been shown to increase savings in other settings, such as Save More Tomorrow programs (Thaler and Benartzi 2004).
the insurance premium, and free enrollment in the insurance. Farmers in the first group were told they would receive their choice immediately, whereas farmers in the second group were told they would receive their choice in one month’s time.\footnote{Delaying delivery this way, by just one month, increased insurance take-up by 21 percentage points. We show that the size of this effect is inconsistent with standard exponential discounting - if the discount rate was high, then why buy insurance in one month? In contrast, it is consistent with present bias (combined with liquidity constraints).} The final channel we consider is imperfect contract enforcement. If either party defaults before harvest time, then the farmer does not pay the premium at harvest, whereas the upfront premium is sunk. Tying the contracts together means that, for the farmer, defaulting on the insurance requires side-selling (selling to other buyers), and vice versa.\footnote{This has two implications. First, it reduces strategic default on the harvest-time premium, the natural concern with removing the transfer across time, since farmers typically value the production relationship. In keeping with this, there was no significant difference in side-selling, or in yield conditional on not side-selling, across pay-upfront and pay-at-harvest treatment groups. Second, however, it can induce default: if the farmer side-sells for other reasons, he automatically defaults on the insurance contract. In our setting, before harvest, the company faced severe financial difficulties and temporarily shut-down their factory, resulting in long delays and uncertainty in harvesting. Because of this, twelve months after our experiment began, there was widespread side-selling: 52\% of farmers side-sold or uprooted, compared to a historical rate of less than 10\%.}

In spite of the large default rates ex-post, three arguments suggest that, ex-ante, any differential effect on take-up by the timing of the premium was limited. First, using the model in \cite{Casaburi and Willis 2017b}, we bound the differential effect on take-up by the effect of a price cut on take-up for upfront insurance. In particular, a percentage price

\footnote{Giving farmers the choice between the premium and insurance for free, rather than the choice of whether to buy insurance, eased liquidity constraints and enabled us to enforce payment in the one month treatment.}

\footnote{If the farmer side-sells neither at-harvest premium payments, nor payouts, occur.}
cut, of size given by the expected probability of side-selling, times the relative (expected) marginal utility of consumption conditional on side-selling, has a larger effect. But the main experiment showed that demand for upfront insurance is inelastic, so for this channel to be important one of these two terms would have had to be very large. Second, while survey measures of trust in the company are correlated with overall insurance take-up, their interactions with the timing of the premium are not, suggesting that concerns of the company defaulting on insurance payouts after harvesting were more prevalent than expectations of side-selling. Third, assuming ex-ante expectations of side-selling are predictive of actual side-selling, then the correlation between take-up and actual side-selling should vary by premium timing. For both individual and local average side-selling, in the data it does not.

In the final contribution of the paper, we present evidence of external validity from a natural experiment in the United States. In developed countries, better legal institutions may make the enforcement of cross-state insurance easier, but better functioning financial markets may also make the transfer across time matter less. We provide evidence that the transfer across time does still matter, using a policy reform in the Federal Crop Insurance program, one of the largest in the world. Historically, premiums for the FCI typically were due around harvest time. But, starting in 2012, the premium due date was moved earlier for certain crops, requiring agricultural producers to pay premiums from operating funds. Identifying off of variation across time, crops, states, and county characteristics, we show that the change reduced the amount of insurance purchased, and that, in line with the role of liquidity constraints, the effect was concentrated in counties with smaller farms.

This paper adds to several strands of literature. First, many papers have investigated the demand for agricultural insurance and the factors which constrain it (Cole et al. 2013a; Karlan et al. 2014). Demand is generally found to be low, and interventions to increase it typically have small effects in percentage-point terms. Many of the proposed explanations, such as risk preferences and basis risk (Mobarak and Rosenzweig 2012; Elabed et al. 2013).

9 Karlan et al. (2014) find the highest take-up rates at actuarially fair prices among these studies, at around 40%; but most find significantly lower rates, for example, at around 50% of actuarially fair prices, Cole et al. (2013a) find 20-30% take-up, and at commercial price Mobarak and Rosenzweig (2012) find 15% take-up.
relate to the transfer across states in insurance; we focus on the transfer across time. Several studies have bundled insurance with credit (Gine and Yang 2009; Carter et al. 2011; Karlan et al. 2014; Banerjee et al. 2014), finding that take-up of credit increases little, and in some cases decreases. We effectively do the reverse, bundling credit with insurance.

The closest paper to ours, Liu et al. (2016), finds that, for a livestock mortality insurance provided by the government in China, delaying premium payment increases take-up from 5% to 16%; Liu and Myers (2016) considers the theoretical implications. As far as we know, our paper is the first to provide experimental evidence on the effect of completely removing the intertemporal transfer from insurance contracts, and on the role of liquidity constraints, present bias and other channels.

Finally, our paper adds to a literature on the importance of interlinked contracts, i.e. contracts covering multiple markets, in developing country settings. In particular, our work relates to a body of research that documents the presence of informal insurance agreements in output and credit market contracts (Udry 1994; Minten et al. 2011), and to a recent line of empirical research on the emergence and impact of interlinked transactions (Casaburi and Macchiavello 2016; Casaburi and Reed 2014; Ghani and Reed 2014; Macchiavello and Morjaria 2014, 2015).

The remainder of the paper is organized as follows. Section 1.2 describes the setting...
in which the experiment took place and how tying an insurance contract to a production contract affects enforcement. Section 1.3 presents the main experimental design and results. Section 1.4 presents evidence on channels, from the main experiment and from two additional experiments. Section 1.5 presents evidence of external validity from a natural experiment in the U.S. Finally, section 1.7 discusses the policy relevance of the results, presents ideas for future work, and concludes.

1.2 Setting, contract farming, and interlinked insurance

We work in partnership with a contract farming company in Western Kenya, one of the largest agri-businesses in East Africa. The company, founded in 1971, operates a large sugar factory which needs a steady supply of sugarcane. To supply the factory, the company contracts around 80,000 small-holder farmers to grow sugarcane. We offer insurance to some of these farmers. The setting is ideal for studying the intertemporal transfer in insurance because, as we explain below, contract farming offers a way to charge the premium at harvest time. Several other aspects also make it a good setting for developing and evaluating an insurance product: a large number of farmers, a long panel of data on production and plot characteristics, and important production risks.

Sugarcane, the crop which we insure in the study, is the main cash crop in the region. It accounts for more than a quarter of the total income for 80% of farmers in our sample, and more than one half of total income for 38% of farmers. It is not seasonal (in the region) and, once planted, lasts upwards of three growing cycles. Growing cycles are long - each one lasts around sixteen months - which means that the difference between paying the insurance premium upfront or at harvest time is particularly stark. The first cycle, called the plant cycle, involves higher input costs and hence lower profits than the subsequent cycles, called the ratoon cycles, and yields decline over cycles. Crop failure is rare, but yields are subject to significant risks from rainfall, climate, pests and cane fire.

Farmers who grow sugarcane are typically poor, but not the poorest in the region. In our sample, 80% of farmers own at least one cow, the average total area of cultivated land is
2.9 acres, and the average sugarcane plot size is 0.8 acres. Very few farmers in the study area have had experience with formal insurance.  

1.2.1 Contract farming  

Contract farming involves the signing of a production contract between farmers and buyers, at planting, which both guarantees the farmer a market and binds them to sell to the company, at harvest. It is a production form of increasing prevalence (UNCTAD 2009), and our setting is typical. Farmers, termed outgrowers, enter into a contract with the firm at planting time, with the contract covering the life of the cane seed, meaning multiple harvests over at least four years. The harvesting is done by company contractors, who subsequently transport the cane to the company factory where it is weighed. Farmers are paid at each harvest, by weight, at a price set by the Kenyan Sugar Board, the regulatory body of the national sugar industry.

Interlinked credit A major benefit of contract farming is that the company can supply productive inputs to farmers on credit, and then recover these input loans through deductions from harvest revenues. Such practice, often referred to as interlinking credit and production markets, is widespread and our setting is no exception: the company provides inputs such as land preparation, seedcane, fertilizer, and harvesting services, with the costs (plus interest, at 1% per month) deducted from harvest revenues.

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15 Those farmers that do have experience of insurance have mostly had health or funeral insurance.

16 Refined sugar is subject to import tariffs and quotas in Kenya.

17 Interlinkages, where a single contract or transaction between agents spans different markets, are an important feature of many agricultural markets in developing countries (Bardhan 1980; Bell 1988; IFAD 2003).

18 Inflation in Kenya was around 6% per annum during the study, so the real interest rate on input loans from the company was 7% per annum.

19 In addition to the risks mentioned above, company delays in these input provisions are a further source of risk for farmers.
Contract enforcement  The company must rely on self-enforcement of the contract, and thus the repayment of the input loan. This is because, as is common in developing countries, the cost of direct enforcement with a small farmer is prohibitively high. So, while illegal, farmers may side-sell (i.e. break the contract by selling to another sugarcane company) with little risk of prosecution. By side-selling, farmers avoid repaying the input loan, and are paid immediately upon harvesting, but they are typically paid a significantly lower price for their cane. While the company cannot directly penalize farmers for side-selling, the company will collect any dues owed to it (plus interest) if possible, either from the same plot if it is re-contracted in the future, or from other plots of the farmer if he contracts multiple plots. Since sugarcane is a bulky crop, the cost of transporting the cane to other sugar factories is often prohibitively high, and so side-selling is generally less of a concern than for more easily transported crops. Both the high transportation cost and monitoring by company outreach workers (discussed below) make partial side-selling unlikely.

We do not have direct information on the historical levels of side-selling in our context, but the administrative data we do have allows us to bound it. Prior to our experiment, in 2010-12, an average of 12% of plots which harvested in ratoon 1 did not harvest in ratoon 2, and figure 1.5 shows how this varied geographically. This is an upper bound on side-selling during this time, since some of these cases will be where farmers uproot the crop immediately after the ratoon 1 harvest (for example because of crop disease or poor yields). Since side-selling is illegal, obtaining detailed information from farmers about its causes and consequence is difficult.

The company is unlikely to strategically default on the contract. The main responsibility for the company under the contract is to purchase the farmer’s cane at the price set by

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20 Macchiavello and Morjaria (2014) show that, in the context of coffee in Rwanda, higher competition reduces input loans potentially for this reason.

21 Any debt owed on a plot remains on the plot even if it is sold, and the debt is collected from future revenues even if the plot is subsequently farmed by another farmer. At the time we ran our experiment, debt collection remained at the plot level: if a farmer defaulted on a loan on one plot, the company would not recover that loan from revenues from other plots farmed by the farmer. However the company changed this policy before harvest time for our farmers, so that defaulted loans on one plot could be recovered from other plots of the same farmer.
the Kenyan Sugar Board. Failure to do so would likely be reported to the Board, with consequences for the company, as farmers are well represented politically in the region. Farmers are, however, vulnerable to non-strategic default. If the company were to become insolvent, it would be unable to honor its agreement to purchase the cane, in which case farmers would be forced sell to another buyer. This happened, temporarily, 12 months after the start of our experiment, affecting some of the farmers in our sample. In Section 1.4.4 we discuss in detail the implications for the interpretation of our results - to summarize that discussion, multiple tests find no evidence that ex-ante anticipation of the shock affected our main results and we bound the size of the role it could have played.

**Administration** The company has to coordinate with its 80,000 farmers; how it does so has two implications for our study. First, the company employs outreach workers to visit farmers in their homes and to monitor plots. These outreach workers market the insurance product we introduce, as detailed in the next section. Second, because of fixed costs in input provision, the outreach workers must group neighboring plots into administrative units called fields, which can be provided inputs and harvested concurrently. As detailed in Section 1.3 in our experiments we stratify treatment assignment at the field level. In our study sample, fields contain on average 8.7 plots.

1.2.2 **Interlinked insurance**

In standard insurance contracts the farmer pays upfront, so all of the contract risk is placed on the farmer.\(^{22}\) Charging the premium at harvest time reduces the risk faced by the farmer: if the insurance company defaults before harvest time, at least the farmer will not have to pay the premium. However, it places significant counterparty risk on the insurer, the risk that the farmer does not pay the premium when harvests are good. In contract farming settings, future premium payments can be better enforced using the same mechanism which

\(^{22}\)Consistent with this, trust has been shown to be an important issue in shaping insurance take-up in other settings (Dercon et al. 2011, Cole et al. 2013a, Liu et al. 2016).
is already used to enforce repayment of input loans. Namely, the buyer can provide the insurance, and charge the premium as a deduction from harvest revenues.

Tying together the insurance and production contracts in this way, which we refer to as interlinking, increases the cost to the farmer of defaulting on the premium payment. In an interlinked contract, the only way default on the premium payment is to also default on the production contract, by selling to another buyer. As such, default compromises not only access to insurance in future periods, but also to all the other gains from the interaction with the buying company, including the current and future purchase guarantees as well as future input provision.\(^{23,24}\)

However, interlinking the insurance also has a potential cost in terms of enforcement. Namely, counterparty risk in the farming contract spills over into the insurance contract.\(^{25}\) If a farmer decides to side-sell for reasons unrelated to the insurance contract, doing so mechanically triggers default on the insurance contract. While, under certain conditions, this need not affect the functioning of the insurance market (for example, if default on the product contract is orthogonal to potential insurance payouts), it does limit the states of the world that can be covered by an interlinked insurance product.

Another concern with interlinking insurance with contract farming is it increases side-selling relative to that which would occur without insurance. However, there are two reasons to believe that this effect will be minimal in our setting. First, the value of the insurance premium is likely to be much smaller than pre-existing input loans, such as seeds and fertilizer. As argued above, the choice of strategic default depends on the comparison between the static benefits of the default and the continuation value of the relationship; the insurance premium is unlikely to be marginal in this decision.\(^{26}\)

Second, given the insurance

\(^{23}\)The same argument is often cited as an important advantage of interlinking credit markets and product markets.

\(^{24}\)Interlinking also has the additional benefit of the insurance being offered by a firm that the farmer is familiar with, which may help with trust.

\(^{25}\)The same cost exists arises from interlinking credit and product markets.

\(^{26}\)Further, if the farmers value access to insurance in future years, offering it would increase the continuation value of the relationship with the buyer, and hence insurance provision could actually reduce the occurrence of
design (detailed in the next section), the farmer has limited information about whether he will receive the insurance payout at the time when he has to decide whether to sell to the company. In keeping with this, Section 1.4.4 shows indeed that interlinked insurance did not increase side-selling.

Finally, we note that in contract farming settings, since many of the inputs are provided by the company, there is less scope for insurance to impact productivity than in many other settings. The only inputs required from the farmer are the use of their land, plus labor for planting, weeding, and protecting the crop. This means that insurance is less likely to induce moral hazard, which would lower productivity, but also that insurance may be less likely to enable risky investments, which would increase productivity.

1.3 Does the transfer across time affect insurance demand?

This section describes the main experiment of the paper, in which we compare take-up for insurance when the premium is paid upfront to take-up when the premium is paid at harvest time, thus removing the intertemporal transfer. Doing so has a large effect: in our setting, charging the premium as a deduction from harvest revenues, rather than upfront, increases take-up by 67 percentage points.

1.3.1 Experimental design

Treatment groups  The experimental design randomized 605 farmers across three treatment groups. In all three treatments the farmers were offered the same insurance product, described below. The only thing that we varied across groups was the premium payment. In the first group (U1), farmers were offered the insurance product and had to pay the premium upfront. The premium was charged at “full price”, which across the study spanned between 85% and 100% of the actuarially fair price. In the second group (U2), payment was again required upfront, but farmers received a 30% discount relative to the full price. Finally, in the side-selling.
third group (H), farmers could subscribe for the insurance and have the premium (full-price) deducted from their revenues at harvest time, including interest charged at the same rate used for the inputs the company supplies on credit (1% per month). Randomization across these treatment groups occurred at the farmer level and was stratified by field.

**Insurance design** The insurance was offered by the company and the terms of the payout of the insurance were the same across the different experimental treatments. There was no intensive margin of insurance and farmers could only subscribe for the entire plot, not for parts of it. The insurance product offered was a double-trigger area yield insurance, preferred to a standard rainfall insurance product because risk factors other than rainfall affect yields. Under the double-trigger design, a farmer receives a payout if two conditions are met: first, their plot yield has to be below 90% of its predicted level; second, average yield in their field must be below 90% of its predicted level. The design borrows from other studies that have used similar double trigger products in different settings, and relied on rich administrative panel data at the plot level which helped with the design and pricing of the insurance in numerous ways. The product is very much a partial insurance product: in the states where payouts are triggered, it covers half of the plot losses below the 90% trigger, up to a cap of 20% of the predicted production revenues. Finally, farmers only receive insurance payouts if they sell their cane to the company, as agreed under the production contract.

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27 For this group, the expected interest was added to the initial premium when marketing the insurance product.

28 The company collects rainfall information through stations scattered across the company catchment area. However, data quality issue is a concern and the predictive power of this rainfall data is low.

29 The data included information on production levels, plot size, plot location, and crop cycle, and was available for a subsample of plots for the period 1985-2006 and for the entire company catchment area from 2008 onwards. The data was used to compute the predicted yields at the plot and area level which were needed for the double trigger insurance design. The historical data also made it possible to run simulations of alternative prediction models, and to compare the predictive power and costing of alternative insurance products. The simulations verify that the double trigger product performs well in terms of basis risk - the proportion of farmers who receive a payout when the second area-level trigger is added is about 74% of those who would receive it with a single-trigger insurance. Additional calculations suggest the product does much better than an alternative product based on rainfall indexes.
Insurance marketing  The insurance was offered by company outreach officers during visits to the farmers. To reduce the risk of selecting farmers by their interest in insurance, the specific purpose of the visits was not announced in advance. 938 farmers were targeted, 639 (68%) of whom attended. The primary reason (75%) for non-attendance was that the farmers were busy somewhere far away from the meeting location.

To ensure that our sample consisted of farmers who were able to understand the insurance product, in an initial meeting outreach officers checked that the target farmers mastered very basic related concepts (e.g. the concept of tonnage and of acre). A small number of farmers (5%), typically elderly people, were deemed non-eligible at this stage. The final sample for the randomization was 605 farmers. Comparing to the 333 who did not enter the sample, these farmers had slightly larger plots (0.81 vs. 0.75 acres; p-value=0.015) and similar yields (55.5 vs. 54.5 tons per hectare; p-value=0.41).

After the initial group meeting, the outreach officers described the product in detail in one-to-one meetings with each farmer. They provided plot-specific visual aids concerning insurance triggers and payout scenarios. In order to ensure that the target farmers correctly understood the insurance product, outreach officers verified that farmers could correctly answer basic questions about the product before it was offered to them, e.g. the scenarios under which it would pay out. If farmers could not answer these questions, outreach officers re-explained. Farmers then had three to five business days to subscribe, with premiums collected either immediately or during revisits at the end of this period.  

Sample selection  Numerous farmer and plot criteria were used to select the sample, both to increase power and to improve the functioning of the insurance. The experiment

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30 In practice, for a substantial share of these farmers, revisits occurred between one and two weeks after the first visit.

31 The criteria used to select the sample were: plot size - large plots were removed from the sample, to minimize financial exposure from the insurance pilot; plot yields - outliers were excluded, to improve the fit of the predicted yield in the insurance contract; the number of plots in the field - the study targeted only fields with at least five plots, to improve power given the stratified design. the number of plots per farmer - within each field, the few farmers with multiple plots were eligible to receive insurance in only one of those, the smallest one, the number of farmers per plot - plots owned by groups of farmers were excluded from the sample; finally, while contracted farmers are usually subsistence farmers, some plots are owned by "telephone
targeted plots in the early stages of the ratoon cycles (in particular the first and second ratoons), i.e. plots which have already harvested at least once. This choice was made because the yield prediction model performs better for ratoon than for plant cycles. In addition, input costs are lower in the ratoon cycles, leading to fewer deductions from harvest revenues, and thus less incentives for side-selling.

**Data collection** We combine two sources of data for the analysis: survey data and administrative data. Our survey data comes from a short baseline survey, carried out by our survey team during the outreach-worker visits described. As mentioned in section 1.2, the company keeps administrative data on all of the farmers in the scheme. From the administrative data we get information on previous yields, plot size, and time since last harvest. The data also enables us to track whether or not the farmer sells cane to the company at the end of the cycle, and their yield conditional on doing so.

**1.3.2 Balance**

Table A.1 provides descriptive statistics for the three treatment groups using both administrative data and survey data, and shows that the experiment was balanced across most covariates. Since stratification occurred at the field level, we report p-values capturing the differences across the groups that are obtained from regressions that include field fixed effects. Consistent with the specification we use for some of our analysis, and farmers who live far from the plots and manage them remotely - such plots are excluded from our sample.

32 The model performs better for ratoon cycles because previous yields within the same contract, which are available only for ratoon cycles, are a much better predictor of current yields than yields of harvests in a previous contract.

33 The survey was undertaken before randomization and the offering of the insurance product, with the exception of a question on why the farmer chose to take up / not take up insurance, which was asked after.

34 We also use a second source of survey data. Several months later we followed up with a subset of the farmers by phone, to check whether they remembered the terms of the insurance and whether they regretted their take-up decision, as discussed below.

35 This also implies that characteristics that do not vary within field, such as location, specific ratoon cycle and average field yield are essentially perfectly balanced across treatment groups.
our pre-analysis plan, we also report p-values when bundling pay-upfront treatments U1 and U2 and comparing them to pay-at-harvest treatment H. The table suggests that the randomization mostly achieved balance across the observed covariates. In particular, only age is significantly different when comparing the bundled upfront group U to H. We confirm below that the experiment results are robust to the inclusion of baseline controls.

1.3.3 Experimental results

Our main outcome of interest is insurance take-up. Take-up rates have been consistently low across a wide range of geographical settings and insurance designs (Cole et al. 2013a, Elabed et al. 2013, Mobarak and Rosenzweig 2012). Yet gains from insurance could be large, both directly and indirectly - farmers are subject to substantial income risk from which they are unable to shield consumption, and previous studies suggest that when farmers are offered agricultural insurance they increase their investment levels (Karlan et al. 2014, Cole et al. 2013b). The central hypothesis tested in this paper is that low take-up is in part be due to the intertemporal transfer in insurance, which differentiates standard insurance products from their purely intratemporal ideal.

The regression model we use compares the binary indicator for insurance take-up – $T_{if}$, defined for farmer $i$ in field $f$ – across the three treatment groups, controlling for field fixed effects:

$$T_{if} = \alpha + \beta Discount_i + \gamma Deduction_i + \eta_f + \epsilon_{if}$$  \hspace{1cm} (1.1)

Figure 1.1 summarizes the take-up rates across the three treatment groups. For groups U2 and H, it also includes 95% confidence intervals of the difference in take-up from U1, obtained from a regression of take-up on treatment dummies.

The first result is that take-up of the full-price, upfront premium is low, at 5%. While low, this finding is consistent with several of the existing crop insurance studies mentioned above. The low take-up shows that reducing basis risk (the risk that the insurance will not pay out when farmers have a bad yield – one of the proposed explanations for low demand for rainfall insurance) by using an area yield double-trigger design is not enough to raise
adoption, suggesting that the availability of rich plot-level data, one of the main advantages a large firm may bring to insurance, may not be sufficient to generate high demand for insurance.

The second result (the main result of the paper) is that delaying the premium payment until harvest, thus removing the transfer across time, has a large effect on take-up. Take-up of the pay-at-harvest, interlinked insurance contract (H) is 72%, a 67 percentage point increase from the baseline, upfront (U1) level, and one of the highest take-up rates observed for actuarially fair crop insurance. Since the only difference from the upfront treatment group is the timing of the payment premium, the results show that in our setting farmers do want risk reduction, they just do not want to pay for it upfront.

The third result, which allows us to benchmark the importance of the second, is that offering a 30% price discount to the upfront premium has no statistically significant impact
on take-up rates. The point estimate for the effect is 1 percentage point, and even when considering the upper bound of the confidence interval, take-up only increases by 8 percentage points. While this upper bound is consistent with substantial demand price elasticity (given the low baseline take-up) it suggests that medium-sized subsidies have limited scope to prompt large increases in demand in absolute terms in this setting. In subsection 1.4.4 we use this result to quantifying the possible importance of imperfect contract enforcement for our results.

Table 1.1 presents regression analysis of these treatment effects, and shows that they remain stable across a variety of specifications. Column (1) reports the coefficient from the simple regression used to generate the histogram in Figure 1.1. As mentioned above, the pay-at-harvest product (H) has 67 percentage points higher take-up relative to the “full-price” pay-upfront product (U1), which is significant at the 1% level, whereas the 30% price cut product (U2) has just 1 percentage point higher take-up, which is far from significant. The difference between the pay-at-harvest (H) and the reduced price pay-upfront (U2) products is also significant at the 1% level. Column (2) adds fixed effects at the field level, the stratification unit. The results are virtually unchanged. Column (3) pools the upfront treatments U1 and U2, consistent with the specification we use later in the heterogeneity analysis. Columns (4) and (5) further add controls for plot and farmer characteristics, respectively. Finally, Column (6) includes both types of controls.

**Farmer understanding** One key question for the interpretation of the high take-up rate is whether farmers understood what they were signing up for. We believe that they did for two reasons. The first reason is, as mentioned above, farmers were asked questions to test their understanding of the product before it was offered to them. The second reason is, several months after the recruitment, we called back 76 farmers who had signed up for the pay-at-harvest insurance. We did so in two waves. In the first wave of 40 farmers, we began by reminding the farmers of the terms of the insurance product (the deductible premium and the double trigger design) and then checked that the terms were what the farmers had understood when originally visited. All farmers said they were. We then asked the farmers
Table 1.1: Main Experiment: Treatment Effects on Take-Up

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% Discount</td>
<td>0.013</td>
<td>0.004</td>
<td>0.013</td>
<td>0.008</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[0.032]</td>
<td>[0.033]</td>
<td>[0.033]</td>
<td>[0.032]</td>
<td>[0.033]</td>
<td>[0.033]</td>
</tr>
<tr>
<td>Pay At Harvest</td>
<td>0.670***</td>
<td>0.675***</td>
<td>0.673***</td>
<td>0.680***</td>
<td>0.687***</td>
<td>0.697***</td>
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<tr>
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<td>[0.028]</td>
<td>[0.033]</td>
<td>[0.032]</td>
<td>[0.032]</td>
</tr>
<tr>
<td>Field FE</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Plot Controls</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Farmer Controls</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Mean Y Control</td>
<td>0.046</td>
<td>0.046</td>
<td>0.052</td>
<td>0.046</td>
<td>0.046</td>
<td>0.046</td>
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<tr>
<td>Observations</td>
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<td>605</td>
<td>605</td>
<td>605</td>
<td>605</td>
<td>605</td>
</tr>
</tbody>
</table>

Notes: The table presents the results of the Main Experiment. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. Specification (3) bundles together treatment groups U1 (Pay Upfront) and U2 (Pay Upfront with 30% discount) as baseline group. Plot Controls are Plot Size and Previous Yield. Farmer Controls are all of the other controls reported in the balance table, Table A.1. Stratification occurred at the field level. *p<0.1, **p<0.05, ***p<0.01.

if they would sign up again for the product if offered next season. 32 (80%) said they would while 3 (7.5%) said they would not. The remaining 5 (12.5%) stated that their choice would depend on the outcome of the current cycle. In the second wave of 36 farmers, we did not prompt the farmers about the insurance terms, but instead asked farmers to explain them to us. 25 (69%) were able to do so. Of this second wave of farmers, after reminding those who had forgotten the terms, 28 (85%) said they would sign up for the product if offered next season.

To summarize, the results in this section show that pay-at-harvest insurance, enabled by interlinking product and insurance markets, has high take-up at actuarially fair price levels, while its standard, pay-upfront equivalent has low take-up (even with a substantial price cut), consistent with experience in other settings.

1.4 Why does the timing of the premium payment matter?

Throughout this section we refer to theoretical results from the accompanying paper, Casaburi and Willis (2017b). The model in that paper shows that liquidity constraints, intertemporal preferences, and imperfect contract enforcement could all drive the experimental results presented in Section 1.3. In this section we provide evidence which suggests
that all three of these channels play an important role in constraining demand for upfront insurance.

Before further discussing the mechanisms which can explain our results, we first note several which cannot. Since demand for pay-at-harvest insurance is high, and the only difference with upfront insurance is the timing of the premium payment, we can rule out many of the mechanisms shown to constrain insurance demand in other settings. This includes basis risk (the risk that insurance does not pay out when needed) and the risk preferences of farmers (Clarke 2016; Mobarak and Rosenzweig 2012; Elabed et al. 2013), the presence of informal insurance (Mobarak and Rosenzweig 2012), and farmer understanding of insurance (Cai et al. 2015).

Liquidity constraints are a natural candidate for the gap in demand between pay-upfront and pay-at-harvest insurance because, as shown in Proposition 1, they introduce a cost of holding the savings which are implicit in upfront insurance. Several studies have documented liquidity constraints among similar populations in the region of the study (Duflo et al. 2011; Cohen and Dupas 2010) and, also shown in Proposition 1, liquidity constraints may matter even if they do not bind at the time farmers are offered insurance – they drive a difference between paying upfront and paying at harvest if there is some chance they bind before harvest. Liquidity constraints are also tightly tied to wealth, and Proposition 2 showed that, as a result, they are a larger constraint on demand for upfront insurance among the poor.

Intertemporal preferences are another important candidate for explaining the large difference in demand for upfront vs. deduction insurance. Among intertemporal preferences, we are particularly interested in present bias. This is for three reasons: first, a recent literature shows evidence that present bias is responsible for significant distortions in intertemporal decisions in similar settings (Loewenstein et al. 2003; Duflo et al. 2011);

36 As shown in Proposition 1, intertemporal preferences only differentially affect the decision to take up insurance when individuals have a non-zero chance of being liquidity constrained before the next harvest. As shown by Duflo et al. (2011) and Cohen and Dupas (2010), this is likely to be the case for some farmers in our setting. Further, liquidity constraints are an endogenous outcome of the intertemporal optimization problem farmers face, for which intertemporal preferences are of key importance.
second, with present bias, the type of insurance offered has welfare implications, since the
decision to forgo upfront insurance for present consumption is not time consistent, and
future selves may regret it; third, if present bias is driving our results, the implications for
insurance design are very different – as argued in Casaburi and Willis (2017b), a product
under which the premium is paid after take-up, but before harvest, may still have high
demand without the contract enforcement concerns of a pay-at-harvest insurance.

Finally, imperfect contract enforcement could be responsible for the observed difference
between pay-upfront and pay-at-harvest insurance. If either party defaults on the contract
before harvesting, the upfront premium is sunk, whereas the farmer does not pay the
premium at harvest. As shown in Casaburi and Willis (2017b), anticipation of this possibility
can mechanically drive a wedge between the pay-upfront and pay-at-harvest insurance
products.

Before presenting evidence on individual channels, we note that in the main experiment
we elicited measures of preferences over the timing of cash flows, using standard (Becker-
DeGroot) Money Earlier or Later questions (Cohen et al. 2016). However, we did not detect
heterogeneous treatment effects by these Required Rate of Return variables, as shown in
table A.3. This is possibly driven by measurement issues, limitations associated with the
hypothetical nature of the questions, and limited statistical power. In addition, standard
lab-experiment measures in a given domain (e.g. the timing of cash disbursement) may fail
to hold predictive power on other domains, such as how to use that money.

In the rest of this section we do the following. We begin with evidence on liquidity
constraints, first from treatment heterogeneities in the main experiment, and then from a
second experiment. Then we present a third experiment which targets present bias, before
presenting the evidence we have for the importance of contract risk. Finally, we briefly

37 A recent experimental literature considers what such questions elicit, and suggests difficulties with using
them to measure intertemporal preferences (Andreoni and Sprenger 2012a, Augenblick et al. 2015, Cohen et al.
2016).

38 For instance, Kaur et al. (2015) find no correlation between lab experiment measures of time inconsistency
and workers’ choices on effort and labor contracts.
discuss other, behavioral channels, which could play a role and which we would like to investigate in future work.

1.4.1 Is upfront payment more costly for the poor & the liquidity constrained?

It is often argued that income variation is more costly for the poor, and so they should have higher demand for risk reduction. Yet the poor demand less insurance. Proposition 2 showed that the transfer across time in insurance is a possible explanation – the poor are more likely to be liquidity constrained, and liquidity constraints increase the cost of paying the premium upfront. Evidence that the poor often borrow at high interest rates and forgo high return investments provides weight to this potential explanation. If it is true, in our experiment we would expect the gap between pay-upfront and pay-at-harvest insurance to be higher among the poor.

We report how demand for the two types of insurance varies in our experiment with proxies for wealth and liquidity constraints, and thus the heterogeneous treatment effect of the transfer across time. The proxies come from both administrative data and from the baseline survey, and include yield levels in the previous harvest, sugarcane plot size, number of acres cultivated, whether the household owns a cow, access to savings and the portion of income from sugarcane. In order to gain power, we bundle together the two upfront groups (full price and 30% discount). Thus, the regression model is:

\[
T_{if} = \alpha + \beta \text{Deduction}_i + \gamma x_i + \delta \text{Deduction}_i \times x_i + \nu_f + \epsilon_{if}
\] (1.2)

Table 1.2 presents the results, which suggests that the treatment effect does indeed vary by wealth and liquidity constraints. While not all of the interaction coefficient estimates are significant, the results in the table show that less wealthy and more liquidity constrained households are differentially more likely to take-up the insurance when the premium is to be paid through harvest deduction, as predicted by proposition 2. For example, delaying premium payment until harvest time has an effect which is 14 percentage points larger for

\[39\]We mentioned the option of bundling the two upfront treatment groups when registering the trial.
those who do not own a cow, and 18 percentage points larger for those who would do not have savings to cover an emergency requiring a Sh 1,000 ($10) outlay. Further, also in line with proposition 2, the effect comes from demand for pay-at-harvest insurance being higher among the poor. From a policy perspective, this result implies that pay-at-harvest insurance may be particularly beneficial for poorer farmers, who are typically in stronger need of novel risk management options.
Table 1.2: Main Experiment: Heterogeneous Treatment Effects by Wealth and Liquidity Constraints Proxies

<table>
<thead>
<tr>
<th>X</th>
<th>Land Cultivated (standardized)</th>
<th>Own Cow(s) (standardized)</th>
<th>Previous Yield (standardized)</th>
<th>Plot Size (standardized)</th>
<th>Portion of Income from Cane</th>
<th>Savings for Sh1,000</th>
<th>Savings for Sh5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>X * Pay At Harvest</td>
<td>-0.065**</td>
<td>-0.141*</td>
<td>-0.079**</td>
<td>-0.001</td>
<td>0.052*</td>
<td>-0.175**</td>
<td>-0.131</td>
</tr>
<tr>
<td></td>
<td>[0.033]</td>
<td>[0.079]</td>
<td>[0.031]</td>
<td>[0.031]</td>
<td>[0.028]</td>
<td>[0.069]</td>
<td>[0.097]</td>
</tr>
<tr>
<td>X</td>
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<td>-0.022</td>
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<td>-0.016</td>
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<td></td>
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<td>[0.019]</td>
<td>[0.017]</td>
<td>[0.043]</td>
<td>[0.059]</td>
</tr>
<tr>
<td>Pay At Harvest</td>
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<td>0.823***</td>
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</tr>
<tr>
<td></td>
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<td>[0.028]</td>
<td>[0.028]</td>
<td>[0.096]</td>
<td>[0.035]</td>
<td>[0.031]</td>
</tr>
<tr>
<td>Mean Y Control</td>
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<td>0.052</td>
<td>0.052</td>
<td>0.052</td>
<td>0.052</td>
<td>0.052</td>
<td>0.052</td>
</tr>
<tr>
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<td>1</td>
<td>1.126</td>
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<td>Observations</td>
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<td>566</td>
<td>605</td>
<td>605</td>
<td>567</td>
<td>564</td>
<td>563</td>
</tr>
</tbody>
</table>

Notes: The table shows heterogenous treatment effects on take-up from the Main Experiment, by different proxies for liquidity constraints. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance, and in each column the relevant heterogeneity variable (X) is reported in the column title. Treatments U1 (Pay Upfront) and U2 (Pay Upfront with 30% discount) are bundled together as baseline group, as specified in the pre-analysis plan. Land cultivated is the standardized total area of land cultivated by the household. Own Cow(s) is a binary indicator for whether the household owns any cows. Previous Yield is the standardized tons of cane per hectare harvested in the cycle before the intervention. Plot size is the standardized area of the sugarcane plot. Portion of Income from Cane takes value between 1 (“None”) to 6 (“All”). Savings for Sh 1,000 (Sh 5,000) is a binary indicator that equals one if the respondent says she would be able to use household savings to deal with an emergency requiring an expense of Sh 1,000 (Sh 5,000). 1 USD = 95 Sh. All columns include field fixed effects. *p<0.1, **p<0.05, ***p<0.01.
1.4.2 Do people buy upfront insurance, given enough cash to do so?

In line with the importance of liquidity constraints, when we surveyed farmers in the upfront treatment group about why they did not purchase insurance, their main reason was lack of cash. In this section we present a second experiment which investigates this further. The experiment answers the question: if farmers did have the cash to buy upfront insurance, would they do so?

Experimental design

In this experiment, which targeted 120 farmers, we cross cut the pay-upfront and pay-at-harvest treatments of the main experiment with a cash drop treatment. Under the cash drop, during the baseline survey enumerators gave farmers an amount of cash slightly larger than the price of the insurance premium, around an hour before company outreach workers offered farmers the insurance product. The treatment mimics closely one of the arms in Cole et al. (2013a). This cross-cut design allows us to test whether the impact of the cash drop varies across the pay-upfront vs. pay-at-harvest groups, as well as assessing the relative impact of the cash drop compared to the premium deferral.

Before presenting results, we first consider what this cash treatment does, and how we might expect farmers to respond. The first thing we note is that the cash ensures that farmers do have enough cash to pay for the insurance if they wish to, removing any hard cash constraint, and addressing the most commonly cited reason for not purchasing upfront insurance. But, while the cash drop eases liquidity constraints, it need not remove them entirely - an individual is liquidity constrained if they are not able to borrow any more at the market interest rate; after receiving the cash drop, farmers may still have wanted to borrow more.

The experiment is thus best interpreted as answering whether upfront insurance is the marginal expenditure, given an increase in cash which removes any hard cash constraints. Evidence from other settings suggests that the answer may be no. When interlinking insurance with credit, Gine and Yang (2009) and Banerjee et al. (2014) find that demand
for credit actually decreases when bundled with insurance. If insurance was the marginal expenditure, if anything we would expect the opposite.

One concern with cash drop designs is that they may induce a reciprocity effect – to reciprocate the cash gift, farmers may be more likely to buy the insurance product. We tried to minimize the risk of reciprocity by having the survey enumerator give the cash gift at the beginning of the meeting – in contrast, the insurance product is offered by a company outreach worker, at the end of the meeting. We discuss further the role of reciprocity below, but note for now that it can affect demand regardless of the timing of the premium payment, hence the cross-cut design of our experiment to help to control for it.

Finally, we note that contractual risk is held constant across cash and non-cash treatment groups, so that any differential take-up is not driven by contractual risk.\textsuperscript{40}

**Experimental results**

We use the following regression model:

\[ T_{if} = \alpha + \beta \text{Discount}_{if} + \gamma \text{Cash}_{if} + \nu \text{Discount}_{if} * \text{Cash}_{if} + \eta_f + \epsilon_{if} \quad (1.3) \]

Figure 1.2 presents the results. First, it is reassuring to note that, in this different sample, the comparison between the pay-upfront and pay-at-harvest groups resembles that of the main experiment. Take-up for the upfront group is slightly larger (13%), but, again, introducing at-harvest payment raises take-up dramatically (up to 76%). Second, the cash drop raises substantively the take-up rate in the upfront group (up to 33%), suggesting it does reduce liquidity constraints. However, the impact of the cash drop is much smaller than that of the harvest time premium - among those who do purchase pay-at-harvest insurance, many do not purchase pay-upfront insurance even if they do have the cash to do so. For these individuals upfront insurance is not the marginal expenditure - farmers prefer to use the additional money for other purposes (e.g. consumption, labor payments, school

\textsuperscript{40}Ignoring any second order effects that the cash drop may have on side-selling, which are likely to be very small given the size of the cash drop
Figure 1.2: Cash Constraints Experiment: Insurance Take-Up by Treatment Group

Notes: The figure shows insurance take-up rates across the four treatment groups in the cash constraints experiment. In the Pay Upfront group, farmers had to pay the premium when signing up for the insurance. In the Pay Upfront + Cash group, farmers were given a cash drop slightly larger than the cost of the premium, and had to pay the premium at sign-up. In the Pay At Harvest group, if farmers signed up for the insurance then the premium (including accrued interest at 1% per month) would be deducted from their revenues at (future) harvest time. In the Pay At Harvest + Cash group, farmers were given a cash drop equal to the cost of the premium and premium payment was again through deduction from harvest revenues. The bars capture 95% confidence intervals.

fees). Third, the cash drop also has an impact on take-up rates in the pay-at-harvest group (from 76% to 88%). While in a more complex model this could potentially be a wealth effect, in our simple model the wealth effect should if anything reduce insurance demand\textsuperscript{41} As mentioned above, this could also be reciprocity, whereby some farmers may feel obliged to purchase the insurance after receiving the transfer, as discussed in \textit{Cole et al.} (2013a). The difference in impact of the cash drop between farmers offered the at-harvest premium and those offered the upfront premium is 8%, which is small. While it is imprecisely estimated, we take this as evidence that the cash drop had relatively little effect on take-up beyond that caused by reciprocity\textsuperscript{42}

\textsuperscript{41}This wealth effect is likely to be small.

\textsuperscript{42}Interpreting the difference-in-difference is also made more difficult because we have to make an assumption
Table 1.3 confirms the patterns described above. Column (1) presents the basic level impact of the cash drop and pay-at-harvest treatments. We add field fixed effects in column (2) and additional controls in column (3). Across the specifications, we can always reject the null on the equality of the two treatments at the 1% level. The coefficient on Cash is large and significant at the 5% level in column (1) and remains similar in size but loses some precision as we add more controls. In columns (4) to (6), we look at the interaction between the two treatments. The coefficient on the interaction is always negative, as we would expect, but it is small and insignificant. It is imprecisely estimated, but even at the upper bound of the (very wide) confidence interval it cannot account for half of the difference between pay-upfront and pay-at-harvest insurance in the main experiment.

Table 1.3: Cash Constraints Experiment: Treatment Effects on Take-Up

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay At Harvest</td>
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<td>0.603</td>
<td>0.589</td>
<td>0.633</td>
<td>0.635</td>
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<tr>
<td></td>
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<td>[0.077]</td>
<td>[0.078]</td>
<td>[0.100]</td>
<td>[0.105]</td>
<td>[0.107]</td>
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<tr>
<td>Cash</td>
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<td>0.208</td>
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<td>[0.074]</td>
<td>[0.079]</td>
<td>[0.079]</td>
<td>[0.102]</td>
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<td>[0.111]</td>
</tr>
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<td>Pay At Harvest * Cash</td>
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<td>-0.071</td>
<td>-0.100</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>[0.148]</td>
<td>[0.156]</td>
<td>[0.159]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field FE</td>
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<td>Y</td>
<td>Y</td>
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<td>Y</td>
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<tr>
<td>Plot Controls</td>
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<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Mean Y Control</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
</tr>
<tr>
<td>P-value: Deductible = Cash</td>
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<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

Notes: The table presents the results of the Liquidity Constraints Experiment. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. The baseline (omitted) group is the Pay Upfront group, where farmers had to pay the premium upfront and did not receive a cash drop. Plot Controls are Plot Size and Previous Yield. Stratification occurred at the field level. *p<0.1, **p<0.05, ***p<0.01.

To summarize, the results show that cash drops do relatively little to close the gap between pay-upfront and pay-at-harvest insurance. There are two potential explanations: farmers are not liquidity constrained, or farmers are very liquidity constrained and hence insurance is not the marginal expenditure. The next experiment will help to disentangle the two, since it should only find an effect if farmers are liquidity constrained.

on how reciprocity affects the probability of take-up. We use a linear probability model, and so implicitly assume that reciprocity affects the probability of take-up linearly.
1.4.3 Does delaying the premium payment by one month increase take-up?

If present bias is a major driver of our results, then delaying the premium payment by just a short amount of time may affect take-up. Here we describe a third experiment in which we did exactly this. We begin by introducing the experimental design, referencing the theoretical discussion in Casaburi and Willis (2017b) to explain exactly what the experiment tests. Then we present the results, which suggest that present bias does play an important role.

Experimental design

The aim of the experiment was to compare insurance take-up when the premium had to be paid at sign-up, to insurance take-up when the premium payment was delayed until one month later. However, for reasons explained below, the design was slightly different. A sample of 120 farmers was randomly allocated to two treatment groups. Both groups were offered a choice between either a cash payment, equal to the insurance premium, or free enrollment in the insurance. The difference between the treatment groups was when they would receive what they chose. In the first treatment group, the Receive Choice Now group, farmers were told that they would receive what they chose immediately. In the second group, the Receive Choice in One Month group, farmers were told that they would receive what they chose in one month’s time (the cash payment offered to farmers in this case also included one month of interest).

Offering the choice between cash or the insurance for free, rather than the choice to buy insurance, allowed us to isolate the role of intertemporal preferences in two ways. First, it ensured that the choice in the Receive Choice in One Month group could be enforced (since the premium payment the following month did not rely on the farmer paying out of her own pocket). Second, like a cash drop, it relaxed any hard cash constraints, ensuring the farmer could take-up the insurance if he wanted to. In standard models, take-up under this choice should be the same as take-up when the farmer is given the choice to purchase insurance

Randomization was again stratified at the field level.
following a cash drop, as in the cash constraints experiment above. But a literature dating back to Knetsch and Sinden (1984) suggests the two may be different: the former is akin to the Willingness to Accept, whereas the latter is the Willingness to Pay and may include an endowment effect.

As shown in Casaburi and Willis (2017b), for a one month delay in premium payment to have made a difference, the farmer must have been liquidity constrained at the time of the experiment. If the effect is large, it suggests one of three things, two of which we argue were unlikely in our setting. First, credit constraints may have varied across time periods (Dean and Sautmann 2014), and the experiment could have happened to take place at a time of large and very short-run liquidity constraints (for example due to an aggregate shock). However, we ran the experiments across two months (plus a one-month pilot beforehand) and the results, presented below, are stable across these periods, suggesting this explanation is unlikely. Second, if farmers were heavy exponential discounters, i.e. they had low $\delta$, then they would have preferred to pay one month later. However, even with a one month delay, insurance still involves a transfer across a large time period, and so in this case the farmer would still have been unlikely to buy it. Thus, if we find a large effect, we are left with just the third possibility: farmers were present biased.

Appendix Table A.6 reports the balance test across the two groups. We note that, due to the small sample size, there are significant imbalances across the two groups in the share of men and the acres of land cultivated. As discussed below, results are robust to the inclusion of these variables as controls.

Experimental results

Figure 1.3 shows that the take-up share in the Receive Choice in One Month group is 72%, compared to a baseline of 51% in the Receive Choice Now group. This 21 percentage

---

44 See Horowitz and McConnell (2002) for a summary of the literature.

45 We note that the baseline take-up for the “Receive Choice Now” group is larger than the take-up in the group Upfront Premium+Cash in the Liquidity Constraints experiment, which could be due to several factors. First, there could be variation across farmer characteristics as the two experiments targeted different samples.
point increase suggests that a shift of only one month in the timing of the cash transfer (while keeping the net present value constant) has a large impact on insurance take-up. While the experimental design does not allow us to distinguish between time-consistent and time-inconsistent discounting directly, the large effect is inconsistent with exponential discounting, as argued above. In contrast, it is consistent with present bias, as the Receive Choice in One Month treatment provides farmers with a commitment device on how to use the cash transfer, potentially overcoming their time inconsistency.

![Insurance Take-Up (N=120)](image)

**Figure 1.3: Present Bias Experiment: Insurance Take-Up by Treatment Group**

*Notes:* The figure shows insurance take-up rates across the two treatment groups in the present bias experiment. In the Receive Now group, farmers chose between an amount of money equal to the premium and free subscription to the insurance, knowing that they would receive their choice straight away. In the Receive in One Month group, farmers made the same choice, but knowing that they would receive whatever they chose one month later. The bars capture 95% confidence intervals.

Second, as mentioned above, this experiment estimates the willingness to accept for upfront insurance, whereas the liquidity constraint experiment estimates the willingness to pay, given liquidity. In particular, there may be an endowment effect in the latter associated with handing the cash to farmers at the start of the visit. Third, while the Liquidity Constraints experiment occurred early in late Summer 2014, the Intertemporal Preferences experiment was implemented in Spring 2015, shortly after the end of the dry season (December-March). It is possible this could make the risk of low harvest more salient for the farmers.

46In particular, sample size limitations prevented us from running an additional treatment where the cash transfer is postponed by two months, rather than one, and concerns about new information being a confounder prevented us from asking farmers to revisit their decision one month later.
Table 1.4 confirms these results across different specifications. The gap between the two treatments remains statistically significant at 1% when adding field fixed effects, plot controls, farmer controls and both set of controls together. We note that the point estimate raises from 0.25 in the baseline specification with field fixed effects (Column 2) to 0.33 when adding both set of controls, though the difference in the two estimates is not statistically significant. This suggests that, if anything, accounting for the baseline imbalances reported above increases the estimate of the impact of requiring farmers to sign up in advance.

### Table 1.4: Intertemporal Preferences Experiment: Treatment Effects on Take-Up

<table>
<thead>
<tr>
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<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receive Choice in One Month</strong></td>
<td>0.213*</td>
<td>0.252***</td>
<td>0.255***</td>
<td>0.294***</td>
<td>0.301***</td>
</tr>
<tr>
<td></td>
<td>[0.087]</td>
<td>[0.090]</td>
<td>[0.092]</td>
<td>[0.109]</td>
<td>[0.111]</td>
</tr>
<tr>
<td><strong>Field FE</strong></td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
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<td>N</td>
<td>Y</td>
</tr>
<tr>
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<td>Y</td>
</tr>
<tr>
<td><strong>Mean Y Control</strong></td>
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<td>0.508</td>
<td>0.508</td>
<td>0.508</td>
<td>0.508</td>
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<tr>
<td><strong>Observations</strong></td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

*Notes:* The table presents the results of the Present Bias Experiment. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. The baseline (omitted) group is the Receive Now group, where farmers chose between an amount of money equal to the premium and free subscription to the insurance. In the Receive Choice in One Month group, farmers made the same choice, but were told that what they chose would be delivered one month later (plus one month’s interest if they chose cash). Plot Controls are Plot Size and Previous Yield. Farmer Controls are all the other controls reported in the main balance table, Table A.1. Stratification occurred at the field level. *p<0.1, **p<0.05, ***p<0.01.

We note that the design mitigates the traditional trust concerns associated to standard time preferences experiments (Andreoni and Sprenger 2012a). In the Receive Choice in One Month treatment, both the cash transfer and the insurance sign-up depend on the field officer revisiting the field, so there are no differential trust concerns across the two choices. It is still possible, though implausible, that a farmer may think the field officers are more likely to return if she chooses the insurance. However, visits are organized at the field level and thus revisits cannot depend on individual choices. Further, and probably most importantly, the respondents have the contact info of the relevant company field staff (and, in most cases, of the IPA staff).

While present bias can lead to under subscription in pay-upfront insurance, one might...
think that it could also lead to over subscription and hence future regret in pay-at-harvest insurance. While we believe that this is a real possibility with the sale of goods on credit, where benefits are borne immediately, in the case of insurance there is no clear immediate benefit to subscription. On the contrary, pay-at-harvest insurance eliminates the time gap between cost and benefit that standard insurance products introduce. In line with this argument, as discussed above, in follow-up calls with 40 farmers who took-up the pay-at-harvest insurance, only 7.5% of farmers said they would not take-up the product again.

1.4.4 Imperfect enforcement

In the case of the harvest time premium, if either party defaults on the contract before harvesting, the farmer does not pay the premium. Anticipation of this possibility mechanically drives a wedge between take-up of the pay-upfront and pay-at-harvest insurance products, as shown in Casaburi and Willis (2017b). While the two experiments described above show that counterparty risk does not fully explain our results, since they hold it almost constant across treatments, it is likely that farmers had a non-zero prior for the probability of contract default. In this section we attempt to understand the importance of this channel. We first discuss what happened under the contracts, and then detail the evidence that we have for the effect of imperfect enforcement on take-up decisions. While we find some evidence that counterparty risk did matter for overall levels of take-up, we find no evidence for a differential effect by the timing of the premium payment.

Before the farmers in our study were due to harvest, the contract-farming company ran into serious financial difficulties. These financial difficulties led to the closure of the factory for several months, during which time the company did not harvest any cane, and

\[47\]

In the main experiment we collected several variables related to trust and farmers’ relationship with the company. However, the heterogeneity analysis does not deliver any clear conclusion. In addition to limited power, it is possible that the variables do not properly capture the specific expectations and trust concerning the insurance product. We report the results in Table A.2. While the failure to detect heterogeneity in the treatment effect along these variables poses an obvious caveat, qualitative evidence from the survey provides suggestive evidence that the interlinked insurance contract may help to address trust issues and we hope it will motivate further work on the topic.
to subsequent severe delays in harvesting due to the backlog. Consequently, the farmers whose cane was mature during this time faced uncertainty around harvesting: when it would happen, and whether it would happen at all. As a result, unsurprisingly, a significant proportion of our farmers side-sold (i.e. did not sell to the company). Figure 1.4 shows that the rate of side-selling was 52% across the three experiments. Figure 1.5 is a histogram of the harvest rate (one minus the side-selling rate) by sublocation, and also for comparison shows a histogram of a lower bound\(^{48}\) for the historical harvest rate in the same locations.

The figure shows that default was much higher than historical rates, and underlines the fact that farmers face counterparty risk under upfront insurance contracts.

![Graph showing share of harvested plots](image)

**Figure 1.4: Contractual Default: Proportion Who Harvest with Company in Main Experiment**

*Notes:* The figure shows the proportion of farmers from the main experiment who subsequently harvested with the company, as agreed under the contract. In the Pay Upfront group, farmers had to pay the full-price premium when signing up for the insurance. In the Pay Upfront + Discount group, farmers had to pay the premium at sign-up but received a 30% price reduction. In the Pay At Harvest group, premium payment was through deduction from (future) harvest revenues, and included the accrued interest. The bars capture 95% confidence intervals.

\(^{48}\)The historical measure of the harvesting rate is a lower bound on the true harvesting rate because of the data we had available to construct it. The measure is constructed as the proportion of farmers who previously harvested a Plant or Ratoon 1 cycle who appear in the data as harvesting the subsequent cycle. However, some of these farmers will have uprooted the crop after harvesting, and thus will never have begun the subsequent cycle.
Figure 1.5: Histogram of Harvesting With Company, by Sublocation

Notes: The histogram shows the proportion of farmers who harvested with the company in the sublocations in which we undertook the experiment. The data is by sublocation and we plot separate histograms for the main experiment (which is just for the farmers in our sample, who were due to harvest approximately twelve months after our experiment) and for the period prior to the experiment, from 2011 to 2014 (which is for all farmers in the sublocations). The historical measure is a lower bound on the harvest rate, since it is calculated as the proportion who harvested in the previous cycle who do not harvest this cycle, some of whom will not have grown cane this cycle. We note two things from the histograms. First, harvesting with the company is much lower during the experiment than historically, in line with the financial troubles at the company. Second, there is a large amount of geographic variation in the harvesting rate among farmers in our sample.

The widespread default ex-post raises two important questions: did the insurance product induce side-selling; and were expectations of default responsible for the difference in take-up, ex-ante?

Insurance did not affect side-selling

There is no evidence that insurance affected side-selling, in line with the design of the insurance product and the assumptions and arguments of our model. Figure 1.4 shows that the share of plots which side-sold is similar across treatment groups, in spite of very different levels of insurance take-up. However, it is not the level of side-selling, but whether or not it is selective which is important for whether pay-at-harvest insurance could be offered in equilibrium, as shown in Casaburi and Willis (2017b). Proposition 4 showed
that, with pay-at-harvest insurance, those with low yields are less likely to side-sell and those with high yields are more likely to, and these two effects could cancel each other out. However, if that were the case, we would expect yield conditional on selling to the company to be higher among the upfront insurance group, and we see no evidence of this in Figure 1.6 (we can rule out a 15% standard deviation effect on yield). Further, yield (or more precisely, insurance payout) conditional on not side-selling is what matters for the functioning of the market. The fact that pay-at-harvest insurance has little effect on yield is again consistent with some of the features of the insurance product that may inhibit selection (i.e., the double trigger and the limited scope for changing inputs).

![Average Tons of Cane per Harvested Plot](image)

**Figure 1.6:** Contractual Default: Harvest Weight Conditional on Harvesting with Company in Main Experiment

**Notes:** The figure shows the harvest weight, conditional on harvesting with the company, for farmers in the main experiment. In the Pay Upfront group, farmers had to pay the full-price premium when signing up for the insurance. In the Pay Upfront + Discount group, farmers had to pay the premium at sign-up but received a 30% price reduction. In the Pay At Harvest group, premium payment was through deduction from (future) harvest revenues, and included the accrued interest. The bars capture 95% confidence intervals.

49 Besides selection concerns, one might also worry that insurance induced moral hazard. However, moral hazard, if present, would work in the same direction as conditional side selling, in that the pay-at-harvest treatment group would show higher levels of moral hazard and thus lower yields.
Did anticipation of default affect take-up differentially?

Given the extent of side-selling, it is particularly important for us to consider how important ex-ante expectations of contract risk were in driving our main result. We use two main pieces of evidence to argue that the role was limited. Before doing so, we first reiterate that the additional experiments explained above hold constant contractual risk, and thus show that both liquidity constraints and present bias are part of the story. Further, in the Receive Choice in One Month treatment, which is a completely upfront product and thus fully exposed to contract risk, take-up reached 72%, suggesting that the expected probability of default was unlikely to be high.

Our first argument for why the role of contract risk was limited relies on Proposition 5, which tells us that we can bound the differential effect on take-up of ex-ante expectations on contract default by that of a price cut in the upfront premium. In particular, the differential effect is less than that of a proportional price cut in the premium, of the expected probability of side-selling weighted by the relative marginal utility of consumption when side-selling. However, in our main experiment, a 30% price cut made almost no difference to take-up of upfront insurance, suggesting a low price elasticity. Thus, unless ex-ante expectations of either the probability of default or of the marginal utility of consumption in the case of default are extremely high, imperfect enforcement is unlikely to account for a large part of the difference in take-up between pay-upfront and pay-at-harvest treatments. We cannot rule out high marginal utility in the case of default - it is possible that default is associated with significant financial stress for the farmer – but it would have to be very high to explain a large fraction of our results.\[50\]

Our second argument for the limited role of contract risk considers heterogeneous treatment effects of delaying the premium payment, by plausible proxies for ex-ante expectations of the probability of default. If the ex-ante probability of default did drives a difference in

\[50\] The difference with the effect of liquidity constraints is that the liquidity constraints channel is subject to the effect of present bias, as well as any other risks in the period between the take-up decision and harvest time which may lead the household to be liquidity constrained, and the one month experiment showed that just a one month delay has a significant effect.
take-up between pay-upfront and pay-at-harvest insurance, and there was heterogeneity in the probability, then, conditional on other covariates, we would expect a take-up regression to show a positive interaction between proxies for the probability of default and the harvest time premium. We consider two such proxies for the probability of default. First, in the baseline survey, we asked respondents about their trust in, and relationship with, the company. Table A.2 shows that while some of these measures do predict overall levels of take-up (consistent with a belief that the company will not make insurance payouts even if the production contract is upheld), they do not predict take-up differentially by premium timing. Second, we consider actual side-selling, both of individual farmers and of local averages (Figure 1.3 shows that there was substantial geographical variation in side-selling), and both in the season in question and in the previous season. For measures of side-selling in the season in question, this is based on the assumption that the actual realization of side-selling was correlated with the ex-ante probability of side-selling, and comes with the caveat that we are conditioning on an ex-post variable. Table A.4 shows that also we find no evidence for heterogeneous treatment effects for any of these proxies for ex-ante expectations of contract default.
Table 1.5: Main Experiment: Take-Up by Harvest Status

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<th>(3)</th>
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<th>(5)</th>
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<td>0.207</td>
<td>0.202</td>
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<td>0.687</td>
<td>0.869*</td>
<td>0.687</td>
<td>0.869*</td>
<td>0.687</td>
<td>0.869*</td>
<td>0.687</td>
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</tr>
<tr>
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<td>-0.096</td>
<td>-0.072</td>
<td>-0.096</td>
<td>-0.072</td>
<td>-0.096</td>
<td>-0.072</td>
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</tr>
<tr>
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<td>-0.018</td>
<td>-0.018</td>
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<tr>
<td>U2*Share Harvested in Subloc</td>
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<td>0.010</td>
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<td>0.010</td>
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<td>U2*Plot Harvested</td>
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<tr>
<td>Mean Y Control</td>
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</table>

Notes: This table presents take-up during the experiment by subsequent harvesting behavior approximately twelve months later. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. H is a binary indicator for the Pay At Harvest treatment group. U2 is a binary indicator for the Pay Upfront with 30% discount treatment group. Share harvested in Field is the proportion of farmers in the Field (an administrative, geographic unit) who harvest with the company. Share harvested in Subloc is the proportion of farmers in the Sublocation (a geographic identifier which is coarser than Field) who harvest with the company. PAST Share harvested in Subloc is the same variable, but instead covering the time period 2011-14, before the experiment, when side-selling was lower. Plot harvested is a binary indicator for whether the farmer harvests his plot with the company. Specifications (6)-(10) bundle groups treatments U1 (Upfront Premium at full price) and U2 (Upfront Premium at 30% discount) as baseline group. Regressions contain field fixed effects and are clustered at the field level. *p<0.1, **p<0.05, ***p<0.01.
1.4.5 Other channels

This section briefly discusses several additional channels which could also drive a difference in take-up between upfront and deduction premium treatment groups. We have no evidence for these channels and leave an experimental analysis of them to future work.

First, according to relative thinking (Tversky and Kahneman 1981, Azar 2007), people may make choices based on relative differences in costs, even when the rational model dictates that they should only consider absolute differences. In our setting, the premium could be perceived as a large amount when farmers consider it as an isolated expense, but as a small amount once farmers consider it as a share of their harvest revenues. As such, the large difference in take-up between pay-upfront and pay-at-harvest insurance could be more to do with the latter being charged as a deduction, rather than the timing per se. A similar explanation is also offered by Salience Theory. If we interpret the model of Bordalo et al. (2012) as one of multiple time periods, diminishing sensitivity suggests that the upfront payment period may be more salient than the harvest time payment period; since income will be higher at harvest time. Salience also provides a similar explanation to quasi-hyperbolic discounting for why charging the premium in the future may result in higher demand than charging it at take-up, even without the future premium being charged as a deduction.

A second mechanism which could be responsible is prospect theory (Kahneman and Tversky 1979; Kőségi and Rabin 2007). While a thorough application of the theory is beyond the scope of this paper\footnote{Such an application would require defining how the reference point is set, both for the time at which the upfront premium is paid and for harvest time.}, intuitively upfront payments may fall in the loss domain, while deduction payments, at least when yield are high, may be perceived as lower gains. The fact that farmers may be more sensitive to losses than gains may then partially explain the large response to the timing of premium payment. This channel is again more related to the harvest time premium being charged as a deduction, rather than being paid later.

\footnote{We thank Nathan Nunn for pointing out this explanation.}
Since the pay-at-harvest insurance requires no payment at sign up, there is a third possible mechanism: a zero-price today effect. Empirical studies find a jump in demand at zero price across a wide range of settings (Cohen and Dupas 2010). A possibility, about which we are unaware of any papers, is that there is a similar effect when there is a zero upfront price, i.e. no payment to be paid at purchase. Such an effect could be an alternative explanation for the finding in Tarozzi et al. (2014) that offering anti-malarial bednets through loans has a large effect on take-up. It would also help to explain the prevalence of zero down-payment financing options for many consumer purchases, such as cars as furniture.

1.5 External validity

The previous results show that charging the premium upfront, rather than at the same time as any payout would be made, reduced demand significantly for an agricultural insurance product in Kenya, and that liquidity constraints and intertemporal preferences play an important role. A wide body of work documents that these mechanisms also shape financial decisions in the developed world. For instance, a literature starting with Deaton (1991) and Zeldes (1989) points at the relationship between liquidity constraints and saving decisions, and Laibson (1997) sparked a body of empirical investigations on the impact of time-inconsistency on savings. Further, a recent literature on payday lending shows that some pay extremely high interest rates.

In the final section of the paper, we consider the implications of the intertemporal transfer in insurance contracts in developed countries, where better legal institutions may make the enforcement of cross-state insurance easier, but better functioning financial markets may also make the transfer across time matter less. We present empirical evidence from a natural experiment that, in spite of this, the timing of the premium payment also affects adoption of crop insurance among farmers in the U.S..
1.5.1 Evidence from U.S. Federal Crop Insurance

We exploit a natural experiment concerning the timing of the U.S. Federal Crop Insurance (FCI) premium payment. The FCI is the largest insurance scheme in the world, with a total of around 2 million policies sold in 2010. The program, which offers both crop-yield and crop-revenue insurance, is heavily subsidized by the federal government (Wright 2014). Historically, under the FCI farmers pay the insurance premium around harvest time, similar to the pay-at-harvest premium in our experiment. But this changed for some crops, in some states, in 2012.

Empirical design

The 2008 Farm Act (the relevant part of which was implemented in 2012) moved the premium payment earlier in the season for certain crops, typically to around two to three months before harvesting. Crucially for our identification strategy, the change in timing varied across crops and states. For corn, the most common grain grown in the United States, the billing date shifted earlier throughout the country (from October to August). For wheat, the second most common grain, the billing date changed only for states growing mostly spring wheat (North West and Midwest), but not for those states growing winter wheat (Central and South).

To test the effect of this change on crop insurance adoption, we exploit the variation over time and across states and crops to implement a triple difference approach at the county level. For this purpose, we obtained data from the Risk Management Agency on the number of crop insurance policies sold between 2009 and 2014 by crop and county. We focus on states that harvest at least 500,000 acres of both corn and wheat in 2010, and we include only counties that grew both grains in the same year. The final sample includes 11 states and 899 counties.

53 Public Law 110-234.
Equation 1.4 shows the estimating equation of our triple-difference approach:

\[ IHS(Policies)_{cst} = \beta_1 Post_t \times Treat_{sk} + \eta_{ck} + \eta_{st} + \eta_{kt} + \eta_{sk}t + \epsilon_{sckt}, \]  

(1.4)

where the dependent variable is the inverse hyperbolic sine transformation of the number of insurance policies sold in county \(c\) in state \(s\) in crop \(k\) in year \(t\). In years after 2012, the dummy variable \(Treat_{sk}\) equals one if the state-crop pair is exposed to the reform. The model includes county-crop fixed effects (\(\eta_{ck}\)), state-year fixed effects (\(\eta_{st}\)), crop-year fixed effects (\(\eta_{kt}\)), and a time trend estimated separately for each state-crop (\(\eta_{sk} \times t\)). We cluster standard errors by state-crop, as that is the level of our treatment.

\(\beta_1\) identifies the effect of the earlier premium payment on take-up under the identifying assumption that, upon including all of the fixed effects listed above, county-level take-up of crop insurance had common trends across both corn and wheat, absent the policy change.

To assess the importance of wealth and liquidity constraints in this new setting, we also test whether the reform had differential impact by the average plot size in the county-crop, measured in acres. To do so we augment the model to estimate a heterogeneous treatment effect term (\(Post_t \times Treat_{sk} \times AvgPolicySize_{ck}\)):

\[ IHS(Policies)_{sckt} = \beta_1 Post_t \times Treat_{sk} + \beta_2 Post_t \times Treat_{sk} \times IHS(AvgPolicySize)_{ck} \]

\[ + \eta_{ck} + \eta_{st} + \eta_{kt} + \eta_{sk} \times Post_t \times IHS(AvgPolicySize)_{ck} \]

\[ + \eta_s \times Post_t \times IHS(AvgPolicySize)_{ck} + \eta_{sk} \times IHS(AvgPolicySize)_{ck} \times t + \epsilon_{sckt} \]  

(1.5)

This model allows average plot size to impact the dependent variable differentially in each state and crop after 2012 (terms \(\eta_{k} \times Post_t \times IHS(AvgPolicySize)_{ck}\) and \(\eta_s \times Post_t \times IHS(AvgPolicySize)_{ck}\)). It also includes the interaction between the state-crop specific trends and the average policy size by county-crop (\(\eta_{sk} \times IHS(AvgPolicySize)_{ck} \times t\)).

**Empirical results**

Table 1.6 Column (1) estimates equation 1.4. It shows that the change in timing reduced the number of insurance policies sold in the county-crop by approximately 4.3%. Column
An increase of 10% in the average county plot size reduces the negative impact of the reform on insurance adoption by 0.52%. This result is confirmed in Column (3) where we add state-crop-year fixed effects. Column (4) replaces the average county-crop plot size variable with a dummy for whether the county-crop average plot size is above the median for that state-crop. The regression confirms the findings of column (2) and suggests the negative impact of Column (1) is entirely driven by counties with farms below median size, in line with Proposition 2.2, which says that the difference in timing should only matter for those who risk facing liquidity constraints. Column (5) shows that this result is again robust to the inclusion of state-crop-year fixed effects.

**Table 1.6**: U.S. Federal Crop Insurance Regression Table

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<td>-0.060***</td>
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**Notes**: The table presents the affect of the change in the premium billing date for U.S. Federal Crop Insurance on insurance adoption. Data are at the county-crop-year level. The dependent variable is the inverse hyperbolic sine ($\approx \log(2) + \log(x)$) of the number of policies sold in the county-crop-year. Treatment is a binary indicator equal to one if the billing date for the county-crop is earlier than the harvesting period from 2012 onward. AvgPlotSize is the average plot size in the county. Column (1) shows the basic difference-in-differences by state-crop (Equation (1.4) in the paper). Columns (2)-(5) show the heterogeneity by average plot size in the county-crop (Equation (1.5) in the paper). Columns (2)-(3) present heterogeneity by the inverse hyperbolic sign of the average plot size in the county-crop. Columns (3)-(4) present heterogeneity by a binary indicator that is equal to one if the average plot size in the county-crop is above the median in the state-crop. Standard errors clustered by crop-state. *p<0.1, **p<0.05, ***p<0.01.

The negative and statistically significant impact of the reform on insurance adoption

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54 In this model, we drop state-year fixed effects, crop year fixed effects and the state-crop trends.
suggests that the mechanisms driving the results of our experiment in Kenya may also affect risk management choices for farmers in developed countries, albeit with a lower intensity. This could be why the FCI premium has historically been due around harvest time. As in our experiment, the effect of the 2012 reform was largest among smaller farmers, in line with Proposition 2 and with the role of liquidity constraints. The effect is unsurprisingly much smaller than in our experiment. There are several natural explanations: the change in timing is much smaller (and does not interact with any present bias, since in both cases premiums are due in the future); farmers in the US may be less likely to be liquidity constrained; and finally, very importantly, late premium payments for FCI are only penalized by a penalty interest rate of 1.25% per month (within reason – beyond a certain date insurance access is revoked for subsequent seasons), which bounds the size of the possible effect of earlier payment.

1.6 Discussion

From a policy perspective, boosting crop insurance take-up is an ongoing challenge. The results in this paper show that changing the timing of the premium payment represents a promising idea for doing so, which warrants replication in other settings. While the enforcement mechanism used in the paper could be used in most contract farming settings, whose presence is growing steadily in developing countries (UNCTAD 2009), two questions which we hope to investigate in future work are particularly important to understand whether the idea could be applied more widely: would other timings of crop insurance products also boost take-up, and are there ways to ensure payments of harvest time premiums outside of contract farming settings?

1.6.1 Other timings of insurance transfers

In order to boost take-up, does the premium need to be paid at harvest time, or is there another timing which would have a similar effect? This question is important because of enforcement: the earlier the premium is paid, the less there is room for moral hazard on
its payment. Our one month experiment suggests that just delaying the premium payment slightly may have a sizeable effect on take-up. But seasonality may be important too - if the premium was paid at the previous harvest time, rather than early on in the agricultural season, farmers may be less liquidity constrained, and thus more willing to purchase insurance. A related question is whether there are other timings of the insurance payout which farmers would prefer. Even in a bad season farmers may well have liquidity at harvest time, only running out later in the season - especially under present bias. If farmers are sophisticated, then they may prefer an insurance product which pays out later in the season, when times are hardest.

1.6.2 Other ways to enforce harvest-time payments

If the premium is charged at (subsequent) harvest time, are there other ways to enforce payment by the farmer, beyond interlinking the product and insurance markets? A comparison to credit suggests there could be: the enforcement constraint for cross-state insurance is, if anything, easier than that for credit, since in the case of insurance a net payment is only required in good states of the world. Whether methods used to ensure repayment in credit, such as relational contracting, group liability, and credit scores could be used for cross-state insurance is an important question.

1.6.3 Other benefits of interlinking insurance and product contracts

In addition to improving the enforcement of a premium paid at harvest, we note finally that interlinking insurance and production contracts can benefit insurance design and administration in several other ways. The first concerns data availability. For administrative purposes, large buyers in contract farming schemes often collect detailed plot-level data, including output and farm sizes. These records, which can span for decades, can address data limitations for costing insurance products, a fundamental constraint in the design of area yield products [Elabed et al., 2013]. This could be particularly relevant as area yield insurance may display lower basis risk than rainfall index insurance, as was the case in our
setting. Second, administrative costs are likely to be lower. For example, company field assistants already visit farmers’ plots at contract inception, and in an interlinked contract that visit could include insurance recruitment, at minimal additional cost. This would reduce the gap between actuarially fair premiums and market premiums, which can be large.  

Third, getting people to renew their insurance contracts has been a challenge in other settings, with high dropout rates among farmers who do not receive an insurance payout in the first season (Cole et al. 2014; Cai et al. 2016). Under an interlinked contract, farmers could credibly sign up for insurance contracts which cover multiple seasons, increasing the chance that they receive an insurance payout before policy renewal is due. Finally, evidence that farmers increase their productive investments and output when insured (Karlan et al. 2014) provides another rationale for interlinked contracts. If product buyers are partial residual claimants on farmers’ production, they make a profit on the additional quantities produced. Thus, unlike a third party insuring agent, they may not need to break even on the insurance sales.

1.7 Conclusion

By requiring that the premium be paid upfront, standard insurance contracts introduce a fundamental difference between their goal and what they do in practice: they not only transfer income across states, they also transfer income across time. In the companion paper (Casaburi and Willis 2017b) we argued that this transfer across time is at the heart of several explanations offered for the low take-up of insurance, such as liquidity constraints, present bias, and trust in the insurer.

In the context of crop insurance, the transfer across time can be removed by charging the premium at harvest time, rather than upfront. Doing so in our experiment, by charging the premium as a deduction from harvest revenues in a contract farming setting, resulted in a high level of insurance take-up at actuarially fair prices. In contrast, when the premium was

56 In Karlan et al. 2014, market prices are 50% higher than actuarially fair prices.
charged upfront, take-up for the same insurance product was 67 percentage points lower, and the effect of the timing was largest among the poorest, as predicted in Casaburi and Willis (2017b).

We discussed the numerous channels which could be responsible for our main experimental result, and presented evidence which showed that two of the three most natural ones play a role. Heterogeneous treatment effects suggested that liquidity constraints mattered, and a first experiment on channels showed that they ran deeper than simply not having the cash to pay the premium. A second experiment on channels provided further evidence for the importance of liquidity constraints, and showed that present bias was also a significant constraint on the demand for upfront insurance, since take-up rose substantially when the premium payment was delayed by one month. Finally, we considered the role of contractual risk. A lack of trust in the insurance provider is a common reason given for not buying not buying insurance in similar settings, and ours was no different: heterogeneous treatment effects showed that insurance take-up was higher overall among those who trusted the company. But, while contractual risk may drive a difference between take-up of pay-upfront and pay-at-harvest insurance, in our setting, we find no evidence across multiple tests for such a differential effect, in spite of a financial shock which led to high levels of default among our farmers before harvest.

In the final empirical contribution of the paper, we showed that the intertemporal transfer affects the demand for crop insurance in other settings too, using a natural experiment from the U.S. We then finished with a discussed of the implications of the results for the design of crop insurance products, and of the related questions which the results raise.
Chapter 2

Time vs. State in Theory: Implications for Insurance and Preference

Elicitation\textsuperscript{1}

2.1 Introduction

In the textbook model of insurance, income is transferred across states of the world, from good states to bad\textsuperscript{2} In practice, however, most insurance products also transfer income across time: the premium is paid upfront with certainty, and any payouts are made in the future, if a bad state occurs. This paper, a counterpart to Casaburi and Willis (2017a), develops a model of insurance which includes this temporal dimension, and uses the model to investigate the implications of, as well as possible explanations for, the transfer across time.

We begin with an illustrative example to provide intuition. The simple two-period, two-state model contrasts a textbook, purely cross-state insurance product, with a typical

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\textsuperscript{2}For an example of the textbook model of insurance, see example 6.C.1 in Mas-Colell et al. (1995). Such purely cross-state insurance contracts do exist – examples include futures contracts and social security.
real-world insurance product which is paid for upfront. The model shows that when the 
(shadow) interest rate faced by the insuree is different from that (implicitly) offered on the 
insurance premium, the transfer across time affects the demand for insurance. In particular, 
it is the interest rate that the insuree faces, rather than their intertemporal discount rate, 
which determines the cost of the transfer across time, although of course the two may be 
linked.

We then embed the cross-state and cross-time insurance products into a workhorse 
dynamic consumption model. We do so for four reasons: to develop comparative statics in 
a standard model; to propose ways to identify the different channels for the corresponding 
empirical paper (Casaburi and Willis 2017a); to investigate how the transfer across time 
affects the interaction between insurance and other ways to manage risk; and to consider 
the implications of alternative timings of the premium payment. We first set up the 
background dynamic consumption model, a buffer-stock savings model (as in Deaton 1991) 
which includes a borrowing constraint, quasi-hyperbolic discounting, and cyclical incomes. 
This background model shows how risky income flows affect transfers across time in the 
absence of insurance, through self-insurance, and how liquidity constraints make risk more 
costly, as they make such self-insurance harder. Second, they make self-insurance, through 
consumption smoothing harder, and thus increase the gains from risk reduction.

Within this dynamic consumption model we then consider demand for marginal units 
of two insurance products: one where the premium is paid upfront, and one where the 
premium is paid at the same time as any payouts. We initially assume perfect enforcement 
of both contracts. The model shows that liquidity constraints are central for any difference 
between the two products - they make paying the premium upfront more costly if the 
borrowing constraint may bind, or almost bind, before the payout date. Liquidity constraints 
also make self-insurance, the other way to smooth risk, harder, and hence the transfer across 
time in insurance may reduce demand precisely when the potential gains from insurance 
may be largest. In other words, credit and purely cross-state (textbook) insurance are 
substitutes, but, because of the transfer across time, credit and standard insurance can be
complements.

The model also shows that the transfer across time in insurance can help to explain why the poor demand so little of it. In the model the poor are more susceptible to liquidity constraints, and thus face a higher shadow interest rate. This means both that they are less able to self-insure, and thus would have higher demand for cross-state insurance, but also that the transfer across time is more costly for them, so that they have a larger drop in demand when having to pay the premium upfront. If this second force is strong enough, as it will be if the insuree is sure to be liquidity constrained before any payouts, then the poor will demand less insurance.

We also develop a reduced-form version of the model. It allows us to infer the cost of the transfer across time, and whether different insurance products would be taken up, from investment behavior at differ risk-free interest rates. Empirically, this allows us to make simple statements based upon observed investment behavior, and is less demanding than fitting the full dynamic model. It also gives a simple idea, quantitatively, of when we should expect the transfer across time to prevent people from buying insurance.

We then turn to imperfect enforcement, which can affect both the demand and supply of the two insurance products. We first incorporate it into the model of demand, showing that the possibility of imperfect enforcement introduces a wedge between pay upfront and cross-state insurance, if default may happen between contract signing and the time at which any payout is due. We also consider a simple model of the supply of insurance, which outlines why imperfect enforcement of the premium payment is a likely reason for why insurance premiums are typically paid upfront. Combining demand and supply, we then show that which products can be traded depends on the possibility of defaulting on both sides. Intuitively, if defaulting is relatively low cost for the insuree, then cross-state insurance will not be traded, and, in contrast, if there is a high chance that the provider will default, pay-upfront insurance will not be.

We next discuss the implications of the results of this and the accompanying paper (\citealt{casaburi2017empirics}), as well as questions for future work. Since the transfer
across time is almost ubiquitous in insurance products, the implications are potentially broad. We first discuss under which settings the time between premium payment and any payouts may be particularly large, or when liquidity constraints may be particularly strong, and hence when the transfer across time is likely to be most costly. Second, we consider settings in which income flows are particularly variable over time, in which case the exact timing of the financial transfers can be important. Finally, we consider questions related to enforcement of cross-state insurance products. First we ask, is there a reason to offer cross-state insurance, which is essentially a bundled credit and insurance product, rather than just offering the two products separately? We give two possible reasons. Then we turn to how a cross-state insurance product may be enforced. To do so, we first discuss the role of the government, and whether this reason can explain government intervention in some insurance markets. Then we make the comparison to enforcing the repayment of credit and, motivated by approaches used there, suggest several instruments which may be used to make a cross-state insurance product work in practice.

In the final contribution of the paper, motivated by needing to consider consumption smoothing across both time and state in the above, and also by how we interpret the results in Casaburi and Willis (2017a), we consider the problem of preference elicitation over time and risk. Recent work has discussed the difficulty of using preferences over monetary transfers to elicit time discounting (Chabris et al. 2008; Cubitt and Read 2007), since money is fungible and need not translate into consumption at the time at which it is received. Two papers have used direct choices over effort or consumption, rather than over monetary payments, to overcome such confounders when eliciting discounting (Augenblick et al. 2015; Augenblick and Rabin 2016). We propose that the same method also be used to elicit preferences over risk, and over time and risk together, and in turn to better understand how preferences over consumption relate to preferences over money. We then outline an experiment using the method which could test a number of behavioral theories which are relevant to the demand for insurance.

The paper is related to a number of other literatures. First, the transfer across time in
insurance is studied implicitly in finance, but the focus is on how insurance companies benefit by investing the premiums \cite{Becker_Ivashina2015}, rather than on the cost for consumers, our focus. A recent exception is a largely theoretical literature \cite{Rampini_Viswanathan2010,Rampini_Viswanathan2013,Rampini_et_al2014} which argues that firms face a trade-off between financing and insurance. \cite{Rampini_Viswanathan2016} apply similar reasoning to households.\footnote{These papers are part of a wide literature on how imperfect enforcement affects the set of financial contracts which exists \cite{Bulow_Rogoff1989,Ligon_et_al2002}, to which we add by considering the implications of imperfect enforcement for the timing of insurance premiums.}

Many empirical papers investigate why demand for insurance is low across different settings. Some of the proposed explanations relate to the transfer across states in insurance, such as risk preferences and basis risk \cite{Mobarak_Rosenzweig2012,Elabed_et_al2013,Clarke2016}, others to the transfer across time, such as liquidity constraints and trust. The most closely related papers, which discuss the transfer across time explicitly, are \cite{Liu_et_al2016} and \cite{Liu_Myers2016}. The latter is a theoretical paper - our treatment here differs in a number of ways: for example, we consider the interaction of insurance and self-insurance, the relationship between insurance demand and wealth, supply-side reasons for the transfer across time, and alternative timings of premium payments.

An recent influential literature has tried to explain why long-term hazard-risk insurance contracts, such as life insurance, often front-load payments. This is another form of transferring income across time. \cite{Pauly_et_al1995,Cochrane1995} is a theoretical exposition of why this practice might evolve when there is one-sided contract enforcement and reclassification risk.\footnote{Reclassification risk is the risk that premiums may increase differentially over time with future information revelation over the risk the insuree faces.} \cite{Herring_Pauly2006,Hendel_Lizzeri2003,Finkelstein_et_al2005,Handel_et_al2015} provide empirical evidence, including on the resulting constraint on insurance demand which arises through liquidity constraints.

\footnote{They show that limited liability results in poorer households facing greater income risk in equilibrium, even when a full set of state-contingent assets is available.}
Finally, the last part of the paper on preference elicitation is related to a number of recent papers. Chabris et al. (2008), Cubitt and Read (2007) discuss the problem of using money-based experiments to elicit discounting, and Augenblick et al. (2015), Augenblick and Rabin (2016) propose alternatives. Rabin (2000) argues that standard experimental methods for eliciting risk aversion provide measures of risk aversion which are incompatible with expected utility theory. The fungibility problem is one possible explanation.

The remainder of the paper is organized as follows. In section 2 we present a very simple model to provide intuition. In section 3 we develop the background dynamic consumption model and present the results from it that will enable us to consider the interaction between insurance and self-insurance. In section 4 we then introduce the two insurance products into this model and consider the demand for them. In section 5 we consider the role of the transfer across time in insurance supply, and why it is the case that insurance products are typically paid upfront. In section 6 we discuss the implications of the results, when the transfer across time is likely to be particularly costly, and ways in which cross-state insurance may be enforced in practice. In section 7 we turn to the problem of preference elicitation. Finally, section 8 concludes.

2.2 Illustrative example

In this section we present simple two-period models to outline the basic intuitions which are developed more formally later in the paper. We begin with the case of insurance demand and then turn to preference elicitation.

2.2.1 Insurance demand

In the model there are two periods, period 0 and period 1. In period 1 there are two states, \( \{L, H\} \), which occur with probability \((p, 1 - p)\). Household income is given by \(y_0\) in period 0 and \(y_L^1\) and \(y_H^1\) in period 1 (where \(y_L^1 < y_H^1\)), and the household can save at interest rate \(R\). The household discounts at rate \(\delta\) and maximizes expected utility, so the households
maximization problem is:

$$\max_{c_0} u(c_0) + \delta(pu(y^L_1 + R(y_0 - c_0)) + (1 - p)u(y^H_1 + R(y_0 - c_0)))$$  \hspace{1cm} (2.1)$$

Solving the household’s maximization problem gives the standard Euler equation:

$$u'(c_0) = \delta R (pu'(c_1^L) + (1 - p)u'(c_1^H))$$  \hspace{1cm} (2.2)$$

Now, consider an actuarially fair insurance product which pays out one unit in the low state, $y^L_1$. The standard design for such an insurance product is that the premium is paid in advance, in period 0. Suppose the interest rate paid on the insurance premium is $R_I$. Since we assume that it is actuarially fair, at interest rate $R_I$ the insurance product has premium $R_I^{-1}p$ in period 0. The expected net benefit of buying this product is then:

$$\delta pu'(c_1^L) - R_I^{-1}pu'(c_0)$$  \hspace{1cm} (2.3)$$

Consider now instead an insurance product which must be signed up for in period 0, but now whose premium can be paid in period 1. Such a product is akin to a direct transfer within period 1, from state $H$ to state $L$. Since we again assume that the product pays out 1 in state $L$ (before deducting the premium), and is actuarially fair, the premium is $p$. The
expected net benefit of buying this product is then:

$$\delta(p(1 - p)u'(c^L_1) - (1 - p)pu'(c^H_1))$$

$$= \delta p(1 - p)(u'(c^L_1) - u'(c^H_1))$$ (2.4)

which is always positive. Using the simple Euler equation, equation (2.2), we see the difference in expected net benefits between the two types of insurance is:

$$(R_1^{-1} - R^{-1})pu'(c_0)$$ (2.5)

Hence, under the standard insurance design, the cost of the intertemporal transfer in standard insurance products may prevent households from smoothing their consumption across states - the agent buys insurance iff:

$$\delta p(1 - p)(u'(c^L_1) - u'(c^H_1)) \geq (R_1^{-1} - R^{-1})pu'(c_0)$$

$$\iff (1 - p)(u'(c^L_1) - u'(c^H_1)) \geq (R/R_1 - 1)(pu'(c^L_1) + (1 - p)u'(c^H_1))$$ (2.6)

This last expression shows just how indirect the role of intertemporal preferences in this model. The direct intertemporal cost comes from a monetary cost, through the difference in interest rates faced the by the agent and implicit in the insurance product, rather than through any direct effect on consumption. Later we introduce a more direct effect of discounting into the cost of the intertemporal transfer, by introducing a borrowing constraint which results in a shadow interest rate which is influenced by the discount rate.

### 2.2.2 Preference elicitation

This simple example highlights a basic point - theoretically, preferences over the timing of money payments reflect the interest rate faced, $R$, rather than the discount rate, $\delta$, since preferences are defined over consumption, not monetary flows. Even if we add a borrowing constraint, i.e. $c_0 \leq y_0$, money flows and consumption are still only loosely tied, unless individuals are liquidity constrained. Even when liquidity constrained, while the marginal propensity to consume is 1, preferences over timing still only reflect $\frac{u'(y_0)}{\delta Eu(y_0)}$, which is a
function of \( y_0 \) and \( y_1 \) (which are typically unobserved). In spite of this loose link between the two, many papers use preferences over the timing of monetary payments to elicit discounting. The basic problem is well known, and papers often rely on interpretations such as narrow bracketing to argue for the relevance of their estimates.

A related problem arises for eliciting preferences over risk by using choices over monetary lotteries. In this case there is generally not the concern that money can be transferred across the different states of the world in the lottery, since the risks are not diversifiable. However there is a different concern: if the money is going to be smoothed over time, then the actual consumption risk is very small. To illustrate the problem, suppose we have a two period model now with two states in the first period, and suppose that the certainty equivalence of a lottery which pays 1 half the time and 2 half the time, in period 0, is \( e \). The narrow bracketing interpretation is: \( 0.5u(1) + 0.5u(2) = u(e) \). However, assuming full optimization by the agent, the correct interpretation is \( 0.5V(y_0 + 1, y_1) + 0.5V(y_0 + 2, y_1) = V(y_0 + e, y_1) \), where \( V \) is the indirect utility from the income streams. This adds two complications: first, background consumption is not zero, and second that the uncertainty is smoothed across consumption in the two periods (this second concern disappears if the household is liquidity constrained in period 1). Rabin (2000) detailed how assuming that such experiments can be used to elicit risk aversion results in unrealistic conclusions. Again, either narrow bracketing or liquidity constraints need to be invoked to ensure the experiments reflect risk aversion as commonly understood.

A proposed solution to these problems, for eliciting discount rates, has been to use choices over effort for a narrowly defined task, rather than choices over money. Under the assumption that preferences over effort in the task are separable from utility over consumption (and other forms of effort), and are time separable and discounted in the same way as preferences over consumption, then it is easy to see how this overcomes the fungibility problem. In section 7 we propose that a similar method be used to elicit preferences over risk, and consider what we might learn from doing so jointly for preferences over risk and time.
2.3 Background dynamic model

In the next sections we develop a full dynamic model which captures both the cross-state and cross-time transfers in insurance. To do so we begin by setting up a background intertemporal model, without insurance, into which we will introduce an insurance product in the next section. Proofs and derivations are in the appendix.

The background model is a buffer-stock savings model, as in Deaton (1991), with the addition of present-biased preferences and cyclical income flows (representing, for example, agricultural seasonality).

**Time and state** We use a discrete-time, infinite horizon model. Each period $t$, which we will typically think of as one month, has a set of states corresponding to different income realizations. The probability distribution over states is assumed to be memoryless and cyclical, representing, for example, cyclical agricultural incomes.

**Utility** Individuals have time-separable preferences and maximize present-biased expected utility $u(c_t) + \beta \sum_{i=1}^{\infty} \delta^i \mathbb{E}[u(c_{t+i})]$ as in Laibson (1997). We assume that $u(.)$ satisfies $u' > 0$, $u'' < 0$, $\lim_{c \rightarrow 0} u'(c) = \infty$ and $u''' > 0$. We also assume that $\beta \in (0, 1]$ and $\delta \in (0, 1)$.

**Intertemporal transfers** Households have access to a risk-free asset with constant rate of return $R$ and are subject to a borrowing constraint. As in Deaton (1991), we assume $R \delta < 1$.

---

5We note that time-separable preferences equate the elasticity of intertemporal substitution, $\psi$, and the inverse of the coefficient of relative risk aversion, $\frac{1}{\gamma}$. As such they imply a tight link between preferences towards risk and towards consumption smoothing, both of which are relevant for the demand for upfront insurance. Recursive preferences would enable us to untangle the two (Epstein and Zin 1989), which would provide an additional interpretation for our results. Namely, if $\psi \ll \frac{1}{\gamma}$, then we may expect a large gap between the demand for upfront and deductible insurance, since the cost of variation in consumption over time would greatly exceed that of variation in consumption across state.

6We assume prudence, i.e. $u''' > 0$, as is common in the precautionary savings literature (and as holds for CRRA utility), to ensure that the value of risk reduction is decreasing in wealth, i.e. Lemma 2.1 part 3. Prudence and liquidity constraints interact, strengthening the result, but our proof requires prudence to ensure the result holds with strict inequality.

7The results are identical if instead there is a borrowing limit $a_t$ so that $x_t - c_t \geq a \forall t$. Also, the model may be extended to assume a private investment technology $F(k)$, or similarly a wealth-dependent interest rate. Then the individual is liquidity constrained at time $t$ iff $F'(k_t) > R$. 

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Income and wealth  Households have state-dependent income in each period $y_t$. We assume $y_t > 0 \forall t \in \mathbb{R}^+$. We denote wealth at the beginning of each period by $w_t$, and cash-on-hand once income is received by $x_t = w_t + y_t$.

Household’s problem  The household faces the following maximization sequence problem in period $t$:

$$\max_{(c_{t+i})_{i \geq 0}} \left[ u(c_t) + \beta \mathbb{E} \left[ \sum_{i=1}^{\infty} \delta^i u(c_{t+i}) \right] \right]$$

subject to, for all $i \geq 0$,

$$x_{t+i+1} = R(x_{t+i} - c_{t+i}) + y_{t+i+1}$$

$$x_{t+i} - c_{t+i} \geq 0$$

Denote the value function of the household by $V_t$. Since income is memoryless, $V_t$ is a function of just one state variable, cash-on-hand $x_t$. Since preferences are not time-consistent, $V_t$ is different from the continuation value function, denoted $V_{t}'$, which is the value function at time $t$, given time $t-1$ self’s intertemporal preferences, i.e. without present bias. We assume that households are naive-$\beta\delta$ discounter, in that they believe that they will be exponential discounter in future periods (and thus may have incorrect beliefs about future consumption functions). There is evidence for such naivete in other settings (DellaVigna and Malmendier 2006), and with the exception of Proposition 2.2, the comparative statics with respect to wealth, all of the propositions below follow through with slight modification in the sophisticated-$\beta\delta$ case.

Iterated Euler equation  We are interested in the effect of changing the timing of the premium payment, so we need to compare the marginal utility of consumption across time.

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8As a technical assumption (to avoid complications arising from zero consumption), we actually assume that $y_t$ is strictly bounded above zero $\forall t$.

9The required modification is replacing $\beta$ by a state-specific discount factor, which is a function of the marginal propensity to consume. Proposition 2.2 and Lemma 2.1 parts 1 and 3 may no longer hold. Concavity and uniqueness of the continuation value, $V_{t}'$, is no longer guaranteed, and we have not yet been able to prove the comparative statics of insurance demand with respect to wealth, because of the additional complication of the state-dependent discount factor.
periods. We can do so using the Euler equation, given in this model by:

\[
 u'(c_t) = \max\{\beta \delta R E[x', \bar{c}_{t+1}], u'(x_t)\} = \beta \delta R E[x', \bar{c}_{t+1}] + \mu_t
\]  

(2.8)

(2.9)

where \(\mu_t(x_t)\) is the Lagrange multiplier on the borrowing constraint, and the tilde in \(\bar{c}_{t+1}\) represents that the decision is with respect to period-\(t\) self’s beliefs about consumption in period \(t + 1\). We can iterate the Euler equation to span more periods:

\[
u'(c_t) = \beta(R\delta)^H E[u'(\bar{c}_{t+H})] + \lambda_{t+H}^H
\]

(2.10)

where \(\lambda_{t+H}^H(x_t)\) is a measure of the extent to which transfers between time \(t\) and time \(t + H\) are distorted by (potential) borrowing constraints defined as follows:

\[
\lambda_{t+H}^H = \mu_t + \beta E[\Sigma_{i=1}^{H-1} (R\delta)^i \tilde{\mu}_{t+i}]
\]

(2.11)

For the rest of this section we omit the tildes for notational simplicity. Since all decisions are being made in period 0, all variables are with respect to time 0 beliefs. The following lemma provides the main results from the model which will be useful when considering the demand for insurance.

**Lemma 2.1.** \(\forall t \in \mathbb{R}^+:\)

1. \(V_t, V_t^c\) exist, are unique, and are concave.
2. \(\frac{dc_t}{dx_t} < 1\), so investments (and wealth in the next period) are increasing in wealth.
3. \(\frac{d^3V_t}{dx_t^3}, \frac{d^3V_t^c}{dx_t^3} > 0\), so the value of risk reduction is decreasing in wealth.
4. \(\frac{d\lambda_{t+H}^H}{dx_t} < 0\), i.e. the distortion arising from liquidity constraints is decreasing in wealth.

The intuition behind part 3 of the lemma is as follows. The value of risk reduction depends on how much the marginal utility of consumption varies across states of the world. Two things drive this. First, how much the marginal utility varies for a given change in

\[10 R^H + \frac{\lambda_{t+H}^H}{\beta d E[u'(\bar{c}_{t+H})]}\] is the shadow interest rate that the household faces for such transfers.
consumption; this gives rise to the comparative static through the standard force of prudence (i.e. \( u'' > 0 \)). Second, how much consumption varies for a given change in wealth, i.e. the marginal propensity to consume. Concavity of the consumption function, a consequence of prudence (Carroll and Kimball 1996) and strengthened by the borrowing constraint (Zeldes 1989; Carroll and Kimball 2005), further drives the comparative static.

2.4 Time vs. state in insurance demand

In this section we add marginal units of insurance into the above dynamic consumption model. We first consider the case when the insurance contract is perfectly enforceable, and then we allow for imperfect enforcement. The model shows how different channels interact to affect insurance demand, explores the interaction of insurance with self-insurance, and motivates the experiments and empirical tests to identify the role of the various channels in the accompanying empirical paper Casaburi and Willis (2017a). Agricultural insurance is our motivating example, so we use terms appropriate to that setting - for example, the time of the insurance payout will be referred to as harvest time, and the insurees will be referred to as farmers.

2.4.1 Insurance with perfect enforcement

We begin with the case where insurance contracts are perfectly enforceable. For tractability, at several points we make first order approximations for the costs and benefits of the insurance contracts. Such approximations are likely to be reasonable in the setting in Casaburi and Willis (2017a), as the insurance product offered there only provides partial coverage.

11Mathematically, consider the value of a marginal transfer of a state with \( x + \Delta \) to a state with \( x \), assuming both are equally likely. The value of this transfer is (one-half times) \( V'(x + \Delta) - V'(x) = u''(c(x + \Delta)) - u''(c(x)) \approx u''(c(x))c''(x)\Delta \). The derivative of this with respect to wealth, \( x \), is \( \Delta(u'''(c(x))c'(x)^2 + u''(c(x))c''(x)) \), which shows the role of both \( u''' \) and \( c'' \).

12The premium is small (3% of average revenues) and correspondingly the insurance product has relatively low coverage (maximum payout of 20% of expected revenue). In addition, there are two other reasons to believe that a first order approximation is reasonable in our setting. First, we are concerned with differential
**Timing**  We assume that the decision of whether to take up insurance is made in period 0, and any insurance payout is made in period $H$, the harvest period. Since the take-up decision is our main focus, and is made in period 0, all expectation operators in this section are with respect to information at time 0 and we drop the time subscript below.

**Payouts**  Farmers can buy one unit of the insurance, which gives state-dependent payout $I$ in period $H$, normalized so that $\mathbb{E}[I] = 1$. We assume that the random variable $y_{H} + I - 1$ second-order stochastically dominates $y_{H}$.\(^{13}\)

**Premium**  We consider two possibilities for the timing of premium payment: upfront, at time 0; and at harvest, at time $H$. If paid in period $H$, the insurance premium is 1, equal to the expected payout of the insurance (commonly referred to as the actuarially-fair price).\(^{14}\) If paid upfront, in period 0, the insurance premium is $R^{-H}$. Thus, at interest rate $R$, upfront and at-harvest payment are equivalent in net present value.

**Demand for insurance**  The farmer buys insurance if the expected benefit of the payout is greater than the expected cost of the premium. Thus, using first-order expansions of the value functions, the envelope theorem, and first order conditions, to first order the take-up take-up according to the timing of the premium payment, so that second order effects which affect upfront and deductible insurance equally play no role. Second, the double trigger of the insurance is designed to minimize moral hazard, and many of the inputs are provided by the company. Thus there is less scope for the insurance to affect input provision. In line with this, as we report in Casaburi and Willis (2017a), we see no impact of insurance on yield.

\(^{13}\)Historical simulations using administrative data suggest this assumption is reasonable in the setting in Casaburi and Willis (2017a) - while the insurance product does involve basis risk because of the second, area-yield based trigger, this trigger only prevents payouts to 26% of those who would receive the payout under the single trigger.

\(^{14}\)We follow the convention of the literature and denote by the actuarially fair price the price at which a risk-neutral insurance company would break even, assuming the risk is uncorrelated with market risk and assuming zero administrative costs.
decisions are:

\[
\begin{align*}
\beta \delta^H \mathbb{E}[u'(c_H)] & \leq \beta \delta^H \mathbb{E}[Iu'(c_H)] & \text{(pay-at-harvest insurance)} \\
R^{-H} u'(c_0) & \leq \beta \delta^H \mathbb{E}[Iu'(c_H)] & \text{(pay-upfront insurance)}
\end{align*}
\] (2.12)

This clarifies the difference between the take-up decisions for pay-upfront and pay-at-harvest insurance: for pay-at-harvest insurance, the decision is a comparison of the marginal utility of consumption across states (future states when insurance does pay out vs. when it does not); whereas for pay-upfront insurance, the decision is a comparison of marginal utility across both states and time (future states when insurance does pay out vs. today). To relate the two decisions, we use the iterated Euler equation, equation (2.10) which gives the following proposition.

**Proposition 2.1.** If farmers are certain they will not be liquidity constrained before harvest (or almost liquidity constrained - the exact condition is that, upon purchasing pay-at-harvest insurance, \( x_t - c_t > R^{-H+t} \) for all times \( t < H \) and for all paths) then they are indifferent between the two insurance contracts. If, however, farmers face a positive probability of being (almost) liquidity constrained, the expected net benefit of pay-at-harvest insurance is higher than that of upfront insurance. To first order:

\[
\text{Difference between expected net benefit of pay-at-harvest and pay-upfront} = R^{-H} \lambda_0^H
\] (2.13)

This difference is equivalent to a proportional price cut in the upfront premium of \( \frac{\lambda_0^H}{u'(c_0)} \) (\(< 1\)).

The intuition for the result is that, since paying the premium at harvest rather than upfront is akin to holding an extra unit of assets until harvest, any reduction in cost is purely down to differences in the (shadow) interest rate faced by the individual and the interest rate offered by the insurer. If, under pay-at-harvest insurance, liquidity constraints

\[15\] The first order expansion used is \( \beta \delta^H \mathbb{E}[V_H^c(w_H + y_H + I)] - \beta \delta^H \mathbb{E}[V_H^c(w_H + y_H)] \approx \beta \delta^H \mathbb{E}[Iu'(c_H)] \) and the first order conditions are \( V_H^c(x_t) = u'(c_t) \). We can use the envelope theorem because insurance payouts \( I \) do not enter into constraints before time \( H \).
will not be close to binding before harvest, then asset holdings can simply adjust to offset
the difference. In particular, switching from paying at harvest time to paying upfront, the
individual can follow the same consumption paths so long as they do not now hit the
borrowing constraint before harvest.

One corollary is that to drive a difference between pay-upfront and pay-at-harvest
insurance, intertemporal preferences must act through liquidity constraints. If discount
rates are high then liquidity constraints are likely to be (close to) binding in some states of
the world, even with a precautionary motive for holding assets. A second corollary follows
from the relationship between liquidity constraints and wealth in the model. Combining
Proposition 2.1 and Lemma 2.1 gives the following result, under the assumption that the
insurance product provides just a marginal unit of insurance (so that we can ignore second
order and higher effects).

Proposition 2.2. Demand for pay-at-harvest insurance is decreasing in wealth. However, the wedge
between pay-upfront and pay-at-harvest insurance is also decreasing in wealth. Among farmers
who are sure to be liquidity constrained before the next harvest, the latter dominates and hence their
demand for pay-upfront insurance is increasing in wealth.16

The proposition tell us that, although demand for risk reduction (pay-at-harvest insur-
ance) is higher among the poor, they may buy less standard (pay-upfront) insurance than
the rich, because the inherent intertemporal transfer is more costly for them. The intuition
is as follows. The value of risk reduction is higher among the poor, because the poor are
more likely to face liquidity constraints after harvest, meaning that they are less able to
self-insure - liquidity constraints make consumption smoothing in response to shocks harder
(so that shocks in income lead to larger shocks in consumption).17 At the same time, the
poor are also more likely to face liquidity constraints before harvest, which makes paying

16 The general point that the gap between pay-upfront and pay-at-harvest insurance is decreasing in wealth
follows from the shadow interest rate being decreasing in wealth. In our model that comes from a borrowing
constraint, but it could be motivated in other ways. Indeed, models sometimes take it as an assumption (e.g.
Dean and Sautmann 2014).

17 The value of risk reduction is also higher among the poor for the standard reason of prudence.
the premium upfront more costly than paying at harvest.

More generally, we can consider how the cost of the transfer across time varies with the parameters of the model. Higher discount rates (i.e. lower $\beta$ or $\delta$) make the transfer across time more costly, as they make the borrowing constraint more likely to bind, and to bind more tightly when it does bind. Higher harvest risk increases the importance of precautionary savings, meaning farmers save more, thus reducing the likelihood that liquidity constraints bind before harvest, and thus making the transfer across time less costly. The effect of risk before harvest however is less clear, as the inherent savings in upfront insurance are illiquid, and thus less helpful in smoothing wealth shocks before harvest.

In the above, we have developed the full dynamic problem, and considered the cost of the intertemporal transfer in terms of the model’s fundamental parameters. An alternative approach is to use observed investment behavior, in particular the potential returns of (risk-free) investments which the farmers makes or forgoes, as a sufficient statistic for the cost of the transfer across time. In appendix section 2.4.3 we develop this approach further to bound the effect of the transfer across time on insurance demand.

**Delaying premium payment by one month**

Here we show that, with present bias, delaying the premium payment by just a short time may increase demand significantly, but only if the farmer is liquidity constrained. We consider the same insurance product as above, but with the premium payment instead delayed by one month (corresponding to the third experiment in Casaburi and Willis (2017a)). Thus the premium is due at period 1, and costs $R^{-H}\lambda_0 = R^{-H}\mu_0$. The following holds:

**Proposition 2.3.** The gain in the expected net benefit of insurance from delaying upfront premium payment by one month is, to first order, $R^{-H}\lambda_0 = R^{-H}\mu_0$. It is the same as that from a proportional price cut in the upfront premium of $\frac{\mu_0}{w(G_0)}$.

The difference between a one month delay in premium payment and a delay until harvest time is the difference between $\lambda_0^1 = \mu_0$ and $\lambda_0^t = \mu_0 + \beta\mathbb{E}[\sum_{i=1}^{H-1}(R\delta)^i\tilde{\mu}_i]$. Thus, since harvest is many months away (i.e. $H$ is large), the effect of a one month delay is likely to be
very small relative to the effect of a delay until harvest, unless either liquidity constraints are particularly strong this month, or there is significant present bias. Present bias shrinks the difference between the two delays (equal to $\beta E \left[ \sum_{i=1}^{H-1} (R\delta)^i \tilde{\mu}_i \right]$) in two ways. First, the effect of future liquidity constraints are discounted by $\beta$, and second, the individual naively believes that he will be an exponential discounter in the future, and hence is less likely to be liquidity constrained.

**Paying the premium at the previous harvest**

Insurance is typically offered part way through the season, around harvest time. Given the seasonality of liquidity in agricultural settings, perhaps demand would be larger if insurance was instead offered at the *previous* harvest time, while farmers were still liquid? Under the above model, such a product design could increase take up, but only if $\tilde{\mu}_i < \mu_i$ systematically, and hence only if farmers are present biased. Otherwise, knowing that they would be liquidity constrained before the next harvest, farmers should if anything have lower demand for insurance paid at the previous harvest rather than part way through the season.\(^{18}\)

### 2.4.2 Insurance with imperfect enforcement

In many settings (and especially in small-holder farming settings), contracts are unlikely to be perfectly enforceable, with both sides facing counterparty risk. This introduces another difference between paying upfront and paying at harvest: if the contract breaks before harvest time, then the farmer does not pay the premium due at harvest, while he would have already paid the upfront premium. Accordingly, imperfect enforcement has implications both for farmer demand for insurance and for the willingness of insurance companies to supply it, both of which we discuss below. We use the same setup as above, and introduce the possibility of default on both sides.

---

\(^{18}\)Savings constraints, which do not feature in the model above, would be another channel through which demand could be higher at the previous harvest rather than part way through the season.
**Default**  *Farmer.* The farmer may strategically default on the harvest time premium, subject to some (possibly state dependent) utility cost $c_D$ of breaking the contract.

*Insurer.* Before harvest, with probability $p_I$ unrelated to yield, there is a stochastic shock which causes the insurer to default on the contract. In the case of default, upfront premium payments are not reimbursed. We ignore the possibility of insurer default which occurs after the farmer’s decision to pay the harvest time premium, since it would not have a differential effect by the timing of the premium payment.

**Timing** In period 0, the farmer decides whether to sign up for the insurance contract, and in the case of pay-upfront insurance pays the premium. At the beginning of the harvest period (period H), with probability $p_I$ there is a shock and the insurer defaults on the insurance contract. If the insurer has not defaulted, the farmer then learns what the insurance payout would be (and his yield) before, in the case of pay-at-harvest insurance, deciding whether to default on the premium at utility cost $c_D$. Finally, if the contract still stands, the insurer pays out any insurance payments due.

The farmer faces two choices: whether to buy the insurance and, in the case of the pay-at-harvest insurance, whether to pay the premium at harvest time. Consider first the choice of whether to pay the premium at harvest time. Denoting the choice to pay by the (state-dependent) indicator function $D_P$, to first order:

$$D_P := I[u'(c_H) + c_D] \geq u'(c_H)$$

---

19 We motivate the assumption that insurer default is exogenous, and in particular unrelated to the payout due, by the assumption that if the insurer defaults, he defaults on payments due to all farmers, not selectively. Such default could represent, for example, the insurer going bankrupt or deciding not to honor contracts. The assumption is reasonable in our setting, since the strategic default by the insurer would likely be highly costly for the farming company, both legally and in terms of reputational costs.

20 Such default could either be assumed to be accounted for within $I$, in which case $EI < 1$, or could be given by a second stochastic shock. Results below are robust to inclusion of such default.

21 In practice he may have considerable uncertainty about both: the company harvests the crop, increasing uncertainty about the yield, and the area yield trigger in the insurance design increases uncertainty about the insurance payout. Such uncertainty shrinks the difference between paying upfront and at harvest compared to that which is derived below.
**Demand for insurance**  Given this defaulting behavior, imperfect contract enforcement drives an additional first-order difference between upfront and deductible insurance:

\[
\text{Difference in net benefit of pay-at-harvest & pay-upfront} = R^{-\lambda H_0} + \beta \delta H p_I E[u'(c_H)] + \beta \delta H (1 - p_I) E[(1 - D_P)(u'(c_H) - c_D - Iu'(c_H))]
\]

(2.15)

It is easy to show that the size of the difference caused by imperfect enforcement is decreasing in the cost of default, \(c_D\). If the cost of default is high enough, \(c_D > \max_s u'(c_H(s))\), the farmer never strategically defaults and the additional difference is just that driven by insurer default.

**Interlinked insurance**

In [Casaburi and Willis (2017a)](#), we tie the insurance contract with a contract-farming production contract. Interlinking the contracts in this way has implications for contractual risk which we consider here, since default on one entails default on the other. Typically, farmers face a cost of defaulting on the production contract, and so such interlinking raises the cost of defaulting on the harvest time premium, \(c_D\). In addition, interlinking may also reduce the risk of the insurer defaulting in the eyes of the farmer, \(p_I\), since the farmer is familiar with the company. However, interlinking may encourage default on the insurance contract, if the farmer wants to default on the production contract for other reasons. Given these forces, in order to understand enforcement of the insurance, we need to understand enforcement of the production contract, and how the two interact. To do so we modify the model developed above, to tie together the insurance and production contracts, and see how doing so affects default, and ultimately the decision to purchase insurance.

As in the imperfect enforcement case, the farmer has two decisions to make: whether to sign up for insurance, and whether to default on the contract at harvest time. The main
difference is in what drives the decision to default, and what defaulting involves: default now implies more than just not paying the premium, it also involves selling to another buyer. We refer to doing so as side-selling, and assume that it results in a state-dependent outside option of \( o(w_H) \), net of any loss caused by the loss of the relationship with the buyer. We defer further discussion of this outside option to the appendix, but note that in our setting this outside option is generally sufficiently low to avoid farmers defaulting on the input loans provided by the company, which are substantially larger than the cost of the insurance premium.

**Default** The timing is as above, and again we solve the farmer’s problem backwards, starting with the decision of whether to side-sell conditional on the company not having defaulted on the farming contract. All decisions are as anticipated at time 0. First consider the case without insurance. We can define the (endogenous) cost of side-selling in this case as \( c_D \), where we purposely use the same notation as above:

\[
c_D = \mathbb{E}[V_H^c(w_H + o(w_H))] - \mathbb{E}[V_H^c(w_H + y_H)]
\] (2.16)

Unlike in the imperfect enforcement example above, \( c_D \) may now be positive or negative. If the farmer values the relationship with the company, and will be paid more by the company, it will be positive. However, if the farmer doesn’t value the relationship, and would be paid more by selling to another company, it will be negative.

Whereas above the farmer may only default in the case of pay-at-harvest insurance, now he may have an incentive to default in all three cases: without insurance, with pay-upfront insurance, and with pay-at-harvest insurance. Without insurance, he defaults if \( c_D \geq 0 \). With insurance, the net payout of the insurance contract enters the decision (\( I \) in the case of pay-upfront, \( I - 1 \) in the case of pay-at-harvest), but seeing that the absolute value of \( c_D \) is likely to be large relative to both the insurance payout and the premium, insurance is unlikely to affect the decision to default. This is important: defaulting because \( c_D \ll 0 \) does not matter for the functioning of the insurance market, whereas selective defaulting to avoid the premium does. While insurance is unlikely to affect side-selling, if it does, then
the following (simple) proposition tells us how.

**Proposition 2.4.** *Pay-at-harvest insurance* makes those with high yields more likely to side-sell, and those with low yields less likely to side-sell. *Pay-upfront insurance* does not affect side-selling of those with high yields, and makes those with low yields less likely to side-sell.

The intuition is that, compared to the case with no insurance, those with pay-upfront insurance may receive the additional insurance payout if they do not side-sell. In the case of pay-at-harvest insurance, there is also a force in the other direction: farmers do not have to pay the premium if they side-sell.

**Demand for insurance**  The main difference from the previous case is now it is the expected marginal cost of defaulting induced by the insurance which matters. For the sake of brevity we omit expressions for the general case here, but note that if insurance does not affect the decision to side-sell, (in which case there is only one indicator function $D$ for harvesting with the company), then the take-up decisions simplify considerably:

\[
\begin{align*}
\text{Take up insurance iff} & \quad \left\{ \begin{array}{l}
\beta \delta^H \mathbb{E}[Du'(c_H)] \leq \beta \delta^H (1 - p_I) \mathbb{E}[DIu'(c_H)] \\
R^{-H}u'(c_0) \leq \beta \delta^H (1 - p_I) \mathbb{E}[DIu'(c_H)]
\end{array} \right. \\
& \quad \text{(pay-at-harvest)} \\
& \quad \text{(pay-upfront)} \\
\end{align*}
\]

Regardless of whether insurance does affect the decision to side-sell, we have the following result, which allows us to bound the effect that imperfect enforcement has on take-up by that of a price cut in the upfront premium.

**Proposition 2.5.** The risk of contract default in the interlinked contract drives a wedge between demand for pay-at-harvest and pay-upfront insurance. The size of the wedge is bound above by that of a price cut in the upfront insurance of

\[
\mathbb{P}\left(\text{side-sell with pay-at-harvest} \right) \frac{\mathbb{E}[u'(c_H) | \text{side-sell with pay-at-harvest}]}{\mathbb{E}[u'(c_H)]}
\]

This result enables us to relate the impact of ex-ante expectations of default to the impact of a price cut in the upfront premium, on which we have experimental evidence from the
main experiment in Casaburi and Willis (2017a).

2.4.3 Reduced form approach: bounding the effect of the transfer across time

Above we considered the household’s full dynamic problem, which incorporates discount factors and stochastic consumption paths. Often, however, we can apply a sufficient-statistic style approach, where we rely on observed behavior to tell us what we need to know, without having to estimate all of the parameters of the full optimization problem. In the case of intertemporal decisions, an individual’s investment behavior, and in particular the interest rates of investments they do and do not make, can serve this role. Households are both consumers and producers. The implications of this dual role have long been considered in development economics. In particular, in the presence of market frictions, separation may no longer hold, so that production and consumption decisions can no longer be considered separately (Rosenzweig and Wolpin 1993; Fafchamps et al. 1998).

In this section we consider what observed investment behavior can tell us about hypothetical insurance take-up decisions, given the intertemporal transfer in insurance. Empirically, investment decisions may be easier to observe than discount factors and beliefs about consumption distributions (which are needed if we consider the full dynamic problem), and other studies provide evidence on interest rates in similar settings - both for investments made and for investments forgone. Using a simplified version of the model developed above, we consider under which conditions farmers would and would not take up insurance, given information on their other investment behavior.

To simplify, we now assume that at harvest time there are just two states of the world, the standard state \( h \) and the low state \( l \), with the low state happening with probability \( p \).\(^{22}\)

We assume that insurance is perfect - it only pays out in the low state (at time \( H \)), and that it is again actuarially fair. To simplify notation, in this section we denote by \( R \) the interest rate on the insurance covering the whole period from the purchase decision until harvest time. We

\(^{22}\)Note that the following can be easily generalized so that these two states represent average outcomes when insurance does not and does pay out respectively.
also assume CRRA utility, so that \( u(c) = c^{1-\gamma}/(1 - \gamma) \).

Under this setup, the expected net benefit of a marginal unit of standard, upfront insurance is:

\[
\beta \delta H \mathbb{E}[c_H(y_l)^{-\gamma}] - c_0^{-\gamma}
\]

Consider first the case that the farmer forgoes a risk-free investment over the same time period which has rate of return \( R' \). Then, first we know that paying upfront is at least as costly as a price increase in pay-at-harvest insurance of \( \frac{R'}{R} \), and second we know that:

\[
\beta \delta H R' \left( p \mathbb{E}[c_H(y_l)^{-\gamma}] + (1-p) \mathbb{E}[c_H(y_h)^{-\gamma}] \right) - c_0^{-\gamma} < 0
\]

Substituting this into the expected benefit of upfront insurance, we can deduce that farmers will not purchase standard insurance if:

\[
R \mathbb{E}[c_H(y_l)^{-\gamma}] < R' \left( p \mathbb{E}[c_H(y_l)^{-\gamma}] + (1-p) \mathbb{E}[c_H(y_h)^{-\gamma}] \right)
\]

\[
\iff \frac{\mathbb{E}[c_H(y_l)^{-\gamma}]}{\mathbb{E}[c_H(y_h)^{-\gamma}]} < \frac{1-p}{\frac{R'}{R} - p}
\]

So, the farmer will not purchase insurance if under all consumption paths:

\[ c_H(y_h) < Ac_H(y_l) \]

with \( A \) given by:

\[ A = \left( \frac{1-p}{\frac{R'}{R} - p} \right)^{\frac{1}{\gamma}} \]

Unsurprisingly, \( A \) is increasing in the (relative) forgone interest rate \( R/R' \), and decreasing in the CRRA \( \gamma \). Also, \( A \) is increasing in the probability of the low state, \( p \), suggesting that the intertemporal transfer is less of a constraint on insuring rarer events.

Similarly, we can consider the case where the farmer makes an investment over the period with risk-free interest rate \( R' \). Under the same logic, we first know that a price raise of pay-at-harvest insurance of \( \frac{R'}{R} \) is at least as costly as paying upfront, and second we also
know the farmer will purchase insurance if, for all consumption paths:

\[ c_H(y_h) > A c_H(y_l) \]

Table 2.1 reports \( A \) for various values of \( R'/R, p, \) and \( \gamma \). The tables thus reports how much consumption must vary between good and bad harvests in order to be sure about farmers’ decisions to buy perfect insurance, given their investment decisions. In the case of forgone investments, it tells us the largest variation in consumption for which we can be sure that the farmer will still not buy perfect insurance; in the case of made investments, it tells us the smallest variation in consumption for which we can be sure that the farmer will buy perfect insurance. We note that \( A \) represents variation in consumption between states at harvest time - not variation in income, which is likely to be significantly larger. The effect can be sizeable. For example, for a risk which has a 20% chance of occurring, if the forgone investment has risk-free rate of return 50% higher than the interest rate charged on the insurance, then farmers with CRRA of 1 will forgo a perfect insurance product even when the consumption in the good state is 71.4% higher than consumption in the bad state.

### 2.5 Time vs. state in insurance supply

While the farmer is better off with the pay-at-harvest insurance, almost all insurance products charge the premium upfront. The most likely reason for this is the possibility for strategic default on the premium under pay-at-harvest insurance, which means that the insurer may be worse off - if \( c_D = 0 \), in the case of pay-at-harvest insurance premiums received are never greater than payouts made, and so the insurer cannot make a profit at any premium price. But, it is not always clear cut - which of the two insurance products could actually be traded depends on both \( c_D \) and \( p_I \), as well as liquidity constraints and preferences as discussed earlier. Intuitively, a high risk of insurer default, \( p_I \), makes pay-upfront insurance harder to trade (as does liquidity constrained farmers), and a small cost of farmer default, \( c_D \), makes pay-at-harvest insurance harder to trade.

While the farmer is better off with the pay-at-harvest insurance, strategic default means
Table 2.1: Reduced form approach: indifference ratio of consumption

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that the insurer may be worse off. Suppose the insurer could set the price of the insurance, \( p \). Under pay-at-harvest insurance at price \( p \), their expected profit conditional on them not defaulting themselves is:

Expected profit for insurer = \( \mathbb{E}[(p - I)D_p(p)] \)

\[ = \mathbb{P}[D_p(p) = 1] \mathbb{E}[p - I|p - I \leq \frac{c_D}{u'(c_H)}] \]

This makes it clear that imperfect enforcement may prevent pay-at-harvest insurance from being offered when \( c_D \) is small, since strategic default means the insurer never makes a
profit, even as he increases price. This is likely the reason why pay-at-harvest insurance is not offered more often. However, charging the premium upfront places all of the risk of default on the farmer, and as we have seen may also activate liquidity constraints.

When $c_D > 0$, which timing of premium payment would prevail in equilibrium is not clear-cut. Intuitively, the risk of insurer default pushes towards pay-at-harvest, whereas the risk of farmer default pushes towards upfront. To the extent that insurer risk is not subject to moral hazard or adverse selection, for example if it is caused by stochastic shocks which occur after take-up, then it may be priced in to the insurance, suggesting upfront may be optimal. But liquidity constraints, as well as the second order effects (not modelled here) of exposing the farmer to risk over whether the insurer will default, push the other way, as does moral hazard on the insurer and adverse selection over insurance companies which are likely to default.

To demonstrate simply how the different forces push towards upfront or at-harvest contracts, we consider the above setup, and assume that insurers know ex-ante whether they will default or not, so are of two types: proportion $1 - p_I$ who never default, and proportion $p_I$ who always default before harvest. Further assume that the farmer cannot tell ex-ante which type he faces. Under this setup, we allow the price $p$ of the insurance to vary, and consider under which conditions a price $p$ could exist under which trade would occur.

For pay-upfront insurance, this requires
\[ pR^{-H}u'(c_0) \leq \beta \delta^H (1 - p_I) \mathbb{E}[Iu'(c_H)] \]

and\(^{23}\)
\[ p \geq 1 \]

For pay-at-harvest insurance, it requires
\[ \mathbb{E}[D_p(p)pu'(c_H) + (1 - D_p(p))c_D] \leq \mathbb{E}[D_p(p)Iu'(c_H)] \]

\(^{23}\)If $p < 1$ the defaulting insurers would still offer insurance, but the farmers would know that only defaulting insurers were offering insurance, and hence would not take it up.
and

\[ \mathbb{E}[p - I|p - I \leq \frac{c_D}{u'(c_H)}] \geq 0 \]

where \( D_p(p) = \mathbb{I}[p - I \leq \frac{c_D}{u'(c_H)}] \). Given these conditions, the following follows easily

**Proposition 2.6.**

**Pay-at-harvest insurance** \( \exists \xi_D > 0 \) for which there is no price at which pay-at-harvest insurance would be traded when the cost of default \( c_D(s) < \xi_D \) \( \forall s \). However, if \( c_D > \max_u u'(c_H(s)) \) \( \forall s \), then deductible insurance could be traded at price 1.

**Pay-upfront insurance** \( \exists p_I < 1 \) such that if \( p_I > p_I \), there is no price at which pay-upfront insurance would be traded.

This proposition shows that the cost of strategic default for the insured, \( c_D \), and the probability of the insurer defaulting, \( p_I \), are key considerations for which insurance products could be exist in equilibrium (and if so how much insurance they could provide). The cost of strategic default is similarly found to be important in a literature discussing another type of purely cross-state insurance: risk sharing (Ligon et al. 2002; Kocherlakota 1996). The literature considers both how \( c_D \) is made large enough for informal risk sharing to exist, typically through relational contracting and punishment mechanisms, and how the size of \( c_D \) dictates the extent of risk sharing which can be achieved. Related to the discussion here, Gauthier et al. (1997) consider how enlarging the contracting space in risk sharing, so as to allow for ex-ante transfers, enlarges the set of parameters for which the first-best outcome is achievable.

### 2.6 Discussion

In this section we discuss the policy implications of the results in this and the accompanying paper (Casaburi and Willis 2017a). We consider when the transfer across time is likely to be especially expensive, alternative insurance designs, and the broader implications of the results for the importance of liquidity.
2.6.1 When is \( t \) large?

There are three important time periods for insurance products: when the contract is signed, when the premium is paid, and when any payouts are due. The potential for intertemporal factors to effect the demand for insurance increases with the time between the premium payment and the potential payout. For the large majority of insurance products, the premium is paid at the time of contract signing (we take this for granted in this section), which is typically at the beginning of the insured period. For such products the time period over which income is transferred, is the time between contract signing and any payout. In this section we consider what affects when the contract is signed, and what could lead to a large time period between signing and payout. We discuss two classes of reasons, both related to information revelation: moral hazard / asymmetric information, and reclassification risk. The key difference is whether the information is complete or incomplete.

For one-time risks, if information is revealed to both parties at the time of payout, then the contract need only be signed just beforehand. If, however, the information revelation process is drawn out, then there are two considerations for when the contract should be signed. First, if there is no asymmetric information, signing the contract later reduces the amount of insurance which can be provided, since any uncertainty which has been resolved in the meantime will no longer be covered - this is reclassification risk. Thus in this case, under the assumption that the premium must be paid upfront (for example due to one-sided contract enforcement), then the tradeoff for the optimal timing of contract signing is between reducing reclassification risk and increasing the cost of the transfer across time. In the case of asymmetric information, there is an extra force: as the information is revealed to the potential buyer of the insurance, there will be asymmetric information and the potential breakdown of the market, meaning there is a tradeoff between adverse selection and the cost of transferring the premium across time.

For hazard-rate risks (i.e. risks which have some hazard rate of occurring, rather than a fixed time at which they may or may not occur), which are not directly modeled above, there
is still a transfer across time - the premium payments are usually periodic and discrete, and paid at the beginning of the period covered. In this case, one interpretation of $t$ being large is that these premium payments are infrequent. Indeed, a simple implication of the model is that higher frequency payments should result in higher demand - in the limit, when premium payments are permanent flows, the temporal distortion disappears. A second interpretation is that even if the time between contract signing and the covered event is not large, the transfer across time may be large if the insured events occur rarely. For example, the transfer across time may help to explain the low take-up for rare-disaster insurance – by definition payouts of such insurance products are rare, meaning long expected delays between payment and payout, and thus potentially large effects of small differences in interest rates faced by insurance companies and their clients.

**Dynamic insurance contracts**

One final case in which $t$ could be considered large, in the case of hazard insurance, is the practice of front-loading in dynamic insurance contracts. A sizeable literature considers the practice of front-loading insurance premiums so as to better cover reclassification risk (i.e. the risk that premiums increase differentially over time for those for whom information revelation suggests are subject to differentially higher risk) in settings with one-sided contract enforcement (as in *Harris and Holmstrom* (1982)). Insurees pay higher premiums at first than their risk profile suggests, in return receiving lower premiums later (essentially locking them in to the contract). This can result in a transfer across a long period of time, and hence the intertemporal cost of such solutions to the problem of one-sided contract enforcement for reclassification risk may be high.

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24 For theoretical expositions, see Pauly et al. (1995), Cochrane (1995), and for empirical evidence, including on the possible role of liquidity constraints, see Herring and Pauly (2006), Hendel and Lizzeri (2003), Finkelstein et al. (2005), Handel et al. (2015).
2.6.2 When is the (shadow) interest rate high?

The transfer across time in insurance reduces demand when the interest rate the insurer offers on the premium is lower than the (shadow) interest rate that the insuree faces on a loan of the same term (or that they would achieve through holding illiquid savings over the term). There are many well known reasons why the insuree could face a high interest rate, such as having low collateral or a bad credit rating, so demand for insurance should be particularly low when this is the case.

Here, we consider two more nuanced points about the shadow interest rate, which are particularly relevant to the transfer across time in insurance. First, if the interest rate is set partially to price-in default risk, should the interest rate on insurance premiums be the same as the interest rate on loans? Second, how does the broader risk environment affect the cost of the transfer across time for the insuree, considering the impact of precautionary savings on the shadow interest rate?

Default risk

Should the insurer require the same interest rate on an insurance premium paid at payout as that for a loan covering the same period? The key question is whether the expected cost of the default risk is the same. A simple argument suggests not. In the case of a straight loan, the client must pay back the loan in both the good and the bad states of the world. In the case of the “loan” for the insurance premium inherent in the cross-state insurance product, there is only the risk that the client does not pay back in the good state of the world, which is also the state of the world when it is easiest for the client to pay.

Risk environment and precautionary saving

Does the wider risk environment affect the shadow interest rate? Yes. As we saw in the theory section, risk which leads to precautionary saving raises the shadow interest rate. Intuitively, if these are risks which may occur between paying the premium and receiving any payout, then holding illiquid savings during this time will be costly - the interest rate
will be higher. In contrast, facing risk after the time at which the payout would be made may make saving easier, as the client will want to build a buffer stock, lowering the shadow interest rate. In short, higher risk before any payout would be made may make the transfer across time more costly, higher risk after any payout would be made may make it less costly.

2.6.3 Timing and liquidity

Previously we considered why the time between premium payment and payouts could be large. Another important aspect of the timing is when payments fall relative to other income flows and expenses of the client. In the accompanying empirical paper Casaburi and Willis (2017a) we discussed that in the case of agricultural insurance, the premium is charged at planting, which is likely to be a time at which households are particularly short on liquidity, and any payouts are received at harvest time, which is likely to be a time when households are particularly liquid. This is exactly the opposite of the household would want - it is easier for them to pay at times when liquidity is abundant, as better for them to be paid at times when liquidity is short. In general the results suggests that the timing of liquidity flows should be a central consideration in the design of payment plans and financial products.

Pre-committing liquidity

The Pay-At-Harvest insurance product in Casaburi and Willis (2017a) allowed farmers to pre-commit harvest revenues to pay for the insurance premium. Allowing farmers to pre-commit liquidity in this way had at least two potential benefits: first, it solved the enforcement problem of a premium due in the future, and second it enabled farmers to commit their future-selves to buying insurance. These points suggest that pre-commitment of future liquidity might be a useful policy tool in other settings, both for insurance and for other products which time inconsistencies may make it hard for people to pay for, such as down payments for mortgages, or purchases of computers. Examples of such liquidity flows where such pre-commitment options could be added are EITC payments (which are
annual, lump-sum payments), paychecks, and cash transfers in developing countries.

One may worry that such pre-commitment leads to over-consumption, if people derive immediate benefit from the consumption and only later pay for it. In the case of insurance we do not think this is likely, as there is no obvious immediate consumption value (and in the Pay-At-Harvest product there is no transfer across time). For goods, if the good is delivered after actual payment this should not be a concern. If, however, the good is delivered immediately, as it often is in zero-down payment financing for consumer durables such as automobiles and furniture, then this may be a real concern.

2.6.4 Credit + upfront insurance vs. at-harvest insurance

Taking a loan to buy pay-upfront insurance, and repaying it at the time of any insurance payouts, leads to the same net transfers as buying pay-at-harvest insurance. So is there any reason to essentially bundle credit and insurance (or debundle insurance and savings, under the econ 101 model of insurance) in this way. Here we discuss two natural candidates.

Enforcement

As mentioned above, enforcing the repayment of the bundled product may be easier than enforcing the credit separately. That is because, in the bad states of the world (when payments are most costly for the client), in the bundled product there is no enforcement constraint as the client is a net recipient, whereas in the unbundled case there is still an enforcement constraint for the credit. Further, limited liability on the credit contract could reduce the incentive to buy insurance through the standard asset substitution problem (Jensen and Meckling 1976).

Behavioral considerations

In the case of agricultural insurance, there are several papers which bundle insurance with credit (Gine and Yang 2009; Carter et al. 2011; Karlan et al. 2014; Banerjee et al. 2014). They typically find that demand for credit goes down, rather than up. One explanation is
that borrowers already have limited liability, so that the insurance is effectively going to the creditor. Another possible explanation is that clients really want money today, rather than money in the bad state of the world tomorrow. If this is due to time inconsistency, then there is a behavioral reason to offer and bundled product rather than the unbundled products: it essentially removes the (temporal) behavioral bias from the decision to buy insurance.

2.6.5 Seasonality vs. risk in agricultural economies

Optimizing consumption paths requires smoothing consumption over both time and state. In agriculture both are challenging, as incomes are both cyclical and risky. The results in Casaburi and Willis (2017a) suggested that the cost of the transfer across time in agricultural insurance products may be greater than the benefit of the resulting transfer across states. This raises a more general question: do farmers consumptions’ vary more over time or over state? And does this reflect preferences, or the financial products available to them. These are questions which requires careful analysis using high frequency panel consumption data. In terms of tools to deal with variation across time and state, while we typically think that insurance products are more complex than credit and savings products, and thus might think that is easier to transfer across time and state, this is not necessarily the case. There is lots of evidence of risk sharing in the developing world, to cover idiosyncratic shocks. Such mechanisms work poorly for smoothing over time in rural economies, where typically everyone is subject to the same seasonal variation. If so, it could be that variation in incomes over time (seasonality) is more costly than variation in consumption over states (risk), in which case a policy implication would be to focus more on products to smooth seasonality rather than products to provide insurance.

2.6.6 Enforcing future premium payments

In Casaburi and Willis (2017a) we enforced the future premium payment by interlinking product and insurance markets. However, often this cannot be done. Are there other ways in which as Pay-At-Harvest insurance product could be enforced?
Role of government

If the transfer across time reduces the demand for insurance, yet cross-state insurance cannot be enforced by private insurance providers, it suggests a role for the government to provide such plans. Indeed, it is perhaps not surprising that the main example of cross-state insurance we know of, U.S. Federal Crop Insurance, is provided by the government. The transfer across time can thus be considered a possible additional justification for government intervention in the insurance market, beyond the standard ones of asymmetric information. At a stretch, this could also be why social insurance is provided by the government - the transfer across time would be too costly for everybody to buy a pay-upfront social insurance product behind the veil of ignorance at birth, giving rise to a cross-state product, and the government provides the cross-state product since it alone can enforce it.

Comparison to microfinance

Next, compare the enforcement constraint for cross-state insurance to that of a loan. In the case of a loan, the client has to repay the loan in all states of the world. By contrast, in the case of cross-state insurance, the client only has to make a payment (the premium) in the good state of the world, which is precisely when paying should be easier. This suggests that methods which have been used successfully to enforce repayment in credit and microfinance, such as collateral, credit scoring, joint liability, and dynamic incentives, may similarly be used to enforce cross-state insurance products.

Insuring groups

Microfinance often lends through groups, to reduce transaction costs and to improve screening and repayment incentives. Here we briefly discuss the idea of offering cross-state insurance to groups. First, clearly it could reduce transaction costs. Could it improve screening and repayment incentives? Yes, but the extent to which this is true is likely related to how correlated group members risks are - the more correlated, the less the group liability will help, as people will all want to default in the same state of the world.
If such groups are also units of informal risk sharing, it is the aggregate risk faced by
the group which is costly, and which would have the highest insurance demand. The basis
risk of an index insurance product is also likely to be lower for this aggregate risk than for
individual, idiosyncratic risk. An interesting possibility is for the group insurance just to
cover aggregate risk faced by the group. However here there is a tradeoff against the bite of
the group liability, as discussed above.

Pre-committing transfers

As mentioned above, predictable flows of liquidity may be harnessed to allow people to
purchase insurance by pre-committing that future liquidity. Examples include cash transfers,
EITC payments, paychecks from formal employers.

2.7 Money vs. effort for eliciting preferences over time and risk

Above we have shown that, due to the transfer across time in insurance, the demand
for insurance depends on the preferences for transferring money across both time and
state. In addition, we have also shown that preferences for transferring money over time
and state do not necessarily correspond directly to preferences parameters, which govern
preferences over consumption. To move from one to the other, we typically need to consider
the willingness and ability to smooth consumption across both time and state - for example,
preferences over the timing of monetary transfers are represented by the shadow interest
rate, which in the dynamic model depends on the need for precautionary savings, which
in turn depends upon both preferences over risk and the ability to smooth across states;
similarly, preferences over risk depend upon the ability to self-insure, i.e. to smooth the risk
over time. In short, as far as money is concerned, preferences over time and state are heavily
interconnected, and both depend upon consumption preferences over both time and state.
Above we considered the implications for the mapping from consumption preferences to
preferences over money. Here we consider, the other direction, in particular what are the
implications for preference elicitation?
Even in settings without risk (and hence without preferences over time and state being linked), recent work has discussed the difficulty of using preferences over monetary transfers to elicit time discounting (Chabris et al. 2008; Cubitt and Read 2007), in spite of hundreds of papers which have done so. The basic problem is that while the experiments are over money, preferences are over consumption. To move from one to the other, we need to know the background consumption level in the different time periods and how they change in response to wealth, for example by knowing the expected marginal utility of consumption. Unless people are credit constrained, in which case we expect the MPC=1, this is complicated. Indeed, without credit constraints, or narrow bracketing, such Money Earlier or Later Experiments are eliciting the interest rate, rather than the discount rate (the discount rate is partially identified by whether total consumption is growing or falling for a given interest rates). This basic problem provides for many potential confounders in preference elicitation exercises.

A recent literature has suggested that discounting be elicited using direct choices over effort or consumption (Augenblick et al. 2015; Augenblick and Rabin 2016), rather than over monetary payments, to overcome the many confounders of monetary experiments. The basic point is that, unlike money, effort or consumption enter directly into the utility function. Thus, under the assumption that preferences over such tasks are separable from other consumption, the confounders disappear.

Here we note that a similar problem exists for using preferences over money to elicit preferences over risk, and propose that the same solution would work. Simply put, preferences over risk are identifying \( V''(w) = u''(c)c'(w) \), rather than \( u''(c) \) - measures of risk aversion will be reduced by a factor of \( c'(w) \) (even if we do know \( c(w) \), which we often do not). If we instead elicit preferences over consumption or effort, then again assuming that they are separable from other consumption, we no longer have the fungibility problem.
2.7.1 Preferences over risk and time

We outline how using such experiments (using choices over real consumption or effort) to jointly measure preferences over time and risk, would enable us to better understand how preferences over money are related to preferences over consumption, and in particular when and how the classic assumption of separation breaks down. We also outline how they could provide better evidence for a number of hypotheses regarding preferences. The closest papers, in terms of trying to jointly test preferences over risk and time, and trying to overcome some of the difficulties in doing so mentioned above, are [Andersen et al. (2008); Tanaka et al. (2010)]. Both use preferences over monetary choices rather than consumption choices; [Andersen et al. (2008)] uses another method to partially address the fungibility of money - they adapt a dual-selves model and assumes that monetary transfers are smoothed across a number of days (the number of days being a parameter in the model).

First, to better understand how preferences over monetary choices and consumption choices are related, we propose an experiment which elicits preferences over time and risk, both for consumption and for money. Behavior regarding choices over consumption and money should be highly related when liquidity constraints or narrowing bracketing apply, much less so when they do not. In monetary choices, they both lead to both higher risk aversion and to discount factors reflecting preferences, rather than interest rates (and thus lead in turn, potentially, to present bias). Liquidity constraints would give a low intertemporal rate of substitution, whereas narrow bracketing need not. Liquidity constraints would also mean that money in the next period should not influence risk preferences for money today. We envisage experiments similar to the convex time budgets proposed in [Andreoni and Sprenger (2012b)], but modified to allow convex state budgets, or even convex time-state budgets.

Second, using choices over effort rather than money would remove the money fungibility problem which is often present in evidence for classic preference hypotheses. We could answer questions such as: what are typical risk aversion parameters (without the concern that risk is smoothed over time); are the coefficient of relative risk aversion and the intertem-
poral rate of substitution linked, or are Epstein-Zinn preferences more accurate (without the concern that the ability to smooth income may change over time); are preferences over risk time invariant, and vice-versa?

Third, motivated by the insurance example, we would like to test whether people discount uncertain outcomes in the same way as certain outcomes. This relates to the interpretation of the results in the accompanying paper, Casaburi and Willis (2017a) - do the results simply reflect that insurance is subject to the same temporal distortions as other investments, or is there something specific about discounting a product which is designed to reduce risk?

2.8 Conclusion

By requiring that the premium be paid upfront, standard insurance contracts introduce a fundamental difference between their goal and what they do in practice: they not only transfer income across states, they also transfer income across time. We have argued that this transfer across time is at the heart of several explanations offered for the low take-up of insurance, such as liquidity constraints, present bias, and trust in the insurer. Once the temporal dimension of insurance contracts is taken into account, we have shown that a standard borrowing constraint can resolve the puzzlingly low demand for insurance among the poor – while the poor have greater demand for risk reduction, they face a higher cost of paying the premium upfront.

The transfer across time is almost ubiquitous in insurance products. We suggest that imperfect contract enforcement is the likely explanation, and discuss when the transfer across time is likely to be particularly costly, and thus constrain demand for insurance the most. Examples include settings when the information revelation process is slow, giving rise to reclassification risk; settings where there is likely to be asymmetric information; among those who face high interest rates; and in settings with lots of background risk. We also make a comparison between the purely cross-state insurance product and credit, and use the example to motivate ways in which the enforcement constraint may be eased.
Finally, motivated by the interaction of time and state in insurance demand, we propose an experimental methodology for separating preferences over time and risk in consumption, and for understanding how preferences over consumption and money diverge.
Chapter 3

Public Infrastructure and Private Durables

3.1 Introduction

Many developing countries are investing heavily in public infrastructure to catch up with high rates of growth of urbanization. Infrastructure investments have several special features which place high demands on public institutions. For example, the timelines are often long, requiring forward planning and political stability, and the budgets are often large and asymmetric information widespread, making accountability difficult and providing opportunities for corruption. As such, appropriate infrastructure policy depends upon the institutional environment. In this paper, we consider one such aspect of infrastructure which is particularly relevant in settings of high growth and high uncertainty, and has policy implications for this infrastructure boom. Namely, public infrastructure investments often complement or substitute with private investments in durables. For example, a real estate developer may want to build housing or offices near a subway station; in rural areas of developing countries, households may want to build wells and latrines if they do not expect to get water and sewage connections.

1Co-authored with Michael Kremer, Harvard University
When private durables and public infrastructure are complements or substitutes, optimal private investment decisions depend on expected future public investment decisions. In turn, future optimal public investment depends on current private investment, creating a dynamic coordination game. In some cases, this may create the potential for multiple equilibria. In the case of substitutes, equilibria where only private durables are built may co-exist with equilibria where only public infrastructure is built. In the case of complements, equilibria where both are constructed can co-exist with equilibria where neither are. If governments can commit to future public investment decisions, they may do so to ensure coordination. However, such commitment may be hard or costly to achieve in practice. If governments cannot commit, they may follow second best policies, such as constructing public infrastructure earlier than would otherwise be optimal, rather than risk a coordination failure. If the costs of coordination failures are high, such a mechanism could help to explain the huge infrastructure drive currently observed in a number of developing countries, such as China.

In this paper we model such interactions and how the setting affects both first-best investments and which investments get made in equilibrium, and we consider second-best policies when the two diverge. Since demand for infrastructure services grows with wealth, and the driving force for infrastructure investment in our model is economic growth, we base the model on a closed Ramsey growth model with a constant exogenous rate of technical change.

We first consider the case where private durables and public infrastructure are perfect substitutes, but have different cost structures. We assume that the public infrastructure has lower marginal cost but higher fixed cost than the private durable. For example, home solar systems can substitute for grid electricity or water filters for piped drinking water. While private durables can always be invested in, public infrastructure services are only available once public infrastructure has been built. The two are thus dynamic substitutes, and in particular early investment in private durables reduces the gains to subsequent investment
in public infrastructure\textsuperscript{2}

The efficient outcome in the substitutes case depends on many factors, inequality being particularly important. Inequality leads to variation in the timing of private durables investment and in preferences over the timing of public infrastructure investment. If inequality is large enough, private durables (at least for the rich) will be the efficient solution, as it will be too costly for the rich to wait for the poor to generate sufficient demand for public infrastructure. With low levels of inequality, public infrastructure for all will be efficient. With intermediate levels of inequality, the case of interest in this paper, the efficient outcome may be for public infrastructure for all, but arriving at this first-best outcome may not be guaranteed.

Investment in public infrastructure and private durables is a dynamic game between the government and citizens. At intermediate levels of inequality there can be multiple equilibria. If so, there is an equilibrium in which everyone waits for public infrastructure, and it is built. But there is also an equilibrium in which the rich instead buy private durables, since they do not internalize their contribution to the fixed cost of the public infrastructure, and as a result the government either never installs public infrastructure or only installs it much later. While the former, public-infrastructure equilibrium requires significant coordination among the rich in forgoing investment in private durables, the latter, private equilibrium, does not, and so without intervention the private-durables equilibrium may be more likely to occur. In it, those with enough money to buy durables pay too much for services, and the poor initially go without. This can be a force for segregation, since more efficient outcomes are possible when populations are more homogeneous in their demand for infrastructure services - it is a dynamic version of the classic force described in Tiebout (1956).

When multiple equilibria exist, there are several policies which may enable the government to avoid the inefficient, private equilibrium. First of all, if the government can commit\textsuperscript{2}

\textsuperscript{2}A special case of this model is when public infrastructure and private durables are technologically identical, and hence perfect substitutes, but infrastructure has positive externalities and so the government provides it at a subsidy. We consider this case separately in Kremer and Willis (2016).
early to building public infrastructure at the first-best time, then the private equilibrium disappears. However, such commitment may be difficult, given the long time periods and uncertainty involved, especially in settings with bad institutions, political instability or even high political turnover. When governments are unable to make such commitments, they may use second-best policies. One such policy is constructing the public infrastructure early, to avoid people buying the private durable. This could explain, for example, why cities such as Delhi have prioritized building a metro system, to avoid an equilibrium where more and more people buy cars. Another such policy is to tax early purchase of the private durable, to encourage people to wait for the public infrastructure.

We next consider the case of complements, for which location decisions are a prominent example. Suppose that the government is going to decide on the location for a public infrastructure investment, for example where roads, highway exits, or subway stops will be. The services of such public infrastructure are often complements of the services of private durables, such as apartment buildings and office towers. If the government can commit to a location choices ahead of time, it may be a very good idea to do so, since commitment allows the private sector to make the complementary investments in private durables in a more efficient way, i.e. build in the same location. The early announcement of commitment might also avoid inefficient delays in building the private sector durables, or a situation in which the private sector coordinates in such a way that complementary public infrastructure investments cannot be made, for example building in a location where it is difficult to build subway lines. The coordination problem is likely to be larger the greater the number of options for the private durables and the less information private agents have about the actions of others.

This paper adds to a number of literatures. First, the role of commitment in government policy has long been discussed. Indeed, in their seminal article on the role of commitment, Kydland and Prescott (1977) even give an infrastructure example related to this paper, about building houses on flood plains. They claim that the government should commit ex-ante to not building flood defenses such a levees for flood plains. If not, people will inefficiently
build houses on the flood plains, knowing that ex-post the government will be obliged to build flood defenses to protect them. The paper also complements [Kremer and Willis (2016)] which considers the exact substitutes case when the durable has externalities. It derives optimal Pigouvian taxation in this dynamic framework and again shows the importance of commitment. Second, there is a body of work on how infrastructure investment is particularly challenging given the institutions common in developing countries [Laffont (2005)]. This paper suggests an additional such challenge, given the importance of commitment. Finally, [Tiebout (1956)] initiated a literature on the link between urban public service delivery and segregation. The interaction between public infrastructure and private durables laid out above introduces an additional, dynamic force.

The rest of this paper proceeds as follows. In Section 2, we setup a simple background growth model, with consumption of infrastructure services and other goods, which forms the skeleton for the subsequent analysis. In Section 3, we consider the substitutes case, discussing what affects which solution is first best and which outcomes may occur in equilibrium, as well as second best policies when the two differ. In Section 4 we consider the complements case, and show that in many ways it resembles the substitutes case.

### 3.2 Setting

We first layout the basic structure of the model and the solution concepts we will be using.

**Preferences** We consider a continuous time model with three types of goods: infrastructure $I$, private durables $D$, and other consumption $c$. Utility from the consumption of other goods $c$ is assumed separable from utility from infrastructure and durables, and is assumed to be of constant relative risk aversion with constant intertemporal elasticity of substitution $\theta$. The utility from infrastructure and durables, denoted $u(I, D)$, is time invariant $^3$ and may

---

$^3$We are implicitly assuming that the value of the services the infrastructure and durable provides, in units of consumption, grows with consumption growth, which we think is the relevant case for many examples of
have non-zero cross elasticities, accounting for the interactions between public infrastructure and private durables. Future periods are discounted at rate $\rho$.

Discounted lifetime utility is thus:

$$V_0 = \int_0^\infty e^{-rt} \left( \frac{c_{t-1}^{1-\theta}}{1-\theta} + u(I, D) \right) dt$$

(3.1)

We will consider different functional forms for $u(I, D)$. Of particular interest will be the case when $I \in \{0, 1\}$, $D \in \{0, 1\}$, and either $u(I, D) = u_{S\max}\{I, D\}$, the perfect substitutes case, or $u(I, D) = u_{S\min}\{I, D\}$, the perfect complements case.

**Technology and the equilibrium path of consumption** We consider a closed-economy continuous time Ramsey model. Thus we assume a standard Cobb-Douglas production function in capital and labor with exogenous technological progress at rate $g > 0$, agents with homogenous preferences, and perfect capital markets. The Euler equation tells us $\frac{u'(c_t)}{u(c_t)} = \rho - r_t$, where $r_t$ is the interest rate at time $t$. We will generally assume that the economy is in the steady state of the Ramsey model, which implies that $r_t$ is constant and $r - \rho = \theta g$. Thus:

$$u'(c_t) = u'(c_0)e^{-\theta gt}$$

(3.2)

and so

$$c_t = c_0e^{gt}$$

(3.3)

The initial consumption level will be tied down by the transversality condition so that the NPV of total consumption (durable and other) equals the NPV of wealth minus the NPV of net transfers to the government (taxes).

**Public infrastructure and private durable technologies** We assume that, once installed, the public infrastructure and private durables do not depreciate. The production technologies for both are assumed to grow at the same rate as for the rest of the economy, so that...
their costs of production stay constant in units of current other consumption. The durables have constant, per-unit production cost, and are always available on a perfectly competitive private market. The public infrastructure has a constant fixed cost of installation and a constant, per-unit connection cost. It can only be used once it is installed by the government.

**Government** We assume that the government’s objective function is to maximize social willingness to pay, in units of time 0 consumption of other goods.\(^4\) We consider outcomes under different sets of policy tools available to the government, which we discuss further in the relevant sections.

**Structure of the game** We consider two types of game: one in which the government is able to commit at time 0 to their future path of actions, and one in which they are not. When the government is able to commit, at time 0 they decide their path of policies, and then the individual decides each period whether to buy the durable and/or connect to the infrastructure. The game is solved by first solving the individuals’ decisions, given the policy path, and then solving the government’s decision on the optimal policy, given the individuals’ reaction functions. When the government is not able to commit, the timing of the game is that in each period the government sets policies for that period, and then individuals make their decisions for that period based on current government policy and beliefs over future government policy. We only consider Markov Perfect Nash Equilibria (MPNE) in pure strategies.

### 3.3 Perfect substitutes and economies of scale

Infrastructure services can be provided at different scales. While infrastructure is often large-scale and public, small-scale private substitutes exist for a broad set of infrastructures:

\(^4\)We chose this objective so as to not enter into discussions about redistribution - we assume that other instruments are being used to arrive at the optimal level of redistribution. Infrastructure investments, and how they are funded, can have important implications for redistribution - whether or not they can achieve redistribution with lower deadweight loss than direct taxation is an interesting question but not one which we will consider here.
diesel generators, in-home solar and solar lanterns substitute for the electric grid; individual household water storage, wells and septic tanks substitute for grid water and sewage; point of use chlorine substitutes for chlorine dispensers; A/C units and electric radiators substitute for centralized A/C and heating in apartment blocks; private security services may substitute for poor state-run security. In this section we consider the factors which determine which scale is efficient and when efficiency is attained, under the assumption that private durables and public infrastructure are perfect substitutes.

Which scale of technology is efficient depends on many factors. Infrastructure often has important economies of scale, featuring high fixed costs and low marginal costs. For technologies which exhibit very large economies of scale, or for areas of high population density, large-scale public infrastructure is likely to be efficient. However, when population density is low, or when few are willing to pay for infrastructure services, for example when people have different preferences, private durables may be more efficient. Public infrastructure investment leaves more room for corruption, and large-scale infrastructure construction requires careful planning, management and coordination, whereas private durables can often be installed easily, at any time. Thus we might expect public infrastructure to exist less when institutions are bad, for example when governance is weak, corruption is high or managerial capacity is low.

While private durables can help households overcome shortcomings in public infrastructure, by the same measure they also reduce demand for public infrastructure. Thus private durables and public infrastructure are dynamic substitutes, and as a result investments in infrastructure can have multiple equilibria - equilibria where the public infrastructure is built, and equilibria where it is not. The private durables equilibrium then may be one in which those with enough money to buy infrastructure services pay too much for them, while the poor go without.

In this section we consider optimal infrastructure investment in a growing economy with inequality. Inequality means that some demand infrastructure before others. If this

5In ex-Soviet countries heating schemes can even be at the town level.
inequality is large enough, private durables will typically be the efficient solution, as it will be too costly for the rich to wait for the poor to generate sufficient demand for public infrastructure. At intermediate levels of inequality, depending on the objective function of the public infrastructure provider, and the policies available to them, there can be multiple equilibria, since investment in the private durables is a dynamic substitute of public infrastructure. An inefficient equilibrium in which everyone invests in the private durable is particularly likely. With low levels of inequality, public infrastructure will typically be the only equilibrium.

Inequality also leads to inefficiency in terms of when people receive infrastructure, since the optimal time for the poor is not the same as the optimal for the rich. This a possible explanation for segregation when the public infrastructure technology is such that it is installed at the neighborhood level: the earlier installation of public infrastructure in rich neighborhoods generates a higher incentive for rich households to move to them relative to poor households, a dynamic version of Tiebout (1956).

We assume that private and public infrastructure are perfect substitutes, and consider the factors which determine first-best infrastructure investment, as well as those factors which determine whether the first best will be attained, and second-best policies when it cannot. Factors which are particularly important are: the ability to commit both to building the infrastructure and to providing it at an agreed price; the level of inequality in the economy; the growth rate of the economy; and the difference in cost between the two technologies. Since the ability to commit to both building and pricing infrastructure depend crucially on the underlying institutions, we consider outcomes under a range of them.

3.3.1 Setting

In addition to the general setting as presented in section 2, we assume the following.

**Perfect substitutes**  We assume private durables and public infrastructure are perfect substitutes, and refer to services from either of them as simply services. We assume that
I ∈ \{0,1\}, D ∈ \{0,1\}, and \( u(I,D) = u_S \max\{I,D\} \). Thus

\[
V_0 = \int_0^\infty e^{-\rho t} \left( c_I^{1-\theta}/(1 - \theta) + u_S \max\{I,D\} \right) dt \tag{3.4}
\]

The present value of future utility flows from a unit of the durable or the infrastructure is thus \( u_S / \rho \).

**Economies of scale**  Private durables cost \( p_D \) to produce, assumed constant over time. Public infrastructure has fixed construction cost \( F \) and marginal connection cost \( c_I < p_D \), both also assumed constant over time.

**Government**  We consider outcomes under different sets of policy tools available to the government. The first is whether or not the government can commit to its future actions. The second is how it pays for the public infrastructure - we consider two cases, funding though lump-sum taxation, and funding by users (so that the infrastructure is budget neutral). In the case of funding by users, we also consider various abilities to price discriminate. The third set of tools we consider is the ability of the government to tax or subsidize private durables. The final set of tools we consider is the option to privatize the provision of the public infrastructure.

**Inequality**  We assume that there are two types of people, distinguished by their levels of wealth: \( h \) have wealth \( W_H \), and \( l \) have wealth \( W_L \). This, minus exogenous taxes, will generate two different levels of initial consumption: \( c_0^H \) and \( c_0^L \). We parametrize the endogenous \( c_0 \), rather than an exogenous measure of wealth, because it is empirically what we could observe and because it saves us from talking about the production side of the economy.

3.3.2 Consumer’s problem, given prices

We first solve the consumer’s problem for whether and when to buy the private durable or to connect to the public infrastructure, given their beliefs about the price paths of both.
General demand for services

Consider the general case, where the individual faces path \( p(t)_{t \geq 0} \) for the price of the initiation of services - either private or public, we take no stance here. We assume that \( p(t) \) is small enough relative to lifetime wealth that we can ignore the curvature of \( u' \) in calculating the utility cost of buying the services. Denote by \( t^*(p(t)_{t \geq 0}) \) the time when an individual will buy the flow of services. Then:

\[
t^*(p(t)_{t \geq 0}) = \text{argmax}_t e^{-\rho t} \left( \frac{u_S}{\rho} - p(t)u'(c_t) \right)
\] (3.5)

If the problem is convex, this gives the following first order condition for the global maximum:

\[
-\rho \left( \frac{u_L}{\rho} - pu'(c_t) \right) - \frac{d}{dt} u'(c_t) p(t) = 0
\]

Using the Euler equation:

\[
\Rightarrow -\rho \left( \frac{u_L}{\rho} - pu'(c_t) \right) - u'(c_t)((\rho - r)p(t) + \dot{p}(t)) = 0
\]

\[
\Rightarrow u'(c^*_t(p(t)_{t \geq 0})) = \frac{u_L}{p(t)r - \dot{p}(t)}
\] (3.6)

Note that \( c^*_t(p(t)_{t \geq 0}) \) is independent of \( c_0 \)

\[
\Rightarrow e^{-\theta g t^*(p(t)_{t \geq 0})} = \frac{u_L}{(p(t)r - \dot{p}(t))u'(c_0)}
\]

\[
\Rightarrow t^*(p(t)_{t \geq 0}) = \frac{1}{\theta g} \ln \left( \frac{u'(c_0)(p(t)r - \dot{p}(t))}{u_L} \right)
\] (3.7)

Demand for private durables without infrastructure

Suppose that public infrastructure will never be built. Since private durables are available at constant price \( p_D \), the optimal time to buy private durables is then:

\[
u'(c^*_t(p_D)) = \frac{u_S}{p_D r}
\] (3.8)

\(^6\)If there are future flow costs, their NPV can be included in this initial cost.
\[
    t^*(p_D) = \frac{1}{\theta \gamma} \ln \left( \frac{p_{Dr}}{u_S} \right) - \frac{1}{\gamma} \ln(c_0) \tag{3.9}
\]

Demand for public infrastructure

Public infrastructure can only be connected to once it is constructed. Suppose public infrastructure is constructed at time \( t_C \), and is subsequently offered at constant price of connection \( p_I < p_D \). Will the individual wait for the public infrastructure to be built, or will they purchase the private durable first? If the individual connects to the public infrastructure, they will do so at time \( \max \{ t_c, t^*(p_I) \} \). However, if this is too late, the individual will instead install the private durable at \( t^*(p_D) \). The willingness to pay towards the fixed cost for then construction of public infrastructure at time \( t_c \), \( w(t_c) \), is thus given by:

\[
    w(t_c) = \max \{ 0, w \}
\tag{3.10}
\]

where \( w \) solves the following indifference condition:

\[
    \frac{1}{u'(c_0)} \frac{u_S}{\rho} e^{-\rho \max \{ t_c, t^*(p_I) \}} - e^{-\rho \max \{ t_c, t^*(p_I) \}} p_I - e^{-rt_c} w = \frac{1}{u'(c_0)} \frac{u_S}{\rho} e^{-\rho t^*(p_D)} - e^{-rt^*(c_0)} p_D
\tag{3.11}
\]

Denote by \( w^H(t_c) \) the willingness to pay of a rich type and \( w^L(t_c) \) the willingness to pay of a poor type. Then \( w^L(t_c) \) is the same as \( w^H(t_c) \), just shifted to the right by distance \( \frac{1}{\gamma} \ln(\frac{c_H}{c_L}) \).

The importance of beliefs If the agent is told that the public infrastructure will be built at time \( t < t^*(p_D) \), but the public infrastructure project falls through, the agent can still follow his optimal choice for the private durable. However, if \( t > t^*(p_D) \) (and \( w(t) > 0 \)), then waiting to connect to the public infrastructure at time \( t \) means not buying the private durable at the optimal time \( t^*(p_D) \). This introduces two considerations. First, waiting requires the belief that the infrastructure will be built. If the individual does not believe that the infrastructure will be built then they will invest in private durable at time \( t^*(p_D) \), and their subsequent willingness to pay for public infrastructure will be 0. This can be a self-fulfilling prophecy, as we show in Section 3.4, if the construction of public infrastructure
Figure 3.1: Ex-ante willingness to pay towards fixed cost for public infrastructure by construction time

This figure shows the ex-ante willingness to pay towards the fixed cost of public infrastructure at construction time, given a guarantee that it will be built, by type. The ex-post willingness to pay, once they have waited beyond their optimal time to purchase the private durable, $t^*(p_p)$, is $p_p$.

is conditional on demand. Second, once the agent has waited beyond $t^*(p_D)$, their true willingness to pay at build time, conditional on not having bought the private durable is always $p_p$. This introduces a potential hold-up problem, since the provider of the public infrastructure may raise the price of connection once it is built, which we return to in Section 3.4.

3.3.3 Social planner

We assume the social planner can decide if and when to build the public infrastructure, and also when individuals either connect to the public infrastructure or invest in private durables. Clearly, if the government constructs public infrastructure at some time $t_c$, then the socially optimal individual decision is to connect to public infrastructure either immediately or at the unconstrained optimal time. Thus the individual connects at $\max\{t_c, t^*(c_I)\}$ if their willingness to pay is non-negative then, $\bar{w}(\max\{t_c, t^*(c_I)\}) > 0$; if not, then they invest in private durables at time $t^*(c_D)$. Under these optimal decisions, the social surplus from
the construction of public infrastructure at time $t_c$ is given by:

$$S(t_c) = hw^H(t_c) + lw^L(t_c) - F$$  \hfill (3.12)$$

Then we can define the first-best time to build public infrastructure, $t_{FB}$, as:

$$t_{FB} = \arg\max_{t_c} S(t_c) e^{-rt_c}$$ \hfill (3.13)$$

There are three cases for who gets what in this first-best equilibrium:

1. $S(t_{FB}) \leq 0$ - the social surplus from building public infrastructure is negative, so it is never built and everyone buys the private durable at their optimal time to do so.
2. $S(t_{FB}) > 0$ and $w^H(t_{FB}) \geq 0$ - the social surplus from building public infrastructure is positive, and the rich are best of waiting for it to be built. Public infrastructure is built and both types connect to it.
3. $S(t_{FB}) > 0$ and $w^H(t_{FB}) < 0$ - the social surplus from building public infrastructure is positive, but it is built too late for the rich who are better of buying the private durable earlier at their optimal time to do so.

We will focus on case 2, when it is socially optimal to have both types connect to the public infrastructure, as this is when there can be multiple equilibria. We assume that we are in this case for the rest of the substitutes section. In this case we have the following result:

**Lemma 3.1.** If the first best is for the public infrastructure to be built and for the rich to wait for it, $S(t_{FB}) > 0$ and $w^H(t_{FB}) \geq 0$, then the optimal time to build public infrastructure will either be the optimal time to build it just for the rich type, $t_{FB} = t^*_H(c_1 + F/h)$, or late enough such that everybody connects to it immediately on construction $t_{FB} \geq t^*_L(c_1)$.

**Proof**  Clearly the infrastructure will not be built until the rich will connect to it immediately. Now, suppose that the poor do not connect to it immediately. At the optimal time, the benefit from waiting an extra unit of time, in terms of interest on the delayed cost, will equal the cost of delaying the benefit of the services. Hence $t_{FB} = t^*_H(c_1 + F/h)$.  

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The relative efficiency of public infrastructure  What makes public infrastructure more likely to be the first-best policy? There are four forces in the model which obviously weakly increase the efficiency of public infrastructure relative to the private durable: increasing individual willingness to pay towards public infrastructure, increasing the overlap of willingness to pay towards the fixed cost curves, increasing the number of people and decreasing the fixed cost $F$ and the marginal cost $c_I$.

Thus public infrastructure is more likely to be the efficient solution with: higher costs of private durables and lower connection costs of public infrastructure; lower inequality, which brings closer together the $t^*(p_I)$’s and thus the willingness-to-pay curves $w$; higher population density, which increases the total willingness to pay for the public infrastructure; factors which decrease the fixed cost of infrastructure, such as effective governments and fiscal policy. In addition, higher growth increases the relative efficiency of public infrastructure (conditional on the distribution of consumption), as it both increase the maximal individual willingness to pay, and reduces the spread between the willingness-to-pay curves of the rich and the poor ($=\frac{1}{g}\ln\left(\frac{c_H}{c_L}\right)$). However it also narrows each of the willingness to pay curves, as the slopes get steeper. Finally, the intertemporal elasticity of substitution, $1/\rho$ also matters. Increasing $\rho$ decreases the relative efficiency of public infrastructure, since it reduces individual willingness to pay for it and increases the slopes of the willingness to pay curves (through its impact on $r = g + \rho$), decreasing their overlap - intuitively, the timing at which the cost is born matters more.

3.3.4 Benevolent government’s problem

While the social planner was able to dictate when, and if, agents connect to the public infrastructure, a benevolent government may not be able to. In particular, without the policy tools to prevent it, people may invest in private durables before the public infrastructure is built. As such the government and agents are playing a dynamic coordination game, since the willingness to pay for public infrastructure decreases as people invest in private durables. In this section we solve for the MPNE in pure strategies of this game, under
different assumptions regarding the tools available to the government. To do so we first solve for optimal individual behavior given government policy, then solve for optimal policy given individual best responses. We find that there can be multiple equilibria. We are particularly interested in the existence of equilibria in which the rich invest in private durables even though it is inefficient to do so, which arise because they do not internalize the social value of their contribution to the fixed cost of infrastructure.

**Funded by lump-sum taxation**

We first consider a government with access to lump-sum taxation. In this case the benevolent government can make decisions on building the infrastructure but not on when people make private investments. We assume that the government may build the public infrastructure, but then people are free to connect to it when they wish to, at price $p$. The government pays for the infrastructure through lump-sum taxes, only charging marginal cost for connection, to ensure connection at the optimal time and for those for whom it is optimal not to use private durables.

**Commitment** If the government can pre-commit to building the infrastructure at $t_{FB}$, then they should announce such a commitment early on. If this commitment is credible, the equilibrium in which everyone invests in the private technology can be avoided, so we arrive at the social planner’s solution. This announcement must be made before $t_{HI}(p)$, which may be well before the time at which the infrastructure is built. Doing so requires significant forward planning and political capital.

**No commitment** In this case we assume that the government decides each period whether to construct the public infrastructure, and in particular cannot pre-commit to building the infrastructure at a certain date in the future. If everyone believes the government will implement the social planner outcome, then the government will do so. However, if the rich believe that the other rich will buy the private technology, then at time $t_{HI}(p)$ they do buy the private technology. If it is still efficient to provide public infrastructure for the poor,
the government will do so, but the construction date will move back. If it does not, public infrastructure will never be built and everybody will eventually buy the private durables.

As mentioned above, multiple equilibria are not inevitable. It is worth considering what makes them more likely. The existence of both equilibria is guaranteed if the following conditions hold:

\[
S(t_{FB}) > 0 \\
t_{FB} > t^*_H(p_p) \\
\max_t lw^*_I(t) - Fe^{-rt} < 0 \quad \text{or} \quad w^*_H(t^*_L(p_p + F/I)) < 0
\]  

(3.14)

The last condition says that either the infrastructure will not be built for the poor alone, or that, at their optimal construction time, the rich would want to buy the private durable earlier instead of waiting. Considering what happens as the fixed cost \(F\) increases from 0 to infinity, is it clear that for very small \(F\) it is certain that the public infrastructure will be built, and that for very large \(F\) it is certain that it will not be. For a range of intermediate values, e.g. such that \(S(t_{FB}) = -\epsilon\), both types of equilibria must exist.

When multiple equilibria exist, we can see that the government might construct public infrastructure earlier than appears optimal, at \(t^*_H(p_p) - \epsilon\), so as to avoid people instead investing in private durables. Alternatively, another policy instrument the government may consider is a tax on the private durable, to delay its take-up. Such a tax would need to be carefully considered, since taxes are a blunt instrument that would distort decisions on private durable investment among those for whom private durable investment might be optimal, for example those who had very high wealth, or especially high value of the services.

**Median voter and the hold-up problem** Suppose that the rich are to be convinced to wait until time \(t\) for the public infrastructure, and that \(t > t^*_H(p_p)\), their optimal time for purchasing private durables. When time \(t\) arrives, what is to stop the government pushing back the construction of the public infrastructure further - if the poor are a majority, then
the median voter theorem suggests this is likely. There is a hold-up problem once the rich have to wait beyond $t_{Hi}(p_p)$, which is a further reason why commitment may be important.

**Funded by users**

We next consider a case in which the government does not have access to lump-sum taxes and can only finance infrastructure through user fees. As such the infrastructure must be budget neutral. We first consider the case in which the government can charge both an initial fee to have the future option to connect to infrastructure, plus a fee at connection time. In this case the government will generally charge a connection fee of $p_p$, to avoid distorting the time of connection. However, charging up front may not be credible, either because people aren’t sure that the government will be able to build the public infrastructure, or because of the hold-up problem discussed above, whereby the government may subsequently charge a higher connection price than initially agreed. If instead only a connection fee can be charged, people will connect to the public infrastructure later than is optimal, since the connection fee will be more than the marginal cost of connection to cover the fixed cost. This in turn means that connection to public infrastructure is less likely. Again, commitment from the government to a fee schedule, or early construction of the infrastructure, may help.

We consider three types of pricing when the project must be budget neutral: when the government can price discriminate and can observe willingness to pay, when the government can price discriminate but cannot observe willingness to pay, and when the government cannot price discriminate.

**Perfect price discrimination** If the government can price discriminate based on willingness to pay (or wealth, which is synonymous in this model), then the infrastructure will be built as the same time as when the fixed cost is paid for through taxes.

**Price discrimination by connection time** Suppose the government builds the infrastructure at time $t$ and can offer two contracts, with different prices and different connection times, $(t_L,p_L)$ and $(t_H,p_H)$. Then the government faces the following maximization problem:
\[
\max_{(t_H, t_L, p_H, p_L)} h\left(\frac{u_L}{\rho u'(c_{i_H}^{L})} - p_H\right)e^{-r_H t_H} + \left(\frac{u_L}{\rho u'(c_{i_L}^{L})} - p_L\right)e^{-r_L t_L} \quad (3.15)
\]

s.t. \( h p_H e^{-r_H t_H} + l p_L e^{-r_L t_L} \geq F e^{-r_H t_H} + h c_I e^{-r_H t_H} + l c_L e^{-r_L t_L} \) (B.C)

\[
\frac{u_L}{\rho u'(c_{i_H}^{H})} - p_H \geq \frac{u_L}{\rho u'(c_{i_L}^{H})} - p_L \quad (I.C)
\]

\[
\frac{u_L}{\rho u'(c_{i_H}^{L})} - p_H \geq \frac{u_L}{\rho u'(c_{i_L}^{L})} - p_L \quad (I.R_H)
\]

\[
\frac{u_L}{\rho u'(c_{i_H}^{L})} - p_L \geq \frac{u_L}{\rho u'(c_{i_L}^{L})} - p_L \quad (I.R_L)
\]

Essentially the price discrimination introduces an incentive compatibility constraint which means that the government may be able to extract less payment from those with high willingness to pay: the decline in price with respect to connection time may be less steep than is optimal. As such public infrastructure is less likely to be built, and individuals may connect to it later than is optimal.

**No price discrimination**  If the government cannot price discriminate, which is the essentially the case whereby everyone who will connect to the public infrastructure must do so immediately upon construction, then public infrastructure is less likely to be built. If it is built, those with low willingness to pay at build time will never be connected to the infrastructure. Build time \( t \) is dictated by the additional constraint that there must be a price \( p \) such that

\[
h p I[w^H(t) \geq p] + l p I[w^L(t) \geq p] > F \quad (3.16)
\]

**Privatization of infrastructure**

One standard way of providing infrastructure when there are large fixed costs, if for the government to grant a monopoly to a private utility company to provide the infrastructure. In this case there is another potential hold-up problem, related to the one mentioned above, which could prevent the rich from waiting for the infrastructure, and as such the utility company should be subject to regulation regarding the evolution of their prices.
To demonstrate, consider someone who has delayed private investment for the sake of the public infrastructure, so that \( t > t^*(p_p) \). This person’s willingness to pay for the infrastructure at time \( t \) was originally less than \( p_p \). However, at the time the infrastructure is built, given that they have forgone the private durable, they would be willing to pay up to \( p_p \). The company may thus renege on its earlier promise of a connection price of \( p_l \), to instead charge \( p_p \). The possibility of this happening may lead to the person investing in private durable in the first place. In this case commitment can again help, this time commitment to a price - the government should regulate the pricing rules of the company so that they effectively commit to a pricing rule ahead of time.

### 3.3.5 Inequality and segregation

We argued above that higher inequality makes public infrastructure less likely to be built. It also, conditional on public infrastructure being built, reduces total surplus from the public infrastructure. This is because the average distance between the optimal construction time and the actual construction time for individuals increases with inequality, such that more people have to wait longer than they would want to to connect, and also the average time between the infrastructure being built and people connecting to it increases. This potentially provides a dynamic version of the public service provision explanation for segregation first argued in Tiebout (1956). If the natural catchment area of an infrastructure technology is such that migration can occur across distinct catchment areas, and governments can install public infrastructure at different times in different places, then it will install infrastructure earlier in rich areas than poor areas, and this will in turn given additional incentive for the rich to move to rich areas. Simply put, public infrastructure may be provided at more appropriate times to segregated areas than to diverse areas. This also suggests that public infrastructure might be less likely in diverse areas. This of course depends crucially on the natural catchment area for public infrastructure. A nuclear power station or airport may be unlikely to impact segregation, whereas connection to the electricity grid or running water may.
3.4 Complements

Just as in some cases public infrastructure substitutes for private durables, in other cases the two are complements. A particularly common example is how transport connections, electricity, water / sewage and other public infrastructures are local complements to residential and commercial buildings. Other examples are the infrastructure to broadcast high-definition (HD) television, which complement televisions which are capable of displaying high definition pictures, and a charging network for electric cars, which complements their ownership. In the location example, suppose that the government has to decide where to put infrastructure in the future, such as where the roads are going to be, where the highway exits are going to be, where the subway stops are going to be, etc.. If the government can commit to some of these choices ahead of time, it may be a very good idea, since doing so allows individuals and the private sector to make complementary investments in private durables, such as where to build apartment buildings and office towers, in a more efficient, coordinated way. This is particularly important as land prices will push against such agglomeration happening naturally. With a commitment to a future subway station, private construction might then focus on the one location rather than being diffuse (and land values will reflect these future changes early on, avoiding the uncertainty and potential for corruption associated with choosing locations, and hence changes land values significantly, ex-post). Further, situations in which the private sector builds the apartment blocks and office towers in a place where it is especially costly to build subway lines might be avoided.

The implications for government policy are very similar to the substitutes case - coordination is key for ensuring efficiency, and can again be ensured by early announcement of government commitment. As discussed above, however, governments may be unable or unwilling to commit. Absent commitment, governments could use the same second-best policies as in the substitutes case, such as investing early in public infrastructure, or taxing certain investments in durables, to ensure coordination. Examples of such taxation in the location example would include differential land taxes and zoning; in the high-definition television and electric cars examples, the government could subsidize early adopters.
Commitment is more important when coordination among private agents and the government is more difficult to achieve. Several factors affect the ability to coordinate. Coordination becomes harder the larger the number of choices for both the private and public agents and the less there is a focal choice / location (for example, in the location example, when one location is better endowed, or private agents know the objective function of the government). Similarly, coordination is less likely when private agents are less able to observe the actions of others, for example because of simultaneous moves or because agents have an incentive to conceal their actions. In some situations coordination might be the more costly action in the short run, which also makes it less likely. For example, in the housing location example, dense housing is more expensive to build, and in the other examples early adopters have to wait for the infrastructure to be built. Finally the consequences of miscoordination become greater the stronger the complementarities.

3.5 Conclusion

Expectations over future public infrastructure investment can affect current private infrastructure investment. Private infrastructure investment in turn affects future public infrastructure investment, leading to a coordination game which may have multiple equilibria. In both the complements and perfect substitutes cases we have shown that the early announcement of commitment to future public infrastructure investment by the government may help ensure efficient outcomes are achieved. If the government cannot credibly commit, it may wish to construct public infrastructure earlier than would otherwise seem efficient. We suggest that this could be a partial explanation for the very large infrastructure drives observed in a number of countries such as China.

The model suggests that infrastructure investment, and the extent to which it approaches the first best, will depend on technical efficiency of public infrastructure relative to private, inequality, growth, discount rates, population density, the number of alternative investments and the institutional setting. Inequality plays a particularly important role in public infrastructure provision, since the rich may demand infrastructure services earlier than the
poor. For those public infrastructures which are naturally provided at the neighborhood level this compromise suggests a dynamic version of the classic force for segregation described in Tiebout (1956): public infrastructure will be provided earlier in richer neighborhoods, making them more desirable for the rich.
Chapter 4

Guns, Latrines, and Land Reform:
Dynamic Pigouvian Taxation

4.1 Introduction

Standard theory suggests that governments may wish to impose Pigouvian subsidies or taxes on goods which create externalities, such as latrines or cars. We argue that dynamically optimal Pigouvian policies for durable goods will differ from statically optimal policies, since expectations over future government subsidies, taxes, and regulatory policy on durables affect consumers’ current purchase decisions.

Consider for example, a government of a growing developing country with widespread open defecation choosing subsidies for latrines to reduce disease transmission. Statically optimal Pigouvian subsidies will grow over time as the economy develops, but if the government raises subsidies over time, consumers will have incentives to delay purchases, reducing the benefit of the subsidy. In the extreme, delays in private investment caused by anticipated subsidy growth may dissipate up to 100% of the private benefits of the transfers to the consumer, and if the durable generates positive externalities, these delays could potentially lower welfare in the economy relative to a counterfactual without subsidies.

1Co-authored with Michael Kremer, Harvard University
We consider the dynamic game when not only do consumer decisions depend on anticipated future government policy, but optimal government policy is influenced by consumers’ purchase decisions for durables. We show that if the government does not have the ability to commit, there will be multiple Pareto-rankable Markov Perfect Nash Equilibria, including equilibria in which consumers delay purchase, anticipating greater government subsidies in the future. If the government can commit to a future subsidy path, it can eliminate inferior equilibria. Ideally it would commit to first instituting and then withdrawing subsidies, so as to incentivize consumers to adopt the durable good at the socially, rather than privately, optimal date. A government that can commit to a constant subsidy, but not a temporary subsidy, will need to spend more to induce consumers to adopt at the socially optimal date. The problem could potentially be addressed by subsidies on the flow value of durable services or fines for not possessing the durable, but these policies may be difficult to implement.

Government commitment to subsidy paths may be difficult in the presence of multiple subsidy providers, such as NGOs. As outlined above, anticipation of foreign subsidies could reduce welfare by delaying private investment. This provides a potential justification for governments wishing to regulate NGO subsidies for durables, as well as a new potential rationale for the view of many aid sceptics that aid is not only partially dissipated in waste, but could potentially harm the recipient population (although we are not arguing that there is empirical evidence for this theoretical possibility). The problem could be addressed if NGOs subsidize non-durables rather than durables.

The model can be extended to the case in which durables create negative externalities, and to introduce political-economy considerations. For example, from a static perspective, a political party that believes guns create negative externalities would want to introduce Pigouvian taxes or regulations. However, consumers may stockpile guns between the time the party begins campaigning for such a policy and its eventual implementation. In extreme cases, this dynamic force may make the gun control policy counterproductive, leading the government to abandon it altogether. To take another example, a political party that
announces an intent to redistribute land as part of a land reform may reduce current owners’ incentives to invest in the land, thus reducing the benefits of maintaining existing property rights and making land reform more attractive to other political parties and to the median voter.

4.2 Setting

4.2.1 Agents and structure of the game

We consider a game with two types of agent: the individuals who purchase the durable (e.g. a latrine), and the organizations which provide the subsidies or taxes, typically the government. We consider two types of game: one in which the government is able to commit at time 0 to the future path of subsidies or taxes and one in which they are not. When the government is able to commit, at time 0 they decide their path of subsidies $s(t)$ and then the individuals decide each period whether to buy the durable. The game is solved by first solving the individuals’ decisions of whether and when to buy the durable, given the subsidy path, and then solving the government’s decision on the optimal subsidy level, given the individuals’ reaction functions. In reality government might be restricted to a class of functions for $s(t)$, so we also consider two special cases: when governments can only commit to a constant subsidy path, and when they can commit to a path of static Pigouvian subsidies. When the government is not able to commit, the timing of the game is that in each period $t$ the government sets a subsidy $s(t)$ and then individuals decide whether to buy the durable at the subsidized price $p(t)$. We only consider Markov Perfect Nash Equilibria (MPNE) in pure strategies.

4.2.2 Technology, preferences and the equilibrium path of non-durable consumption

We consider a closed-economy continuous time Ramsey model with exogenous technological progress at rate $g > 0$, discount rate $\rho$, and homogeneous agents. We assume
a standard Cobb-Douglas production function in capital and labor with exogenous rate of technology change $g$. Utility is quasilinear in services from the durable $u^I_t$ and total spillovers from others’ durables, $u^S_t$, which are proportional to the number of other people using the durable. Consumption in the other goods has constant intertemporal elasticity of substitution $\theta$, so that discounted lifetime utility of an individual is:

$$\int_0^\infty e^{-\rho t} \left( c_t^{1-\theta} / (1 - \theta) + u^I_t + u^S_t \right) dt$$

All prices in the paper are in units of consumption of other goods. We assume that the value of the services the durable provides, in that unit, grows with consumption growth, which we think is the relevant case for latrines and many other examples of durables which the government might subsidize.

Since we assume perfect credit markets with interest rate $r_t$, the Euler equation tells us:

$$\frac{\dot{u}(c_t)}{u'(c_t)} = \rho - r_t$$

Being in the steady state of the Ramsey model, we have that $r_t$ is constant and $r - \rho = \theta g$. Thus:

$$u'(c_t) = u'(c_0)e^{-\theta gt}$$

(4.1)

The initial consumption level will be tied down by the transversality condition so that the NPV of total consumption (durable and not durable) equals the NPV of wealth minus the NPV of net transfers to the government (taxes).

We assume that the government has lexicographic preferences over social welfare and the cost of subsidies, with social welfare being dominant. This is a simplification and an approximation to the case where government can raise funds at low cost. We initially assume that the government can only subsidize or tax the purchase of the durable, for instance because other types of taxes or subsidies may be too costly to implement. In a later section we consider the case when the government has access to a wider variety of tools.
4.2.3 Durable good

We assume that the durable, once installed, provides constant flow utility $u_L$ and doesn’t depreciate. Thus the present discounted utility of the durable is:

$$\int_0^\infty e^{-rt}u_L dt = \frac{u_L}{\rho}$$

Durables also provide a total social externality $u_S$, so that:

$$u_i^S = \gamma(t)u_S$$

where $\gamma(t)$ is the proportion of the population who have the durable at time $t$. We treat the utility from non-durables, own durables and others’ durables as separable, abstracting from potential complementarity or substitutability.

The durable is always available on the private market, assumed perfectly competitive. It has constant price $p$, assumed small relative to lifetime wealth and to the capital stock at purchase time, and assuming implicitly that the production technology grows at the same rate, $g$, as technology in the rest of the economy. Due to growing consumption, eventually everyone will buy the durable. We assume that the government offers a potentially time-varying subsidy $s(t)$ to this price, positive or negative, where $s(t) = 0$ if the government is not offering subsidies at time $t$. The subsidy is paid for through lump-sum taxation. Define $p(t) = p - s(t)$ as the price at which the agent can buy the durable at time $t$.

4.3 Consumer’s problem

In the game with commitment, the individual knows the price path $p(t)$ from the start. In the general game without commitment, the individual only has beliefs over the future prices. However in equilibrium, as we consider pure strategy MPNE, these beliefs are correct, and hence we can also treat the consumer’s problem as if they know the price path from the start in this case. The individual’s optimization problem, where $w_0$ represents the net present value of his lifetime wealth at time 0, and others purchase the durable at time $t'$. 
is:

\[
v(w_0) = \max_{(c_s)_{s \geq t}} \int_0^\infty e^{-\rho s} u(c_s) \, ds + \frac{u_L}{\rho} e^{-\rho t} \]

s.t. \[\dot{w}(s) = rw(s) - c(s) - p(t) \delta[s = t] - s(t') \delta[s = t']\]

Individual demand for the durable maximizes the (discounted) benefit minus the cost. Suppose that, at \(t\), the individual buys the durable at price \(p(t)\). What is the cost of the expenditure in terms of time 0 utility? It reduces net wealth at time 0 to \(w_0 - e^{-rt} p(t)\). Now, \(v'(w_0) = u'(c_0)\), by the envelope theorem. Thus, the loss in utility at time 0, from paying \(p(t)\) at \(t\), assuming that \(e^{-rt} p(t)\) is small enough so that the curvature of \(v\) can be ignored, is \(e^{-rt} p(t) u'(c_0)\). As for the benefit of the durable, getting it at time \(t\) is worth, in terms of time 0 utility, \(e^{-rt} u_L\). Therefore, given price path \(p(t) = p - s(t)\), individual demand for the durable, \(t^*(p(t)_{t \geq 0})\), satisfies:

\[
t^*(p(t)_{t \geq 0}) := \arg\max_t e^{-rt} \frac{u_L}{u'(c_0)} \frac{u_L}{p} - e^{-rt} (p - s(t))
\]

Unsubsidized case  Consider first the unsubsidized case, where the price is constant at \(p\). In this case the first order condition gives:

\[
-\frac{u_L e^{-pt}}{u'(c_0)} + re^{rt} p = 0
\]

\[
\Rightarrow u'(c_{t^*(p)}) = \frac{u_L}{pr}
\]

(4.2)

Implying the individually optimal purchase time \(t^*\) given by:

\[
t^* := \frac{1}{\partial_s} \ln \left( \frac{u'(c_0)pr}{u_L} \right)
\]

(4.3)

One-time subsidy  Suppose the durable is offered at a one-time different price at time \(t\). Purchasing at that time gives a change in lifetime utility from infrastructure, at time \(t\), of \(\frac{u_L}{p}(1 - e^{r(t-t^*(p))})\). Not purchasing the unsubsidized infrastructure at time \(t^*(p)\) also leads

\[\text{2The } s(t') \delta[s = t'] \text{ term just reflects the fact that the subsidies are paid for by the population. It does not affect the maximization problem of the individual.}

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to a savings, in units of time $t$ consumption, of $pe^{(t-t^*(p))}$. Thus, denoting by $w_c(t)$ the willingness to pay for the durable at time $t$ rather than at price $p$ at time $t^*$, $w_c(t)$ is given as follows:

$$w_c(t) := \max \left\{ pe^{(t-t^*(p))} + \frac{u_L}{\rho u'(c_t)} (1 - e^{\rho(t-t^*(p))}), 0 \right\}$$

$$= \max \left\{ \frac{pr}{\rho} e^{\theta g(t-t^*(p))} - \frac{p\theta g}{\rho} e^{(t-t^*(p))}, 0 \right\}$$

(4.4)

**General subsidy** Now consider the case of a general subsidy. If $s(t)$ is continuously differentiable, the equation for individual demand gives the following first order condition for the optimal time to purchase the durable, $t^*(p(t))$:

$$e^{-\theta t^*(p)} (r(p - s(t^*(p)))) + s'(t^*(p(t)))) = \frac{u_L}{u'(c_0)}$$

This first order condition shows that subsidies, $s(t)$, have two (potentially opposing) effects on the optimal time to purchase the durable, $t^*(p(t))$: the optimal timing becomes earlier with the level of the subsidy, but becomes later with the slope of the subsidy.

### 4.4 Government’s problem

In this section we assume that the externality is positive. Everything follows, with inequalities reversed, for negative externalities. The social planner’s problem is the same as the individual’s problem, except with a utility flow from infrastructure of $u_L + u_S$ rather than just $u_L$. Hence the socially optimal time for purchase of the durable, $t^*_S$, is given by:

$$t^*_S := \frac{1}{\theta g} \ln \left( \frac{u'(c_0) pr}{u_L + u_S} \right)$$

(4.5)

**4.4.1 Government can commit**

We consider how the government can offer the subsidies to get people to purchase the good at this time $t^*_S$, with decreasing levels of commitment.
One-time subsidy

If the government has full control over the subsidy path, clearly the cheapest way for them to achieve the first best time is to offer a subsidy at the socially optimal time \( t^*_S \), which makes the individual indifferent between taking the subsidized price at \( t^*_S \) and the private price \( p \) at \( t^* \), and then to remove the subsidy immediately afterwards. Such a subsidy satisfies \( p - s^* = w_c(t^*_S) \), giving:

\[
s^* = p - \frac{pr}{\rho} e^{\theta g(t^*_S - t^*)} - \frac{p\theta g}{\rho} e^{\gamma(t^*_S - t^*)} = p \left( \frac{u_S}{u_L + u_S} - \frac{p\theta g}{\rho} \frac{u_L}{u_L + u_S} \left( 1 - \left( \frac{u_L}{u_L + u_S} \right)^{\rho/\theta g} \right) \right)
\]

(4.6)

Constant subsidy

If the government isn’t able to commit to a whole price schedule, but only to a constant subsidy, then this subsidy \( s^*_c \) is greater than the subsidy with full commitment \( s^* \):

\[
t^*(s^*_c) = t^*_S \\
\Rightarrow \frac{1}{\theta g} \ln \left( \frac{u'(c_0)(p - s^*_c) r}{u_L} \right) = \frac{1}{\theta g} \ln \left( \frac{u'(c_0) pr}{u_L + u_S} \right) \\
\Rightarrow s^*_c = \frac{u_S}{u_L + u_S} p > s^*
\]

(4.7)

4.4.2 Government cannot commit

If the government is not able to commit upfront, they face a classic commitment problem: individuals know that if they don’t buy at time \( t^*_S \) then the government will wish to raise its subsidy in the next period, since the monetary value of the externality will have increased. In our model this results in multiple equilibria.

Proposition

The Markov Perfect Nash Equilibria in this case are all subsidy paths \( s(t) \) such that:

\[
s'(t) \leq \frac{u_L}{u'(c_0)} - r(p - s(t)) \quad \forall t \geq t^*_S \\
p - s(t) \leq w_c(t) \quad \forall t \in [t^*_S, t^*)
\]

and such that individuals prefer waiting for \( p - s(t^*_S) \) rather than buying at \( p - s(t) \) \( \forall t < t^*_S \). Such paths have subsidies which are bounded below at \( t^*_S \) by the outside option, and first
best timing is achieved\(^3\) but subsidies are not bounded above at \(t_s^*\).

**Proof**

Strategies comprise a subsidy path \(s(t)\) for the government, and a minimal acceptance price \(p_{min}(t)\) for the agents. Before \(t_s^*\), the government doesn’t want the individual to take up. In the subgame after \(t_s^*\), the government wants the individual to take up immediately, whatever the cost. The individual will take up immediately if the \(p - s(t)\) falls at rate no faster than \(g\) both locally and globally, and if the buying subsidized is better than waiting to buy unsubsidized. Consider a price path such that \(p - s(t)\) is falling at the maximal rate, starting at any given \(s(t_s^*)\). The best response of an individual facing this path is to wait until \(t_s^*\), and then buy at minimal price \(p - s(t)\) in future periods. The subgame perfect best response of the government, to this best response of an individual facing the path, is the path itself.

### 4.4.3 Static Pigouvian subsidies

Suppose instead the government follows static Pigouvian subsidies \(s_p(t)\), whose value rises over time: \(s_p(t) = \frac{u_s}{\rho u''(c_1)}\). The individual demand equation then gives:

\[
t^\ast((p - s_p(t))_{t \geq 0}) = \arg\max_t \frac{e^{-\rho t}}{u''(c_1)} \frac{u_L}{\rho} - e^{-rt} \left( p - \frac{u_s}{\rho u''(c_1)} \right)
\]

\[
= \arg\max_t \frac{e^{-\rho t}}{u''(c_1)} \frac{u_L + u_s}{\rho} - e^{-rt} p
\]

This (by design, since the aim of Pigouvian subsidies is to internalize the externality) is the same as the individual optimization problem without subsidies but with private utility flow \(u_L + u_S\). Thus:

\[
t^\ast((p - s_p(t))_{t \geq 0}) = t_s^*
\]

Hence statically optimal Pigouvian subsidies actually again give the optimal investment time, but result in significantly larger subsidy payments than if the government could

---

\(^3\)This is because of our simplifying assumption of governments having lexicographic preferences. The more general case of government facing some cost of raising public funds results in a trade-off between optimal timing (and hence less externalities) and less waste through raising public funds. As such first-best timing is not generally achieved.

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commit to a fixed subsidy level:

\[ s_p^*(t_s^*) = \frac{u_S}{\rho u'(c_L^c)} = \frac{pu_S}{\rho(u_L + u_S)} =\frac{r}{\rho} s^*_c > s^*_c \quad (4.8) \]

### 4.4.4 NGOs and durables

The previous section assumed an unchanging utility function for the government and a single provider of subsidies. Without commitment the game resulted in the first best timing, although at a higher cost (this is because of our simplifying assumption of lexicographic preferences for the government. Under more standard preferences, the government would trade-off timing against total expenditure, and hence timing may be delayed). Now consider a case where either government preferences over subsidies or their ability to provide them over time may change, for example with the election of a new party, or a new provider of subsidies may arrive at a later date. Then agents may expect the subsidy to rise considerably in the future, causing them to delay purchase of the durable beyond the optimal time \( t_s^* \), with associated loss of welfare.

NGOs often have preferences for subsidizing certain types of good which may differ from those of the government. For example, some NGOs may consider latrines as merit goods and wish to subsidize them heavily. NGOs’ preferences may also change over time, as may their presence in a region. When NGO preferences over subsidies are mis-aligned with those of the government, their subsidizing durables may undermine the ability of the government to commit to a subsidy path.

For a simple model of the potential adverse effects of subsidies on durables, suppose that the NGO will arrive at time \( t_N \) and then offers constant subsidy \( s_N \). Suppose also that the individually optimal time to buy at the subsidized price, \( t^*(p - s_N) \), satisfies \( t^*(p - s_N) < t_N \) so that if the individual waits for the subsidy then they will purchase the durable as soon as the subsidy starts. As the price \( p - s_N \to w_c(t_N) \), the willingness to pay for the durable at
time $t_N$, (either through $s_N$ decreasing or $t_N$ increasing) all of the individual benefit from the subsidy is dissipated. Further, if $t_N > t^*$, the optimal time to buy the unsubsidized durable, we see that the subsidy actually delays investment in the durable, because of expectations of future rises in the subsidy, and hence worsens externalities and thus overall national welfare, even if the subsidy is financed from abroad.

For a model which introduces uncertainty on when the NGO will arrive, assume that starting from time $t_N < t^*$, the NGO may arrive at hazard rate $\lambda$. If it arrives it provides the durable for free. This modifies the individual demand function by effectively adding $\lambda$ to the interest rate. Thus, if the individual hasn’t yet received the durable for free, the optimal time to purchase the durable is given by:

$$t^*_N = \frac{1}{\theta_S} \ln \left( \frac{u'(c_0)p(r + \lambda)}{u_L} \right) > t^* \quad (4.9)$$

Clearly when both $t_N \geq t^*$, i.e. there is no possibility of the NGO arriving before when the individual would have bought the unsubsidized durable without the NGO, and the externality $u_S$ becomes large relative to the private benefit $u_L$, the existence of the NGO decreases social welfare, again without even accounting for the cost of the subsidy. While delays can dissipate up to 100% of the private value of the subsidy, they can more than fully offset the social benefit of the subsidy.

If the government wants to ensure the first best time $t^*_S$, it still can do so for those who haven’t already received the durable for free before then, but since the outside option is improved for the individual the subsidy will need to be higher. If $t_N \geq t^*_S$ total government expenditure on subsidies will definitely be higher than in the case without NGOs.

The problem could be solved by NGOs financing non-durables, but NGOs often prefer subsidizing durables to non-durables, believing the former to be more “sustainable”.

### 4.4.5 Tools available to government

In the above we assumed that governments could only subsidize or tax goods through the purchase price. This is a reasonable assumption in many cases, for example such
subsidies or taxes can often be added at the factory gate or point of sale, rather than going house to house which could be prohibitively expensive. In practice alternative tools for funding may be available and may be more attractive (Ashraf et al. 2016). One alternative approach would be to tax or subsidize not owning the good. Often such dual policies are equivalent. However, when the government is able to commit to either a future subsidy or fine in the future, if the policy is correctly designed one will require money to pass through governments hands whereas the other will not, particularly appealing in places of high corruption. Namely, the subsidy offered once at the first best time will result in take-up then. The fine, imposed once just after the first best time, will result in take-up just before, with no fines needing to be collected. In practice such fines might be costly to run, and hence not credible.

The government might also have access to a flow subsidy or tax on ownership. While this is equivalent to a stock subsidy or tax at purchase when the stock value is the net present value of future flow values, there are different implications for the ability to commit. Offering the cash value of the social utility flow at all periods results in first best timing and may be simple to commit to. However, in many examples these flows will be small relative to collection costs, in which case such policies are unlikely to be used.

Another policy which may help with commitment, in the case of varying subsidies, is for the government to agree to pay the subsidies retroactively. However, such policies must be credible, since ex-post the government would want to renge on the retroactive payment.

4.4.6 Decentralized government spending

While we have so far focused on the affect of expectations on private behavior, the same mechanism can impact the public investment decisions. Namely, if local public infrastructure investments can be made at any time by local government, but may be subsidized in the future by national governments, then local government may forgo investment at the optimal time in order to wait for investment from the national government. As above these delays can dissipate all the local surplus from the national government spending, and in the case
of negative externalities, e.g. with poorly maintained highways, the national funding may actually reduce welfare. Again this suggests a role for early commitment by the national government to the future subsidies they will provide and under what conditions.

4.5 Extensions to other settings

4.5.1 Guns

We now consider a case in which there is a durable with a negative externality which the government would like to tax, but there is a delay between the announcement the intention to implement the policy and its actual implementation. Such delays are likely in practice, since changes to law take time, and political parties layout their policies in manifestos before coming to power.

The announcement of the policy will increases sales in the short term, contrary to the aims of the government and worsening the social externality. If the time gap is sufficiently long, then as in the example given above in the section on NGOs, introducing the policy may actually reduce welfare. If the government is to introduce tax $T$ at time $t$, announcing this at time 0, the policy would reduce social welfare if the optimal time to buy a gun is later than $t$, $t^* > t$, and the gain from buying a gun just before the tax is introduced is greater than that from buying a gun at the optimal time once the tax is introduced:

$$\frac{u_L}{\rho u'(c_t)} - p \geq \left( \frac{u_L}{\rho u'(c_{t^*(p+T)})} - (p + T) \right) e^{-r(t^*(p+T)-(p+T))}$$

The Obama administration may be facing this problem. Gun sales spiked to their highest level in two decades after the Sandy Hook shootings. The Washington Post, following a similar spike after the San Bernadino shootings, wrote “This matches a pattern we’ve seen plenty of times in the past: tragedy, followed by calls for gun control, followed by surging firearm sales.” (Ingraham (2016)). While in this case depreciation of guns, constraints in the short term supply of guns, and credit constraints are likely to be much more important factors than consumption growth, space constraints mean we do not develop a new model
for this setting. If a per-period tax on ownership of guns is available, as seems potentially realistic in this case, then the problem goes away. Similarly, the problem also goes away if the government is able to announce a tax which will be applied retroactively from the announcement date.

4.5.2 Land reform

Until now we have considered cases where expectations over future changes in optimal government policy act against the government’s wishes. However, it is possible that the announcement of a future policy change could be self-fulfilling, by making the status quo less attractive. Take the example of land reform and consider a basic model of electoral competition. The main economic justification for private land holdings is that they encourage optimal investment in the land. However, these investments are conditional on beliefs of future ownership. Suppose a pro land reform party announces that, if elected, they will enact extensive land reform. If they have a chance of being elected, this reduces the expected returns to investments in land by land owners, and hence in turn reduces such investments. However, these investments were the justification for not having land reform, and so the marginal voter shifts towards being positive towards land reform and hence so too does the other party, if it is marginal. This makes both land reform and potentially also the election of the pro land reform party more likely.

4.6 Conclusion

Expectations over the government’s future subsidies, taxes, and regulatory policy on durables, such as latrines or guns, affect consumers’ current purchase decisions. In turn, consumers’ purchase decisions affect optimal policy for future government. We study the resulting dynamic game in a growing economy, arguing that dynamically optimal Pigouvian subsidies and taxes on durables will in general differ from their statically optimal levels. Governments seeking to encourage purchase of a particular durable may wish to commit to eventually reducing subsidies so as to advance consumers’ optimal purchase time. If that
is impossible, they may wish to commit to a constant level of subsidies. In their original paper on the benefit of governments committing to rules, Kydland and Prescott (1977) give a somewhat related example in which, without a rule prohibiting it, individuals build on floodplains in the anticipation that ex-post the government will build costly flood defenses.

The existence of multiple sources of subsidy, such as multiple layers of government, and especially in developing country settings, foreign donors and NGOs, may make commitment more difficult. We show that in the extreme case, delays in private investment due to anticipated foreign NGO support may dissipate up to 100% of the private benefits of the transfers, and that if the durable generates positive externalities (e.g., latrines in a setting in which open defecation is common), anticipation of future foreign aid could potentially lower welfare in the home economy. This implies that it may be better for NGOs to subsidize non-durables rather than durables, and provides a potential justification for governments wishing to regulate NGO subsidies for durables.

Anticipated future taxes or regulation, for example, on guns, may encourage current consumption, and if there are delays between announcement and implementation, this effect may be great enough to cause a government which would otherwise prefer taxes or regulation to abandon such a policy. Finally, we discuss political economy implications, noting, for example, that if a political party announces an intent to redistribute land, this may weaken private investment incentives, strengthening the case for land reform.

In a related paper, Kremer and Willis (2016), we consider the case in which infrastructure services can be provided through multiple technologies with different economies of scale. For example, in developing country settings, electricity can be supplied either publicly through the grid or privately through off-grid solar, water can be supplied through municipal systems or wells, and waste can be disposed of through a sewage system or through latrines. We consider a context in which consumers have heterogeneous wealth which lead to differences in individual optimal times to invest in infrastructure. In the absence of commitment, there may be multiple equilibria, including equilibria in which the rich expect that the government will not provide infrastructure, and therefore invest early in private
infrastructure, in turn reducing incentives for the government to invest in infrastructure. To eliminate such potentially welfare-reducing equilibria, the government may wish to commit to install public infrastructure at a specified future time, and if it lacks the ability to do so, it may wish to tax private infrastructure or build public infrastructure early. We show that greater inequality and slower growth both reduce the desirability of public infrastructure, and identify the circumstances in which segregation by wealth is more or less likely to emerge. Optimal policy also depends on the financing options available to the government: imperfect price discrimination may result in a hold-up problem and the use of other second best policies to raise revenue for the investment. We also consider the case when public and private investments are complements (for example, government investments in roads in a particular area may complement private investments in constructing apartment blocks or office buildings).
References


Dean, Mark, and Anja Sautmann. 2014. “Credit constraints and the measurement of time preferences.” Available at SSRN 2423951.


IFAD. 2003. Agricultural Marketing Companies as Sources of Smallholder Credit in Eastern and Southern Africa: Experience, Insights and Potential Donor Role.: Eastern and Southern Africa Division, IFAD.


Appendix A

Appendix to Chapter [1]

A.1 Experimental design
(a) Design of Main Experiment

N=605

Insurance premium: upfront upfront with 30% discount at harvest

Notes: The experimental design randomized 605 farmers (approximately) equally across three treatment groups. All farmers were offered an insurance product; the only thing varied across treatment groups was the premium. In the first group (U1), farmers were required to pay the (“actuarially-fair”) premium upfront, as is standard in insurance contracts. In the second group (U2), premium payment was again required upfront, but farmers received a 30% discount relative to (U1). In the third group (H), the full-priced premium would be deducted from farmers’ revenues at (future) harvest time, including interest charged at the same rate used for the inputs the company supplies on credit (1% per month). Randomization across these treatment groups occurred at the farmer level and was stratified by Field, an administrative unit of neighboring farmers.

(b) Design of Cash Constraints Experiment

N=120

Insurance premium: upfront at harvest

Cash drop: no yes no yes

Notes: The experimental design randomized 120 farmers (approximately) equally across four treatment groups. The design cross-cut two treatments: pay-upfront vs. pay-at-harvest insurance, as in the main experiment, and a cash drop. At the beginning of individual meetings with farmers, those selected to receive cash were given an amount which was slightly larger than the insurance premium, and then at the end of the meetings farmers were offered the insurance product. Randomization across these treatment groups occurred at the farmer level and was stratified by Field, an administrative unit of neighboring farmers.

(c) Design of Present Bias Experiment

N=120

Receive cash or insurance: now in one month

Notes: The experimental design randomized 120 farmers (approximately) equally across two treatment groups. Farmers in both groups were offered a choice between either a cash payment, equal to the “full-priced” insurance premium, or free enrollment in the insurance. Both groups had to make the choice during the meeting, but there was a difference in when it would be delivered. In the first treatment group, the Receive Choice Now group, farmers were told that they would receive their choice immediately. In the second group, the Receive Choice in One Month group, farmers were told that they would receive their choice in one month’s time (the cash payment offered to farmers in this case included an additional month’s interest).

Figure A.1: Experimental design
### A.2 Additional experimental results

#### Table A.1: Main Experiment: Balance Table, Baseline Variables

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<th>Upfront</th>
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<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
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<td>Portion of Income from Cane</td>
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<td>Expected Yield in Bad Year</td>
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<td>Trust Company Field Assistants</td>
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<td>(1.09)</td>
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<td>Trust Company Managers</td>
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</tbody>
</table>

**Notes:** The table presents the baseline balance for the Main Experiment. *Previous Yield* is measured as tons of cane per hectare harvested in the cycle before the intervention. *Man* is a binary indicator equal to one if the person in charge of the sugarcane plot is male. *Own Cow(s)* is a binary indicator equal to one if the household owns any cows. *Portion of Income from Cane* takes value between 1 ("None") to 6 ("All"). *Savings for Sh1,000 (Sh 5,000)* is a binary indicator that equals one if the respondent says she would be able to use household savings to deal with an emergency requiring an expense of Sh 1,000 (Sh 5,000). 1 USD= 95 Sh. *Good Relationship with the Company* is a binary indicator that equals one if the respondent says she has a “good” or “very good” relationship with the company (as opposed to “bad” or “very bad”). *Trust Company Field Assistants* and *Trust Company Managers* are defined on a scale 1 ("Not at all") to 4 ("Completely"). P-values are based on specifications which include field fixed effects (since randomization was stratified at the field level). *p<0.1, **p<0.05, ***p<0.01.
### Table A.2: Main Experiment: Heterogeneous Treatment Effect by Trust

<table>
<thead>
<tr>
<th></th>
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<th>(2)</th>
<th>(3)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Good Relationship with Company</td>
<td>Trust Company Field Assistants</td>
<td>Trust Company Managers</td>
</tr>
<tr>
<td>$X \times \text{Pay At Harvest}$</td>
<td>-0.063 [0.070]</td>
<td>0.021 [0.029]</td>
<td>0.027 [0.028]</td>
</tr>
<tr>
<td>$X$</td>
<td>0.088*** [0.041]</td>
<td>0.035* [0.019]</td>
<td>0.028 [0.017]</td>
</tr>
<tr>
<td>Pay At Harvest</td>
<td>0.726*** [0.035]</td>
<td>0.656*** [0.087]</td>
<td>0.642*** [0.073]</td>
</tr>
<tr>
<td>Mean Y Control</td>
<td>0.052 [0.035]</td>
<td>0.052 [0.087]</td>
<td>0.052 [0.073]</td>
</tr>
<tr>
<td>Mean $X$</td>
<td>0.335 [0.472]</td>
<td>2.885 [1.045]</td>
<td>2.418 [1.099]</td>
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<tr>
<td>S.D. $X$</td>
<td>0.472 [0.472]</td>
<td>1.045 [1.045]</td>
<td>1.099 [1.099]</td>
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<tr>
<td>Observations</td>
<td>568</td>
<td>567</td>
<td>565</td>
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</table>

**Notes:** The table shows heterogeneity of the treatment effect of the pay-at-harvest premium on insurance take-up in the main experiment by different proxies for trust toward the company. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. Treatments U1 (Upfront Payment) and U2 (Upfront Payment with 30% discount) are bundled together as baseline group, as outlined in the pre-analysis plan. The relevant heterogeneity variable is reported in the column title. The notes of Table A.1 provide a definition of the variables used in the heterogeneity analysis. All columns include field fixed effects. *p < 0.1, **p < 0.05, ***p < 0.01.
Table A.3: Main Experiment: Heterogeneous Treatment Effect by Required Rates of Return

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<th>RRR on inputs</th>
<th>RRR 0 to 1 week</th>
<th>RRR 0 to 1 week - RRR 1 to 2 weeks</th>
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<td>X</td>
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<td>Pay At Harvest</td>
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<td>Mean Y Control</td>
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<td>0.052</td>
<td>0.052</td>
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<tr>
<td>Mean X</td>
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<td>S.D. X</td>
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<tr>
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<td>559</td>
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</table>

Notes: The table shows heterogeneity of the treatment effect of the pay-at-harvest premium on insurance take-up in the main experiment, by preferences in Money Earlier or Later experiments. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. Treatments U1 (Upfront Payment) and U2 (Upfront Payment with 30% discount) are bundled together as baseline group. The relevant heterogeneity variable is reported in the column title. These variables come from responses to hypothetical (Becker-DeGroot) choices over earlier or later cash transfers, which give various Required Rates of Returns. 'RRR for inputs' is the required rate of return which would (hypothetically) make farmers indifferent between paying for inputs upfront and having them deducted from harvest revenues. 'RRR 0 to 1 week' is the required rate of return to delay receipt of a cash transfer by one week. 'RRR 0 to 1 week - RRR 1 to 2 weeks' is the difference between the rates of return required to delay receipt of a cash transfer from today to one week from now, and from one week from now to two weeks from now. All columns include field fixed effects. *p<0.1, **p<0.05, ***p<0.01.
**Table A.4: Main Experiment: Harvest Status vs. Wealth & Liquidity Constraint Proxies**

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<td>Observations</td>
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<td>603</td>
<td>559</td>
<td>564</td>
<td>565</td>
<td>562</td>
<td>561</td>
<td>552</td>
</tr>
</tbody>
</table>

**Notes:** This table presents ex-post harvesting behavior by proxies for wealth and liquidity constraints at baseline. The dependent variable is whether the farmer harvested with the company, a binary indicator. The independent variables are as described in Table 1.2. *p<0.1, **p<0.05, ***p<0.01.
Table A.5: Liquidity Constraints Experiment: Balance Table

<table>
<thead>
<tr>
<th></th>
<th>Upfront</th>
<th>Upfront + Cash</th>
<th>Harvest</th>
<th>Harvest + Cash</th>
<th>P-value</th>
<th>P-value</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[U]</td>
<td>[U + Cash]</td>
<td>[H]</td>
<td>[H + Cash]</td>
<td>[H - U]</td>
<td>[Cash - No cash]</td>
<td></td>
</tr>
<tr>
<td>Plot Size</td>
<td>.301</td>
<td>.290</td>
<td>.283</td>
<td>.282</td>
<td>.18</td>
<td>.967</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>(.107)</td>
<td>(.092)</td>
<td>(.121)</td>
<td>(.088)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Yield</td>
<td>54.3</td>
<td>57.8</td>
<td>61.4</td>
<td>54.1</td>
<td>.758</td>
<td>.745</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>(18.4)</td>
<td>(17.9)</td>
<td>(14.8)</td>
<td>(17.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: The table presents baseline balancing for the Liquidity Constraints Experiment. Previous Yield is measured as tons of cane per hectare harvested in the cycle before the intervention. There are fewer covariates for this experiment as it did not have an accompanying survey, so we only have covariates from administrative data. P-values are based on specifications which include field fixed effects (the unit of stratification for the randomization). *p<0.1, **p<0.05, ***p<0.01.
### Table A.6: Present Bias Experiment: Balance Table

<table>
<thead>
<tr>
<th></th>
<th>Receive Now</th>
<th>Receive in One Month</th>
<th>p-value</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plot Size</strong></td>
<td>.328</td>
<td>.292</td>
<td>.093*</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>(.109)</td>
<td>(.105)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td>58.0</td>
<td>57.7</td>
<td>.512</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>(20.1)</td>
<td>(21.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Man</strong></td>
<td>.793</td>
<td>.590</td>
<td>.009***</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(.408)</td>
<td>(.495)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>48.3</td>
<td>47.7</td>
<td>.573</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(12.8)</td>
<td>(11.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Land Cultivated (Acres)</strong></td>
<td>3.47</td>
<td>2.67</td>
<td>.067*</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>(2.92)</td>
<td>(1.72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Any Cow</strong></td>
<td>.844</td>
<td>.852</td>
<td>.987</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(.365)</td>
<td>(.357)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Portion of Income from Cane</strong></td>
<td>3.62</td>
<td>3.32</td>
<td>.193</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(1.12)</td>
<td>(1.945)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Savings for Sh1,000</strong></td>
<td>.327</td>
<td>.295</td>
<td>.526</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(.473)</td>
<td>(.459)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Savings for Sh5,000</strong></td>
<td>.155</td>
<td>.065</td>
<td>.056*</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(.365)</td>
<td>(.249)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected Yield</strong></td>
<td>77.7</td>
<td>87.5</td>
<td>.47</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(65.3)</td>
<td>(38.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected Yield in Good Year</strong></td>
<td>95.1</td>
<td>109</td>
<td>.322</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(70.7)</td>
<td>(48.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected Yield in Bad Year</strong></td>
<td>63.0</td>
<td>69.4</td>
<td>.682</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(61.7)</td>
<td>(32.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Good Relationship with Company</strong></td>
<td>.310</td>
<td>.316</td>
<td>.622</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>(.466)</td>
<td>(.469)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trust Company Field Assistants</strong></td>
<td>3.10</td>
<td>2.83</td>
<td>.315</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(1.02)</td>
<td>(1.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trust Company Managers</strong></td>
<td>2.15</td>
<td>2.11</td>
<td>.32</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(1.13)</td>
<td>(1.03)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** The table presents baseline balancing for the Present Bias Experiment. Previous Yield is measured as tons of cane per hectare harvested in the cycle before the intervention. Man is a binary indicator equal to one if the person in charge of the sugarcane plot is male. Own Cow(s) is a binary indicator equal to one if the household owns any cows. Portion of Income from Cane takes value between 1 (“None”) to 6 (“All”). Savings for Sh 1,000 (Sh 5,000) is a binary indicator that equals one if the respondent says she would be able to use household savings to deal with an emergency requiring an expense of Sh 1,000 (Sh 5,000). 1 USD= 95 Sh. Good Relationship with the Company is a binary indicator that equals one if the respondent says she has a “good” or “very good” relationship with the company (as opposed to “bad” or “very bad”). Trust Company Field Assistants and Trust Company Managers are defined on a scale 1 (“Not at all”) to 4 (“Completely”). P-values are based on specifications which include field fixed effects (since randomization was stratified at the field level). *p<0.1, **p<0.05, ***p<0.01.
### Table A.7: U.S. Crop Insurance Robustness Regression Table

<table>
<thead>
<tr>
<th></th>
<th>DD across states (spring vs. winter wheat)</th>
<th>DD within states (corn vs. winter wheat)</th>
<th>DDD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Post 2012*Treatment</td>
<td>-0.081***</td>
<td>-0.081***</td>
<td>0.044</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.025)</td>
<td>(0.034)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.034)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.031)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.025)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.022)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.015)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.075</td>
<td>0.095</td>
<td>0.147</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.182</td>
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<tr>
<td></td>
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<td>0.132</td>
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<td></td>
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<td>0.190</td>
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<td></td>
<td>0.254</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.265</td>
</tr>
<tr>
<td>Dependent Variable Mean</td>
<td>5.480</td>
<td>5.480</td>
<td>5.653</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>5.653</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.771</td>
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<td></td>
<td></td>
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<td>5.771</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.771</td>
</tr>
<tr>
<td>County*Crop FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Year FE</td>
<td>N</td>
<td>Y</td>
<td>N</td>
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<tr>
<td></td>
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<td></td>
<td>Y</td>
</tr>
<tr>
<td>Crop*Year FE</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>State*Year FE</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>State*Crop Trend</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Observations</td>
<td>5378</td>
<td>5378</td>
<td>8337</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>8337</td>
</tr>
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<td></td>
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<td>10753</td>
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<td></td>
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<td>10753</td>
</tr>
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<td></td>
<td></td>
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<td>10753</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10753</td>
</tr>
</tbody>
</table>

**Notes:** The table provides further details for the triple difference estimates provided in Table 1.6 for the effect of the change in the premium billing date for U.S. Federal Crop Insurance on insurance adoption. Columns (1)-(4) give the difference-in-differences effects which go into the triple difference estimate and columns (5)-(8) present robustness checks for the estimate. Data are at the county-crop-year level. The dependent variable is the inverse hyperbolic sine ($\approx \log(2) + \log(x)$) of the number of policies sold in the county-crop-year. Treatment is a binary indicator equal to one if the billing date for the county-crop is earlier than the harvesting period from 2012 onward. $AvgPlotSize$ is the average plot size in the county. Columns (1) and (2) report a difference-in-differences estimate, which compares insurance take-up for wheat across states: spring wheat states (for which the premium moved before harvest) vs. winter wheat states (for which the premium did not move before harvest time). Columns (3) and (4) report an alternative difference-in-differences estimate, which compares insurance take-up across crops within (winter wheat) states: corn (treated) vs. winter wheat (not treated). Columns (5)-(8) report robustness of the DDD estimate to the inclusion of fixed effects. Standard errors clustered by crop-state. *p<0.1, **p<0.05, ***p<0.01.
A.3 Risk profile of the insurance product

Figure A.2: Simulation of insurance payout based on historical data

Notes: The diagram shows what the proportion of farmers who would have received a positive payout from the insurance in previous years, and gives a sense of the basis risk of the insurance product. The numbers are based on simulations using historical administrative data on yields. The total bar height is the proportion of people who would have received an insurance payout under a single trigger design. This is then broken into those who still receive a payout when the second, area yield based trigger added, and those who do not. We do not have data for the years 2006-2011.
Appendix B

Appendix to Chapter 2

B.1 Proofs and derivations

B.1.1 Background

States Each period t, which we will typically think of as one month, has a set of states $S_t$, corresponding to different income realizations. The probability distribution over states is assumed to be memoryless, so that $P(s_t = s)$ may depend on t, but is independent of the history at time t, $(s_i)_{i < t}$. We assume that the probability distribution of outcomes is cyclical, of period N, so that $S_t = S_{t+N}$ and $P(s_t = s) = P(s_{t+N} = s)$ $\forall t, s$.

Dynamic programming problem

$V_t(x_t)$, the time t self’s value function, is the solution to the following recursive dynamic programming problem:

$$V_t(x_t) = \max_{c_t} u(c_t) + \beta \delta \mathbb{E}_s [V_{t+1}^c(x_{t+1})]$$

(B.1)

subject to, for all $i \geq 0$,

$$x_{t+i+1} = R(x_{t+i} - c_{t+i}) + y_{t+i+1}$$

$$x_{t+i} - c_{t+i} \geq 0$$

where $V_t^c(x_t)$, the continuation value function, is the solution to equation (B.1) but with
\[ \beta = 1, \text{i.e.} \]

\[ V_t^c(x_t) = \max_{c_t} u(c_t) + \delta E_s[V_{t+1}^c(x_{t+1})] \quad (B.2) \]

Because of the cyclical nature of the setup, the functions \( V_t(.) = V_{t+N}(.) \) and \( V_t^c(.) = V_{t+N}^c(.) \) exist for all \( t \).

**Proof of Lemma 1**

**Part (1)** Since \( V^c \) is the solution to a recursive dynamic programming problem with convex flow payoffs, concave intertemporal technology, and convex choice space, theorem 9.6 and 9.8 in Stokey and Lucas (1989) tell us that \( V^c \) exists and is strictly concave. To expand further, the proofs, which are similar in method to subsequent proofs below, are as follows.

**Existence & Uniqueness.** Blackwell’s sufficient conditions hold for the Bellman operator mapping \( V_{t+1}^c \) to \( V_t^c \): monotonicity is clear; discounting follows by the assumption that \( \delta R < 1 \) - taking \( a + a \) is mapped to \( V_{t+1}^c + \delta Ra \); the flow payoff \( u(c_t) \) is bounded and continuous by assumption; compactness of the state-space is problematic, but given \( \delta R < 1 \) the stock of cash-on-hand will not amass indefinitely, so we can bound the state space with little concern Stokey and Lucas (1989) provide more formal, technical methods to deal with the problem. Since it is not the focus of the paper, we do not go into more details.). Thus, the Bellman operator is a contraction mapping, and iterating this operator implies the mapping from \( V_{t+N}^c \) to \( V_t^c \) is a contraction mapping also. \( V_t^c \) is a fixed point of this mapping, and thus exists and is unique by the contraction mapping theorem.

**Concavity.** Assume \( V_{t+N}^c \) is concave. Then, \( V_{t+N-1}^c \) is strictly concave, since the utility function is concave and the state space correspondence is convex, by standard argument (take \( x_{\theta} = \theta x_a + (1 - \theta)x_b \), expand out the definition of \( V_{t+N-1}^c(x_{\theta}) \) and use the concavity of \( V_{t+N-1}^c \) and the strict concavity of \( u(.) \)). Iterating this argument, we thus have that \( V_t^c \) is concave. Therefore, since there is a unique fixed point of the contraction mapping from \( V_{t+N}^c \) to \( V_t^c \), that fixed point must be concave (since we will converge to the fixed point by iterating from any starting function; start from a concave function).
Part (2)

\[V_t(x_t) = \max_c u(c) + \beta \delta \mathbb{E}[V^c_{t+1}(R(x_t - c) + y_{t+1})]\]

Since \(V^c_{t+1}\) is concave, this is a convex problem, and the solution satisfies:

\[u'(c_t) = \max\{\beta \delta \mathbb{E}[V^c_{t+1}(R(x_t - c_t) + y_{t+1})], u'(x_t)\}\]

Define \(a(x_t) = x_t - c(x_t)\). Take \(x'_t > x_t\), and suppose \(a'_t(x'_t) < a_t(x_t)\). Since \(a'_t \geq 0\), we must have \(a_t > 0\). Now, \(a'_t < a_t\) implies \(c'_t > c_t\), so \(u'(c'_t) < u'(c_t) = \beta \delta \mathbb{E}[V^c(Ra_t + y)] \leq \beta \delta \mathbb{E}[V^c(Ra'_t + y)] \leq u'(c'_t)\). Contradiction. Thus \(a'_t(x_t) \geq 0\). Since \(V^c(Ra_t + y_{t+1}) = u'(c_{t+1})\), the concavity of \(V^c\) also implies that \(c_{t+1}\) is increasing in \(x_t\) in the sense of first order stochastic dominance.

Part (3) The proof relies on showing that the mapping from \(V^c_{t+1}\) to \(V^c_t\) conserves convexity, \(\forall t \in \mathbb{R}^+\). Then the proof follows as in 1 above: \(V^c_t\) is the fixed point of a contraction mapping which conserves convexity of the first derivative, hence \(V^c_t\) must be convex. We provide two methods to show that the mapping preserves convexity, the first of which is based on Deaton and Laroque (1992), and the second of which assumes \(V^c_{t+1}\) exists and gives more intuition for where the convexity is coming from.

Version 1 Suppose \(V^c_{t+1}\) is convex.

\[V^c_t(x_t) = u'(c_t) = \max\{\delta \mathbb{E}[V^c_{t+1}(R(x_t - c_t) + y_{t+1})], u'(x_t)\}\]

Define \(G\) by \(G(q, x) = \delta \mathbb{E}[V^c_{t+1}(R(x_t - u'^{-1}(q) + y_{t+1})]\).

\(G\) is convex in \(q\) and \(x\): \(u'\) is convex and strictly decreasing, so \(u'^{-1}\) is convex (and so \(-u'^{-1}\) is concave); \(V^c_{t+1}\) is convex and decreasing, so \(V^c_{t+1}(R(x_t - u'^{-1}(q)) + y_{t+1})\) convex in \(q\) and \(x\) (since \(f\) convex decreasing and \(g\) concave \(\Rightarrow f \circ g\) convex; expectation is a linear operator (and hence preserves convexity).

Now \(V_t' = \max[G(V^c_t(x_t), x_t), u'(x_t)]\), or, defining \(H(q, x) = \max\{G(q, x) - q, u'(x) -\)
Thus, by the convexity of $H$, $H$ is convex in $q$ and $x$. Take any two $x$ and $x'$ and $\lambda \in (0,1)$. Then $H(V^c_t(x), x) = H(V^c_t(x'), x') = 0$. Thus, by the convexity of $H$, $H(\lambda V^c_t(x) + (1-\lambda) V^c_t(x'), \lambda x + (1-\lambda)x') \leq 0$. Now, since $H$ is decreasing in $q$, that means that $V^c_t(\lambda x + (1-\lambda)x') < \lambda V^c_t(x) + (1-\lambda)V^c_t(x')$, i.e. $V^c_t$ is convex.

**Version 2** Suppose $V^{c'}_{t+1}$ is convex.

$$V^c_t(x_t) = \max_c u(c) + \delta \mathbb{E}[V^c_{t+1}(R(x_t - c) + y_{t+1})]$$

$$\Rightarrow V^c_t(x_t) = \delta \mathbb{E}V^{c'}_{t+1}(x_{t+1}) + c_t(x_t)\mu_t$$

$$\Rightarrow V''^c_t(x_t) = \delta \mathbb{E}V^{c''}_{t+1}(1 - c_t(x_t)) + c''_t(x_t)\mu_t + c'_t(x_t)\mu'_t$$

$$\Rightarrow V'''^c_t(x_t) = \delta \mathbb{E}V^{c'''}_{t+1}(1 - c_t(x_t))^2 - \delta \mathbb{E}V^{c'''}_{t+1}c''_t(x_t) + c'''_t(x_t)\mu_t + 2c''_t(x_t)\mu_t' + c'_t(x_t)\mu'_t$$

Now, the first order condition is

$$u'(c_t) = \beta \delta \mathbb{E}V^{c'}_{t+1}(x_{t+1}) + \mu_t$$

Consider first the case where $\mu_t > 0$. Then $c(x_t) = x_t$ and $\nu^{c'}_t(x_t) = u'(c(x_t))$. So $\nu^{c'}_t(x_t) = u'(x_t)$ thus $\nu^{c'''}_t(x_t) = u'''(x_t) > 0$.

So, assume $\mu = 0$. Differentiating the FOC wrt $x$ gives

$$u''(c(x_t))c'(x_t) = \beta \delta \mathbb{E}V^{c''}_{t+1}(1 - c'(x_t))$$

$$\Rightarrow c'(x_t) = \frac{\beta \delta \mathbb{E}V^{c''}_{t+1}(x_t)}{\beta \delta \mathbb{E}V^{c''}_{t+1}(x_t) + u''(c(x_t))}$$

Differentiating again with respect to $w$ gives

$$c''(x_t) = \frac{u''(c(x_t))(\beta \delta \mathbb{E}V^{c''}_{t+1}(1 - c'(x_t)) + u''')}{(\beta \delta \mathbb{E}V^{c''}_{t+1} + u''')^2}$$

$$= \frac{u'' \beta \delta \mathbb{E}V^{c''}_{t+1}(1 - c'(x_t) - u'''c' \beta \delta \mathbb{E}V^{c''}_{t+1}}{(\beta \delta \mathbb{E}V^{c''}_{t+1} + u''')^2}$$
Substituting in to the equation for \( V_{c''} \) gives:

\[
V_{c''}(x_t) = \delta R^3 \mathbb{E} V_{c''}^c \left( \frac{u''}{\beta \delta R^2 \mathbb{E} V_{c''}^c + u''} \right)^2 - \delta R^2 \mathbb{E} V_{c''}^c \left( 1 - c' \right) - u'' c' \beta \delta R^2 \mathbb{E} V_{c''}^c \frac{1}{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')^2}
\]

\[
= \frac{u''^2 \delta R^3 \mathbb{E} V_{c''}^c (\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')} - \beta \delta^2 R^5 u''^2 \mathbb{E} V_{c''}^c \frac{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')}^3}{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')^3}
\]

\[
+ \frac{\beta \delta^2 R^4 u'' c' (\mathbb{E} V_{c''}^c)^2 (\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')}^3}{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')^3}
\]

\[
= \frac{u''^3 \delta R^3 \mathbb{E} V_{c''}^c}{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')^3} + \frac{\beta \delta^2 R^4 u'' c' (\mathbb{E} V_{c''}^c)^2}{(\beta \delta R^2 \mathbb{E} V_{c''}^c + u'')^2}
\]

\[\geq 0\]

**B.1.2 Insurance with perfect enforcement**

**Proof of Proposition 1**

In the following, denote by \( a_t \) the assets held at the end of period \( t \), so that \( a_t = x_t - c_t \).

Suppose farmers have zero probability of being liquidity constrained before the next harvest, when they buy pay-upfront insurance. Denote their (state-dependent) path of assets until harvest by \((a^U_t)_{t < H}\), given that they have purchased pay-upfront insurance. By the assumption that the farmers will not be liquidity constrained before harvest, \( a^U_t > 0 \) \( \forall t < H \) and for all histories \((s_i)_{i \leq t}\). Now, suppose instead of pay-upfront insurance, they had been offered pay-at-harvest insurance. If they invest the money they would have spent on pay-upfront insurance in assets instead, so \( a^H_t(s) = a^U_t(s) + R^H_t \), then they can pay the pay-at-harvest premium at harvest time and have the same consumption path as in the case of pay-upfront, so they must be at least as well off. Similarly, suppose they optimally hold \((a^D_t)_{t < H}\) in the pay-at-harvest case. If instead offered upfront insurance, they can use some of these assets to instead buy insurance, so that \( a^U_t(s) = a^D_t(s) - R^{-H-t} \). Since, by assumption \( a^U_t(s) > 0 \), doing so they can again follow the same consumption path as in the case of pay-at-harvest insurance, so pay-upfront insurance is at least as good as at-harvest insurance. Thus the farmer is indifferent between pay-upfront and pay-at-harvest insurance.

To first order, at time 0 the net benefit of pay-at-harvest insurance is \( \beta \delta H \mathbb{E}(Iu'(c_H)) - \)
\(\beta \delta^H \mathbb{E}(u'(c_H))\), and of pay-upfront is \(\beta \delta^H \mathbb{E}(Iu'(c_H)) - \beta \delta^H \mathbb{E}(u'(c_H)) - R^{-H} \lambda_0^H\) (note that the envelope theorem applies because, in the sequence problem, the insurance payout \(I\) does not enter any constraints before time \(H\). This would no longer be the case if borrowing constraints were endogenous to next period’s income). Thus the difference between the two is \(R^{-H} \lambda_0^H\). Consider a pay-upfront insurance product which had premium \((1 - \frac{\lambda_0^H}{u'(c_0)}) R^{-H}\).

The net benefit would be

\[
\beta \delta^H \mathbb{E}(Iu'(c_H)) - (1 - \frac{\lambda_0^H}{u'(c_0)}) R^{-H} u'(c_0)
\]

\[
= \beta \delta^H \mathbb{E}(Iu'(c_H)) - (u'(c_0) - \lambda_0^H) R^{-H}
\]

\[
= \beta \delta^H \mathbb{E}(Iu'(c_H)) - \beta \delta^H \mathbb{E}(u'(c_H))
\]

This is the net benefit of pay-at-harvest insurance.

Proof of Proposition 2

The value of the pay-at-harvest insurance is \(\beta \delta^H \mathbb{E}(V_H^c(w_H + y_H + I - 1)) - \beta \delta^H \mathbb{E}(V_H^c(w_H + y_H))\). How this changes wrt \(x_0\) is given by:

\[
\frac{d}{dx_0} \left[ \beta \delta^H \mathbb{E}(V_H^c(w_H + y_H + I - 1)) - \beta \delta^H \mathbb{E}(V_H^c(w_H + y_H)) \right]
\]

\[
= \frac{d w_H}{dx_0} \beta \delta^H \left[ \mathbb{E}(V_H^c(w_H + y_H + I - 1)) - \mathbb{E}(V_H^c(w_H + y_H)) \right]
\]

Now, \(\frac{d w_H}{dx_0} \geq 0\), by iterating lemma 1 back from period \(H\) to period 0. Also, \(y_H + I - 1\) strictly second order stochastic dominates \(y_H\) by assumption, and \(V_H^{c'}\) is strictly convex \((V_H^{c''} > 0\) by lemma 1), so \(\mathbb{E}(V_H^{c'}(w_H + y_H + I - 1)) - \mathbb{E}(V_H^{c'}(w_H + y_H)) < 0\). Thus, the value of pay-at-harvest insurance is decreasing with wealth. Now, the reduction in net utility from insurance arising from upfront premium payment is \(R^{-H} \lambda_0^H\), by proposition 1. By lemma 2.1, this is also decreasing in wealth.

If the farmer is certain to be liquidity constrained before the next harvest, when starting with \(x_0\), then his wealth at the start of the next harvest \(w_H\) will be the same as if he started with \(x_0'\), for any \(x_0' < x_0\). This is because wealth in the next period is decreasing in wealth.
this period, so by the time the farmer has exhausted his wealth starting at $x_0$, he will also have exhausted his wealth starting at $x'_0$. Now, since the income process is memoryless, once the agent has exhausted his wealth, his distribution of wealth at the next harvest is the same, irrespective of his history. Thus the farmer has the same value of deductible insurance, regardless of whether he starts with $x_0$ or $x'_0$, but the extra cost of the intertemporal transfer in the upfront insurance starting from $x'_0$ means that the farmer has a lower value of upfront insurance.

**Proof of Proposition 3**

The proof is essentially the same as that of the second half of proposition 2.1.

**B.1.3 Insurance with imperfect enforcement**

**Outside option** $o(s_H, w_H)$

If the farmer chooses to sell to the company he receives profits $y(s)$ (comprising revenues minus a deduction for inputs provided on credit) plus any insurance payout $I(s)$, minus the insurance premium in the case of pay-at-harvest insurance. He also receives continuation value $r_C(s)$ from the relationship with the company, which is possibly state dependent. If he chooses to side sell, he receives outside option $o(s)$ \(^1\) and saves the deductions for inputs provided on credit and for the deductible insurance premium, but loses the continuation value and any insurance payout. We abstract from any impact of insurance on the choice of input supply, since, as argued before, the choice set is limited, the double trigger design of the insurance was chosen to minimize moral hazard, and, as reported below, we see no evidence of moral hazard in the experimental data.

\(^1\)We don’t have detailed information on payments under side selling, but anecdotal evidence suggests that side sellers pay significantly less than the contract company, so a natural assumption would be that $o(s) = ay(s)$, where $a < 1$.
**Proof of Proposition 4**

Consider the decisions to sell to the company (i.e. not to side-sell). Denote the indicator functions for these decisions by $D$, with a subscript representing whether or not the insurer has already defaulted on the insurance contract, and a supercript denoting whether the farmer holds insurance, and if so the type of the insurance.

If the insurer has not already defaulted, they are:

- $D_I = \mathbb{I}[c_D \geq 0]$ without insurance
- $D_I^U = \mathbb{I}[(1 - p_{s_2})Iu'(c_H) + c_D \geq 0]$ with pay-upfront insurance
- $D_I^D = \mathbb{I}[(1 - p_{s_2})Iu'(c_H) + c_D \geq u'(c_H)]$ with pay-at-harvest insurance

If the insurer has already defaulted, they are:

- $D_D = \mathbb{I}[c_D \geq 0]$ without insurance
- $D_D^U = \mathbb{I}[c_D \geq 0]$ with pay-upfront insurance
- $D_D^D = \mathbb{I}[c_D \geq u'(c_H)]$ with pay-at-harvest insurance

Since $(1 - p_{s_2})I(s)u'(c_H(s))$ and $u'(c_H(s))$ are non-negative, and $Iu'(c_H)$ and $(1 - 1)u'(c_H)$ are larger when yields are low, the results follow.

**Proof of Proposition 5**

Consider the net benefit of insurance, which is the benefit of the payout minus the cost of the premium payout. With perfect enforcement, we know that at-harvest insurance is equivalent to upfront insurance with a percentage price cut of $\frac{\lambda_H}{u'(c_0)}$. Denote the net benefit of such an upfront insurance product by $S_{IU}$, and by $S_D$ the net benefit of at-harvest
insurance. Thus:

\[
\mathbb{E}[S_D - S_U] = (1 - p_s)(\sum_{d^U, d^D \in \{0,1\}} P[D^U_I = d^U, D^D_I = d^D] \mathbb{E}[S_D - S_U|D^U_I = d^U, D^D_I = d^D])
\]

\[
+ p_s(\sum_{d^U, d^D \in \{0,1\}} P[D^U_D = d^U, D^D_D = d^D] \mathbb{E}[S_D - S_U|D^U_D = d^U, D^D_D = d^D])
\]

Now, \(D^U_D \geq D^D_D\) and \(D^U_I \geq D^D_I\). Also

\[
\mathbb{E}[S_D - S_U|D^U_I = 1, D^D_I = 1] = \mathbb{E}[S_D - S_U|D^U_D = 1, D^D_D = 1] = 0
\]

This leaves the cases where both default, or where pay-at-harvest defaults and pay-upfront doesn’t. Conditional on \(D^U_I = 0, D^D_I = 0, D^U_D = 0, D^D_D = 0\), we have

\[
S_D - S_U = \beta \delta^H u'(c_H)
\]

When \(D^U_I = 1, D^D_I = 0\), then

\[
S_D - S_U = \beta \delta^H (u'(c_H) - (1 - p_s)Iu'(c_H) - c_D) \leq \beta \delta^H u'(c_H)
\]

Thus:

\[
\mathbb{E}[S_D - S_U] \leq (1 - p_s)(P[D^U_I = D^D_I = 0] + P[D^U_I = 1, D^D_I = 0]) \beta \delta^H E[u'(c_H)|D^U_I = 0]
\]

\[
+ p_s(\sum_{d^U, d^D \in \{0,1\}} P[D^U_D = D^D_D = 0] + P[D^U_D = 1, D^D_D = 0]) \beta \delta^H E[u'(c_H)|D^U_D = 0]
\]

with strict inequality iff \(P[D^U_I = 1, D^D_I = 0] > 0\). The right hand side can be rewritten to give:

\[
\Leftrightarrow \mathbb{E}[S_D - S_U] \leq (1 - p_s)P[D^U_I = 0] \beta \delta^H E[u'(c_H)|D^U_I = 0]
\]

\[
+ p_s P[D^D_D = 0] \beta \delta^H E[u'(c_H)|D^D_D = 0]
\]

\[
\Leftrightarrow \mathbb{E}[S_D - S_U] \leq P(\text{side-sell with at-harvest}) \beta \delta^H E(u'(c_H)|\text{side-sell with at-harvest})
\]

We compare this to the surplus effect on the net benefit of upfront insurance of a further proportional price reduction of \(P(\text{side-sell with at-harvest}) \frac{E(u'(c_H)|\text{side-sell with at-harvest})}{E(u'(c_H))} \).
which is:

\[ P(\text{side-sell with at-harvest}) \frac{\mathbb{E}(u'(c_H)|\text{side-sell with at-harvest})}{\mathbb{E}(u'(c_H))} \mathbb{E}(u'(c_H)) \]

\[ = P(\text{side-sell with at-harvest}) \mathbb{E}(u'(c_H)|\text{side-sell with at-harvest}) \]
Appendix C

Appendix to Chapter 3

C.1 Intuition in figures

As the marginal utility of consumption falls, purchasing infrastructure services becomes more attractive. This figure shows the case of a homogeneous population for whom public infrastructure is the first best.

Figure C.1: Optimal purchase time with homogeneous population
Figure C.2: Optimal purchase time with heterogeneous population, single equilibrium case

Once the population is heterogeneous, some want infrastructure before others. This figure shows the simple case, when the optimal time to build public infrastructure is before the optimal time for the rich to buy the private durable. In this case there is only one equilibrium.
Figure C.3: Optimal purchase time with heterogeneous population, multiple equilibrium case

This figure shows the difficult case, in which there can be multiple equilibrium. The optimal time to build public infrastructure is after the optimal time for the rich to buy the private durable. If the rich wait for public infrastructure, it will be built. If they do not, instead buying the private durable at their private optimal time, it may not be. If the government is able to commit to building the public infrastructure, the private durable equilibrium disappears. If they are not able to, they may build the public infrastructure early, before the optimal time for the rich to buy the private durable, or they may tax the private durable, pushing the private optimal time later. Finally, there is a potential hold up problem. The ex-post willingness to pay of the rich, having waited past their optimal time for the private durable, is higher than their ex-ante willingness to pay.
Appendix D

Appendix to Chapter 4

D.1 Consumer problem and production side

The consumer faces interest rate $r$, has initial wealth plus net present value of future income $w_0$, and chooses both consumption path $(c_s)_{s \geq 0}$ and when to purchase infrastructure, $t$. Their problem is thus:

$$v(w_0) = \max_{(c_s)_{s \geq 0}, t} \int_0^\infty e^{-\rho s} u(c_s)ds + \frac{\mu}{\rho} e^{-\rho t}$$

s.t. $$\dot{w}(s) = rw(s) - c(s) - p(t)\delta[s = t]$$

$$w_0 = \int_0^\infty e^{-rs} c_s ds + p(t)e^{-rt}$$

We can also add in the production side. Firms maximize profits:

$$\pi(t) = F(K, A(t)L) - W(t)L - r(t)K(t)$$

Where $F$ is a constant returns to scale production function, $A(t) = A(0)e^{gt}$ is technology, $W(t)$ is the wage, $L$ is the population, and $K(t)$ is capital. Define $k(t) = K(t)/A(t)L$ and $f(k) = F(k,1)$, then firms rent capital until $f'(k(t)) = r(t)$. Ignoring infrastructure
investment for the moment, this results in the dynamic system:

\[
\frac{\dot{c}(t)}{c(t)} = f'(k(t)) - \frac{\rho}{\theta} \\
\dot{k}(t) = f(k(t)) - c(t)/A(t) - gk(t)
\]

We assume we are in the steady state of this system, in which \(\frac{\dot{c}(t)}{c(t)} = g\) and \(\dot{k}(t) = 0\). We assume that capital can be freely transformed into the durable. Strictly the durable purchase means that we are not in the steady state of the Ramsey model, since there will be a negative shock to capital at the time of investment in the durable. This shock will result in variation of the interest rate around it, and an anticipatory build-up of capital. However, we make the simplifying assumption that \(p\) is sufficiently small compared to \(K(t)\) that we can assume that \(F_K(K(t), A(t)L) \approx F_K(K(t) - p(t), A(t)L)\), and so that we can ignore variation in the interest rate and assume that we are in the steady state of the Ramsey model.

Returning to the consumption problem, we know, because of the constant interest rate, that \(c_s = c_0e^{gs}\). Suppose the individual faces price path \(p(s)\) and decides to buy at time \(t\), while others buy at time \(t'\) and the subsidy is paid for by lump-sum taxation. Then, we have:

\[
w_0 = \int_0^\infty c_0e^{-rs}ds + p(t)e^{-rt} + s(t')e^{-rt'}
\]

\[
= c_0 \int_0^\infty e^{(g-r)s}ds + p(t)e^{-rt} + s(t')e^{-rt'}
\]

\[
= c_0/(r-g) + p(t)e^{-rt} + s(t')e^{-rt'}
\]

\[\Rightarrow c_0 = (r-g)(w_0 - p(t)e^{-rt} - s(t')e^{-rt'})
\]

In a symmetric equilibrium, this will result in:

\[c_0 = (r-g)(w_0 - pe^{-rt})\]

Thus, assuming the individual follows the optimal consumption path, they face the
following maximization problem:

\[
\max_t \int u((r-g)(w_0 - p(t)e^{-rt} - s(t')e^{-rt'})e^{st})e^{-\rho t} ds + \frac{u_L}{\rho} e^{-\rho t}
\]

\[
= \max_t ((r-g)(w_0 - p(t)e^{-rt} - s(t')e^{-rt'}))^{1-\theta} \int e^{((1-\theta)g-\rho)s} / (1 - \theta) ds + \frac{u_L}{\rho} e^{-\rho t}
\]

\[
= \max_t - \frac{((r-g)(w_0 - p(t)e^{-rt} - s(t')e^{-rt'}))^{1-\theta}}{(1 - \theta)(g - \rho)(1 - \theta)} + \frac{u_L}{\rho} e^{-\rho t}
\]

This gives the first order condition:

\[
(w_0 - p(t)e^{-rt} - s(t')e^{-rt'})^{-\theta} (rp(t)e^{-rt} - p'(t)e^{-rt}) - u_L e^{-\rho t} = 0
\]

\[
\Rightarrow u'(c_0)(rp(t)e^{-rt} - p'(t)e^{-rt}) = u_L e^{-\rho t}
\]

Which is the same FOC arrived at in the main text using the envelope condition.