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A Review of the Evidence Linking Child Stunting to Economic Outcomes*

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Abstract

To understand the full impact of stunting in childhood it is important to consider the long run effects of undernutrition on the outcomes of adults who were affected in early life. Focusing on the costs of stunting provides a means of evaluating the economic case for investing in childhood nutrition. We review the literature on the association between stunting and undernutrition in childhood and economic outcomes in adulthood. At the national level, we also evaluate the evidence linking stunting to economic growth. Throughout, we consider RCTs, quasi-experimental approaches, and observational studies. Long-run evaluations of two randomized nutrition interventions indicate substantial returns to the programs (a 25% and 46% increase in wages for those affected as children). Cost-benefit analyses of nutrition interventions report a median return of 17.9:1 per child. Assessing the wage premium associated with adult height, we find that a 1 centimeter increase in stature is associated with a 4% increase in wages for men and a 6% increase in wages for women in our preferred set of studies which attempt to address unobserved confounding and measurement error. In contrast, the evidence on the association between economic growth on stunting is mixed. Countries with high rates of stunting, such as those in South Asia and sub-Saharan Africa, should scale up policies and programmes aiming to reduce child undernutrition as cost-beneficial investments that which expand the economic opportunities of their children, better allowing them and their countries to reach their full potential. However, economic growth as a policy will only be effective at reducing the prevalence of stunting when increases in national income are directed at improving the diets of children, addressing gender inequalities and strengthening the status of women, improving sanitation, and reducing poverty and inequities.

JEL Classification: *I10, J10*

Keywords: *Stunting, Productivity, Economic Growth, Early Childhood Investment*

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1 Introduction

There is growing interest in the long run impact of childhood conditions among both researchers and policy makers, in part because there is mounting evidence that early life environments impact on a variety of later life outcomes, including health, nutrition, cognition, and mortality. In low and middle income countries the role of childhood growth restriction and stunting has been attracting particular attention (Smith and Haddad, 2015), which is likely a reflection of the fact that indicators of progress to address child undernutrition were included in the Millennium Development Goals (Oruamabo, 2015), their inclusion in the post-2015 Sustainable Development Goals, and the sub-optimal progress in many countries at achieving improvements in child nutrition (Stevens et al., 2012). For example, in South Asia, rates of childhood stunting remain at 38% despite rapid economic growth in some countries such as India (Haddad, 2011). Advocacy for inclusion of child nutrition targets in the Sustainable Development Goals appeals to an emerging understanding of the consequences of failure to address early life undernutrition and the consequent impact of restriction of growth and developmental potential on both individuals and society as a whole. Incorporating markers of child nutrition into the new round of global development goals could prove beneficial in lowering stunting prevalence, not least by presenting an opportunity to build commitments to addressing this issue as part of a global policy platform (Smith and Haddad, 2015). However, despite the policy focus on reducing stunting, there remain areas where the evidence is sparse. In particular, while there is an evidence base linking stunting to short run outcomes in childhood such as cognition and educational attainment, evidence on the long run effects is more limited. For example, cost-benefit analyses of nutrition interventions and reviews of potential wage losses associated with early life undernutrition tend to rely on calibrated estimates of returns to schooling, and the fact that children who are stunted have lower levels of educational attainment, rather than measures of the direct association between stunting and adult outcomes (Fink et al., 2016).

It is important for policy makers to have accurate information on the long-run economic benefits associated with investments in child nutrition, particularly in contexts in which government resources are scarce or there is a high opportunity cost of funds due to attractive investment options in other domains such as education and infrastructure. If high-quality evidence demonstrates economic returns to reducing child stunting, this will make it easier to compare returns on investment with these alternatives on the basis of formal cost-benefit analyses (Qureshy et al., 2013).

The aim of this paper is to address this knowledge gap by providing a comprehensive review of the evidence on the long-run economic impact of child undernutrition, mostly as measured by the direct association between stunting and later life outcomes. While there are other overview papers dealing with child undernutrition, they either do not focus on long-run economic outcomes, or else focus on a subset of the literature. In contrast, we provide a comprehensive review of intervention studies that track cohorts of individuals who received nutritional supplements in early childhood into adulthood, but also cover prospective cohorts where we have data on the same individuals across the life course (some of whom may have been stunted, but where there was no randomized intervention), papers which adopt a quasi-experimental approach relying on natural experiments (which affected nutritional intake in childhood), and observational cross-sectional data where we are able to measure the association between adult height and adult wages. After reviewing the individual-level correlates of stunting, we also discuss cost-benefit analyses of nutritional interventions, and the aggregate country-level relationship between stunting and economic growth. This is relevant because there may be spillover effects of child undernutrition on economies and society that would not be captured by simply adding up individual-level estimates. In addition, examining whether economic growth can be expected to successfully reduce stunting prevalence can provide an indication as to which channels are best targeted to achieve childhood nutrition targets.

The goal of reviewing these estimates is to support policy-makers in evaluating whether nutrition programs are an efficient use of public funds, and where programs for reducing child stunting rank in terms of return on investment. We conclude the paper with a discussion on the implications of our findings for countries facing high prevalence of child undernutrition.

2 Methods

We conducted a literature search for studies published up to July 2015 that examined whether childhood stunting or other measures of undernutrition were associated with economic outcomes in later life. We excluded studies that examined outcomes in childhood (such as education or test scores) or other non-economic outcomes in adulthood (such as health or cognition). We also restricted our attention to papers that used measures or proxies of undernutrition in childhood as exposures, rather than broad measures of early life conditions such as socioeconomic status or health. We did not include studies that only examined exposures in utero as the literature focusing on these areas has been covered elsewhere (Almond and Currie, 2011a,b; Currie and Vogl, 2013; Delaney and Smith, 2012). We conducted our literature search using the Pubmed and

Econlit databases for keywords in abstracts and titles related to the following economic outcomes (wages, income, salary, pay, earnings, productivity, capital, resources, work, employment, industry, hours worked, occupation, labor, sector, job, socioeconomic, savings, economic, returns, make ends meet, welfare, poverty) and the following measures of childhood undernutrition (stunting, child development, growth retardation, growth trajectory, linear growth, linear growth retardation, growth faltering, growth failure, early life growth failure, child undernutrition, child malnutrition, child nutrition). Search terms are shown in Table 1.

Table 1: Search Terms

Databases searched:
PubMed, Econlit.
Key terms: (wages, income, salary, pay, earnings, productivity, capital, resources, work, employment, industry, hours worked, occupation, labor, labour, sector, job, socioeconomic, savings, economic, returns, make ends meet, welfare, poverty)
And: (stunting, child development, growth retardation, growth trajectory, linear growth, linear growth retardation, growth faltering, growth failure, early life growth failure, child undernutrition, child malnutrition, child nutrition)

Combinations and variations of these keywords were also included in the search using the wildcard operator, and we supplemented the search using the references of the studies we located, as well as the citations of these studies obtained from Google Scholar. We identified 29 key summary papers that provided conceptual or background material related to research on the long run economic effects of childhood stunting or undernutrition. We also identified 21 prospective studies (some of which were based on similar underlying data and some of which contained data from more than a single country) from 14 cohort studies and 7 intervention studies, along with 5 natural experiment papers which retrospectively tied individuals to periods of adversity argued to be related to undernutrition in early life. We supplemented these prospective studies and review papers with cross-sectional research that examined the relationship between adult height and adult economic outcomes. We identified 10 quasi-experimental instrumental variables papers in this area in which we were able to extract a coefficient measuring the association between a 1 centimeter change in height and the percentage change in wages. A further 17 studies used linear regression to examine the wage premium related to height but did not attempt to adjust for unobserved confounding or measurement error.

We identified another 30 studies that provided evidence on the relationship between adult height and other adult economic outcomes.

An important methodological issue for this literature is how child undernutrition is measured. The papers we consider can be roughly divided into three categories. In the first set, undernutrition in early life is measured contemporaneously during childhood, almost always using height-for-age, and then, in a subsequent iteration of the study, the adult outcomes of these children is observed. Low height-for-age is generally used to indicate failure to reach growth potential due to inadequate net nutrition, and is often dichotomized into an indicator for stunting (being 2 standard deviations or more below the reference height-for-age, typically the World Health Organization growth standard) (Corsi et al., 2011). In the second set, we observe the adult outcomes of individuals for whom we do not have a direct measure of early life undernutrition, but we know that some of these individuals were exposed to an event such as a famine during their childhood. In the third set, we observe the adult outcomes of individuals and their adult heights. In order to emphasize the importance of taking into account how childhood undernutrition was measured, in Tables 3, 4 and 5, we note the exposure used in each study in column 6. In Tables 6 and 7 we note the age at which the exposure (adult height) was measured in column 9.

Each of these approaches to measuring exposure to early life undernutrition has their own advantages and disadvantages, and we return to a discussion of the measurement issue as part of the Appendix. It is important to note, however, that the underlying assumption behind the approach of studying the link between adult height and adult outcomes is that height or length in childhood is sufficiently predictive of adult height that the latter provides an adequate proxy for childhood undernutrition. This hypothesis has been assessed in prospective cohort studies that follow children from birth into adulthood. In the British 1958 National Child Development Study (NCDS) and the 1970 British Cohort Study (BCS), healthier, better nourished children were substantially more likely to go on to reach their height potential (Case et al., 2009). Moreover, a recent review of data from five birth cohorts in low and middle income countries found that the correlation coefficient relating length at 12 months with adult height ranged from 0.43 to 0.49 (Stein et al., 2010). The literature thus supports the hypothesis that, within a given population, growth failure in childhood is predictive of reduced attained stature in adulthood.

The rest of this paper is structured as follows. First, we begin by reviewing existing summary papers. Second, we present an overview of estimates of the association between stunting and subsequent outcomes from long run follow ups of intervention studies, prospective studies that measure stunting or height contemporaneously in childhood but track cohort members into adulthood, and evidence from natural experiments, which retrospectively tie individuals to events associated with periods of undernutrition in early life. Third, we provide a comprehensive assessment of the literature from cross-sectional data that documents the relationship between height in adulthood and wages, comparing estimates from observational and quasi-experimental approaches which are designed to correct for measurement error and potential unobserved confounding. Fourth, we discuss how cost-benefit analyses of nutrition interventions have been conducted, and provide an overview of these findings. Finally, we consider whether there is evidence linking the prevalence of stunting to aggregate effects on economic growth, and whether economic growth in turn affects child undernutrition. We conclude in the discussion section with a summary of the strength of the evidence linking childhood stunting and undernutrition to adult economic outcomes, as well as a review of the implications of these findings for countries with high rates of stunting, particularly those in South Asia.

3 Findings

3.1 Review Papers

Table 2 presents the key background papers that cover topics outlining the rational for investing in nutrition in early childhood (Alderman, 2013, 2010; Behrman, 2009, 1993; Behrman et al., Forthcoming; Dewey and Begum, 2011; Hoddinott et al., 2013a; Victora et al., 2008; Young and Richardson, 2007; World Bank, 2002; Alderman and Sahn, 2016), and details of the long term follow-up of a cohort who received a nutrition intervention in Guatemala which has featured heavily in the literature are provided in Martorell (2005). These papers also provide a summary of the potential pathways linking stunting and undernutrition to economic outcomes (Hübler, 2016), the interaction of nutrition programs with other childhood interventions (Alderman et al., 2014a), the relationship between nutrition, productivity, and economic growth (Behrman, 1993; Fogel, 1994; Strauss and Thomas, 1998), economic returns to other interventions targeted at child and maternal health in low and middle income countries (Halim et al., 2015), global losses associated with malnutrition (Horton and Steckel, 2011), the use of height as a marker for human welfare (Schultz, 2003a; Steckel, 2009, 1995, 2008), child growth and development (Sudfeld et al., 2015), trends in the global prevalence of stunting (Stevens et al., 2012; UNICEF, 2013), and the effectiveness of interventions to reduce child and maternal undernutrition (Ainsworth and Independent Evaluation Group International Bank for Reconstruction and Development, 2010; Bhutta et al., 2008, 2013; Shekar et al., 2006).

Table 2: Key Summary Papers on the Economic Consequences of Childhood Stunting and Undernutrition

Author/Year	Focus
Alderman (2013, 2010)	Summary of pathways linking stunting to economic outcomes and associated costs of malnutrition
Alderman et al. (2014a); Alderman and Sahn (2016)	Integration of nutritional interventions with other childhood programmes, program design and estimation of economic returns
Behrman (1993)	Evidence on nutrition and productivity
Behrman (2009)	Summarizes follow-up study in Guatemala and benefit-cost analyses for early life nutritional interventions
Behrman et al. (Forthcoming)	Potential health and economic benefits of improving early childhood nutrition, long term benefits, and cost benefit analysis
Bhutta et al. (2008, 2013)	interventions to address undernutrition and micronutrient deficiencies in women and children
Dewey and Begum (2011)	Overview of the long run impact of stunting
Fogel (1994)	The role of physiology in economic growth
Halim et al. (2015)	Economic impacts of 23 reproductive, maternal, newborn and child health (RMNCH) interventions, published in 29 empirical studies
Hoddinott et al. (2013a)	Functional consequences of stunting, summarizes literature around each of the links in the life cycle, and estimate benefit–cost ratios for a plausible set of nutritional interventions to reduce stunting
Horton and Steckel (2011)	Estimates of the economic losses from malnutrition worldwide
Hübler (2016)	Summarizes relationship between height and wages from an economic perspective, with summary of recent evidence
Martorell (2005)	Overview of design and findings from the Guatemala Institute of Nutrition of Central America and Panama (INCAP) Study
Norgan (2000)	Physiological perspective on the long-term economic consequences of growth retardation in children and adolescents

Schultz (2003a)	Summarizes key methodological challenges associated with estimating returns to height and human capital from an economic perspective
Steckel (2013, 2009, 1995, 2008)	Overview of literature which uses height as a measure of human welfare
Strauss and Thomas (1998)	Discusses our understanding of the interrelationships between health, nutrition and economic development
Sudfeld et al. (2015)	Association of child growth with child development
Stevens et al. (2012)	Summary of global prevalence and trends in child stunting
UNICEF (2013)	Reviews background studies, current prevalence of malnutrition across various indicators, case studies in improving nutrition, and global initiatives
Victora et al. (2008)	Associations between maternal and child undernutrition with human capital and adult health in low-income and middle-income countries
(Shekar et al., 2006; Young and Richardson, 2007; World Bank, 2002)	Reviews the effectiveness of nutrition interventions and rational for investment in early child development

3.2 Evidence from Intervention Studies, Prospective Cohorts, and Natural Experiments

We were able to locate two long term follow ups of intervention studies conducted in Guatemala and Jamaica. The former, the Institute of Nutrition of Central America and Panama (INCAP) study (Engle and Fernandez, 2010; Stein et al., 2008), allocated nutritional supplements to pregnant women and infants in two Guatemalan villages in the late 1960s and 1970s. Two nearby control villages did not receive the supplements. A number of studies that follow the children included in the INCAP intervention into adulthood find effects of receiving the nutritional supplements on economic outcomes, including productive capacity, wages, expenditure, and the probability of living in poverty (Haas et al., 1995, 1996; Hoddinott et al., 2005; Martorell et al., 2010). Studies which use intention to treat analysis (ITT) find that men who received the supplements as children had, on average, a 46% increase in wages (Hoddinott et al., 2008). The association was not found to be statistically significant for women. An instrumental variables analysis using variation in height-for-age Z score at age 2 predicted by receipt of the nutritional supplement found that a one standard deviation increase in height-for-age was associated with a 21% increase in household per capita expenditure and a 10 percentage point decrease in the probability of reporting living in poverty at ages 25-42 (Hoddinott et al., 2013b). A second intervention study was conducted in Jamaica in the mid-1980s (Gertler et al., 2014). A group of undernourished children were randomly allocated to groups that included a nutrition supplementation intervention, psycho-social stimulation, combined nutrition and stimulation, and a control group. These children were subsequently followed up with in 2007-2008 at age 22. Those who received the stimulation and combined intervention were found to have increased earnings by 25% relative to the control group. The association between the nutritional supplement alone and wages was not statistically significant. These two studies, papers from which are shown in Table 3, are the only two long term follow-ups to nutrition interventions that we are aware of.

We located five natural experiment papers which examined the long run economic outcomes of cohorts exposed to conditions in infancy which were likely to have resulted in undernutrition for those affected. The benefit of this natural experiment approach is that the events of interest can often reasonably be considered as unexpected shocks that affect nutritional status in a way that is unrelated to unobserved characteristics of these individuals, thereby reducing concerns about unobserved confounding. Three of these events are the famine in China in 1959-1961 (Chen and Zhou, 2007), the war-related famine in Greece (1941-1942) (Neelsen and Stratmann, 2011), and the war-related food crisis in Germany (1944-1948) (Jürges, 2013). Although the

Dutch "Hunger Winter" of 1944-1945 also features in this literature (Lumey et al., 2007), we are not aware of any study that examines the economic outcomes of survivors. An additional paper considers exposure to rainfall in Indonesia in early life, which is positively associated with higher crop yields, stature, and thus likely better nutritional status, and found that exposure was associated with higher scores on asset indices (a proxy for household wealth) for women, but was not statistically significant for men (Maccini and Yang, 2009). Survivors of the Chinese famine in 1959-1961 were found to have lower labor supply and reductions in some measures of income compare to surrounding cohorts who were not in infancy during the famine. Those in infancy during the Greek famine of 1941-1942 were found to have lower occupational status when followed up on using national Census data. In contrast, there was no evidence of adverse economic effects of exposure to the German food crisis in childhood, although this study found that those exposed in utero were adversely affected. Kesternich et al. (2014) find that having lived in a European country affected by conflict during Word War 2 was associated with lower wealth in later life for those among the bottom two SES tertiles in childhood, with poor nutrition being one potential channel for this result. A final study examined the relationship between height and adult outcomes using an approach based on sibling comparisons in Sweden, which has the benefit of allowing all observed and unobserved factors constant within families to be controlled for (Rosenzweig and Wolpin, 2000). This study found returns to height in the form of increases in wages and occupational status (Lundborg et al., 2014). Results from these studies are shown in Table 4.

Alderman et al. (2006a) use an instrumental variables approach and report that drought exposure in childhood in Zimbabwe led to height for age Z score 1.25 SD lower, which was estimated to be associated with a 14% reduction in lifetime earnings, however this figure is calculated from calibrated effects of schooling on earnings, rather than a direct association observed in the data, and therefore not included in Table 4. Alderman et al. (2009) conduct a similar analysis for Tanzania.

Table 3: Intervention Studies on the Economic Consequences of Childhood Stunting and Undernutrition

Authors	Location	Data	Design	Year	Exposure	Result
Gertler et al. (2014)	Jamaica	Jamaican Study	Randomized, Intention to Treat	1986-1987	Psychosocial stimulation to growth-stunted toddlers	Intervention increased earnings by 25%
Haas et al. (1995, 1996)	Guatemala	INCAP - Institute of Nutrition of Central America and Panama	Cluster, Randomized, Intention to Treat	1969-1977	Nutritional supplementation experiment during gestation and the preschool years	Maximum oxygen consumption (VO2max) at follow-up was significantly greater in subjects from treated villages of both sexes (+.038)
Hoddinott et al. (2005, 2008); Martorell et al. (2010)	Guatemala	INCAP	Cluster, Randomized, Intention to Treat	1969-1977	Nutritional supplementation experiment during gestation and the preschool years	46% increase in average wages for men
Hoddinott et al. (2013b)	Guatemala	INCAP	Cluster, Randomized, Instrumental Variables/Treatment on Treated	1969-1977	Height-for-age Z score (HAZ) at age 2	1-SD increase in HAZ was associated with increased household per capita expenditure (21%) and a lower probability of living in poverty (10 percentage points)

Table 4: Natural Experiments on the Economic Impacts of Stunting and Childhood Undernutrition

Authors **Natural Experiments**	Location	Data	Design	Year	Exposure	Result
Chen and Zhou (2007)	China	China Health and Nutrition Survey - CHNS	Retrospective matching of cohort to event	1959-61	Famine exposure in early childhood	Labor supply reduced by 1.7-2.1% per .1% excess death rate increase, for the 1959 cohort, the annual per capita agrarian income decreased by approximately 2%
Jürges (2013)	Germany	Census (IPUMS)	Retrospective matching of cohort to event	1945-1946	Famine exposure in early life	Associations with income, occupational status, and employment status for the cohort in utero only, not for those exposed in childhood
Lundborg et al. (2014)	Sweden	Military Records	Prospective, Sibling Fixed Effects	Swedish males enlisting for the military between 1984 and 1997	Height at age 18	.42% increase in earnings per CM, increase in occupational status
Neelsen and Stratmann (2011)	Greece	Census (GEIS 10% Sample)	Retrospective matching of cohort to event	1941-1942	Famine exposure in early life	International Socio-Economic Index of Occupational Status (ISEI), coefficient ranged between .296 and 1.111
Maccini and Yang (2009)	Indonesia	Indonesia Family Life Survey - IFLS	Retrospective matching of cohort to event	1953-1974	Rainfall exposure in early life	Women with 20 percent higher rainfall (relative to normal local rainfall) in their year and location of birth, live in households that score 0.12 standard deviations higher on an asset index. No statistically significant relationship for men

3.3 Evidence from Prospective Studies

Next we present evidence from prospective studies, which have the benefit of measuring stunting or undernutrition in early life rather than relying on adult height, do not generally deal with measurement error or unobserved confounding. Most of these studies use measures of childhood height collected as part of established cohort studies in the UK, Brazil, and the Philippines (Adair et al., 2011; Elliott and Shepherd, 2006; Power and Elliott, 2006; Victora and Barros, 2006). One study that does included a matched control group has followed a cohort of children who were hospitalized for protein-energy malnutrition during the first year of life (matched to a cohort who did not experience the same) in Barbados in 1967-1972 (Galler et al., 2012). Those who experienced the undernutrition episode were found to be lower on social position and standard of living indices in adulthood. An early study in India found that height for age at age 5 was associated with lower work capacity in the teenage years (14-17) (Satyanarayana et al., 1978, 1979). In the Philippines, length-for-age Z score at age 2 was found to be associated with an increase in the probability of being engaged in formal work at age 20-22 for both men and women (Carba et al., 2009). Research from US and UK cohort studies have found that height at various stages in childhood and the teenage years is positively related to work status, wages and measures of socioeconomic status in later life (Case et al., 2005; Case and Paxson, 2008b; Montgomery et al., 1996; Persico et al., 2004; Sargent and Blanchflower, 1994). In a cohort of men born in Helsinki, Finland, between 1934 and 1944, length in the first year of life was associated with subsequent earnings (Barker et al., 2005). A review of three cohort studies in low and middle income countries found that height-for-age Z score at age 2 was associated with an 8% increase in income in Brazil and Guatemala (although the latter was only significant at the 10% level), and a 21% increase in household assets in India (Victora et al., 2008). These data are shown in Table 5. Further notes to the studies outlined in Tables 3, 4 and 5 are presented in Table A1 in the appendix.

Table 5: Prospective Studies on the Economic Impacts of Stunting and Childhood Undernutrition

Authors	Location	Data	Design	Year	Exposure	Result
Galler et al. (2012)	Barbados		Prospective, Matched	1967-1972	Hospitalized for protein-energy malnutrition (PEM) during the first year of life	Hollingshead social position index (-.62) and PCA standard of living index (+.70)
Satyanarayana et al. (1978, 1979)	India		Prospective	1960-1963	Nutritional status age 5 (height for age)	Childhood malnutrition was associated with physical work capacity
Carba et al. (2009)	Philippines	Cebu Longitudinal Health and Nutrition Survey	Prospective	1983-85	Length-for-age Z-score	40% increase in likelihood of formal work compared to not working for men, 0.2 higher likelihood of formal vs. informal work for females
Barker et al. (2005)	Finland	Cohort of men born in Helsinki	Prospective	Cohort Born 1934-1944	Height at any age between birth and 12 years	Each 2 cm increase in length between birth and 1 year was associated with a 3.5% increase in income

Case et al. (2005)	England	National Child Development Study - NCDS	Prospective	Cohort Born 1958	Height at age 16	Increase in employment at age 33, not 46, increase in SES at 33 and 46
Case and Paxson (2008b)	England	NCDS	Prospective	Cohort Born 1958	Height at age 7,11,16	Height associated with income
Montgomery et al. (1996)	England	NCDS	Prospective	Cohort Born 1958	Height at age 16	Odds Ratio of 2.41 for being employed (bottom v top height quintile)
Persico et al. (2004)	England	NCDS	Prospective	Cohort Born 1958		.88% increase in wages per unit, white male workers only
Persico et al. (2004)	US	National Longitudinal Survey of Youth - NLSY 1979	Prospective	Men and women aged 14–21 in 1979	Height aged 16-23	.72% increase in wages per unit, white male workers only
Sargent and Blanchflower (1994)	England	NCDS	Prospective	Cohort Born 1958	Height at ages 11, 16, 23	.2% increase in wages for men per CM increase in height after age 16, .1% for women
Victora et al. (2008)	Brazil	Pelotas birth cohort study	Prospective	Cohort Born 1982	Height-for-age Z score age 2	8 % increase in annual income for per SD increase
Victora et al. (2008)	Guatemala	INCAP	Prospective	1969-1977	Height-for-age Z score age 2	Marginally significant (P <.1) 8 % increase in annual income for per SD increase
Victora et al. (2008)	India	Cohort born in New Deli	Prospective	1969–72	Height-for-age Z score age 2	27 % increase in number of household assets

3.4 Evidence from Cross-Sectional Studies of Adult Height and Adult Income

A difficulty with interpreting the results in the previous section is that it is problematic to compare the magnitude of coefficients across studies because of differences in exposure and outcome measures. In addition, there are relatively few prospective studies that include measures of childhood stunting or undernutrition alongside adult economic outcomes. An alternative approach to assessing the long-run economic impacts of stunting which has less data requirements is to examine the relationship between adult height and adult outcomes. The benefit of this approach is that data on adult height are much more widely available, and it can therefore be implemented with cross-sectional data. It is also much easier to compare results from this literature as there are relatively more studies that examine adult wages or income as the outcome, and a continuous measure of stature as the exposure. As we discuss above, the wage premium for taller individuals is often used to quantify the economic impact of childhood growth restriction because of the association between childhood undernutrition and adult height (Stein et al., 2010).

Nevertheless, because adult height is an imperfect proxy for our exposure of interest, we therefore separately consider the set of studies that adopt a quasi-experimental instrumental variables (IV) approach to correct for potential measurement error. Instrumental variables used in this approach typically include characteristics of respondents' place and time of birth (Schultz, 2003b), as well as procedures designed to correct for measurement error based on observed characteristics only (Elu and Price, 2013b), and finally, twin differences in height and BMI (Böckerman and Vainiomäki, 2013). We provide a methodological discussion of the different approaches in the appendix. These IV results are presented in Table 6, where we report estimates of the expected change in wages (measured in percent) associated with a one centimeter change in adult height (known in the economics literature as the semi-elasticity).

For men, coefficient estimates range from -1% to +10%, with no statistically significant association found in Finland, East Germany, and Ivory Coast (Böckerman and Vainiomäki, 2013; Elu and Price, 2013a,b; Gao and Smyth, 2010; Haddad and Bouis, 1991; Heineck, 2005; Schultz, 2003b, 2002; Tao, 2014; Thomas and Strauss, 1997; Yimer and Fantaw, 2011). For women, coefficient estimates range from -4% in Tanzania and Ivory Coast to +12% in Finland, with non-significant estimates observed in Germany and Ivory Coast. The Tanzanian and Ivory Coast estimates for women are notable outliers as they are negative. One study gave results for a combined sample (a 2% return in Ethiopia). Mean rates of return associated with an additional centimeter of height are 5% for men in 12 studies and 6% for women in 11 studies. Assuming non-significant estimates are equal to zero lowers the mean return to 3% for men but does not affect the estimate for women.

Median rates of return to a centimeter of height are 4% for men and 6% for women.

Corresponding linear regression estimates from studies that only implement OLS models are presented in Table 7 (Böckerman et al., 2010; Case and Paxson, 2010, 2008b; Case et al., 2009; Elu and Price, 2013a; Eren and Ozbeklik, 2013; Furnham and Cheng, 2013; Hübler, 2009; Heineck, 2008, 2005; Kortt and Leigh, 2010; Lindqvist, 2012; Lundborg et al., 2014; Persico et al., 2004; Rashad, 2008; Rietveld et al., 2015; Sargent and Blanchflower, 1994; Smith et al., 2012; Sohn, 2014). Using this approach, coefficient estimates are almost all less than a percentage point. Exceptions are men in one study in China (3%), men and women in Indonesia (8% and 13% respectively) which is substantially higher than other OLS estimates, and men in Mexico (2%). Here the mean and median return for men (based on 20 OLS studies) is 1%, and also 1% for women (based on 14 studies). For women, estimates in China, Germany and Australia are found to be not statistically significant.

For studies that report both IV and linear regression estimates, Figure 1 demonstrates the difference between the coefficient estimates for these two approaches for men and women. Overall, estimates of the median return to height are substantially higher for IV models, particularly for women (a 5 percentage point difference). Further discussion of these papers is given in the appendix, as is a summary of findings from papers which examine economic outcomes other than wages.

Table 6: Quasi-experimental Estimates of the Association between Adult Height and Wages

Authors	Location	Data	Design	Year	All (Association)	Men (Association)	Women (Association)	Age exposure measured	N	Notes
Böckerman and Vainiomäki (2013)	Finland	Older Finnish Twin Cohort Study	Twin FE IV	1990-2004		NS	12%	Varied	1,284	Average yearly earnings over the period; Male estimate is similar but not statistically significant
Elu and Price (2013a)	China	CHNS	IV	2006	10.30%	5%	7%	Varied	1,949	Monthly Earnings
Elu and Price (2013b)	Tanzania	Tanzanian Household Worker Survey	IV	2004		6%	-4%	Unknown	427	Hourly earnings, height in inches, coefficients are scaled by .4, not clear if age is controlled for
Gao and Smyth (2010)	China	China Urban Labour Survey	IV	2005		4.80%	10.80%	Unknown	11,512	Hourly wage; not clear if age is controlled for
Heineck (2005)	Germany	German Socio-Economic Panel - GSOEP	IV	2003		NS	NS	Varied	24,000	East Germany; Gross monthly earnings; Hausman-Taylor IV
Heineck (2005)	Germany	GSOEP	IV	2003		0.50%	NS	Varied	24,000	West Germany; Gross monthly earnings
Hoddinott et al. (2008)	Guatemala	INCAP	Intervention	2002-2004		15.80%	NS	25-42	1,424	Semi-elasticity estimate is taken from Horton and Steckel (2011)
Schultz (2002)	Brazil	Health and Nutrition Survey	IV	1989		8-10%	8-10%	25-54	11,855	
Schultz (2002)	US	NLSY79	IV	1989-1993		1-4%	3-6%	20-28	9,257	
Schultz (2003b)	Ivory Coast	Living Standards Measurement Surveys - LSMS	IV	1985-1989		NS	NS	Varied	12,221	Hourly wage
Schultz (2003b, 2002)	Ghana	LSMS	IV	1985-1990		5.60%	7.60%	Varied	10,888	Hourly wage
Thomas and Strauss (1997)	Brazil	Estudo Nacional da Despesa Familiar - ENDEF	IV	1974-1975		1.43%		Mean=36	10,675	Hourly wage; men in labor market only; regression included log height, semi-elasticity is for a 1 CM increase at mean height
Yimer and Fantaw (2011)	Ethiopia	Ethiopian Urban Household Survey - EUHS	IV	2001	2%			Varied	820	Gross hourly wage; Implementation of IV is not clearly defined

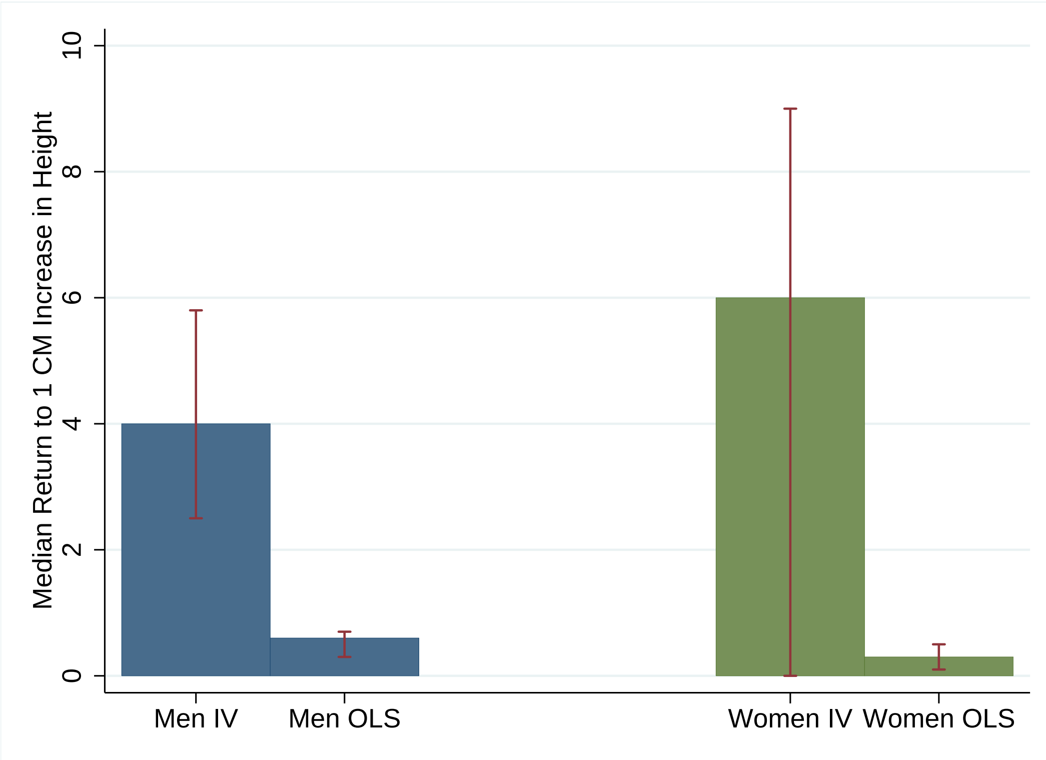
Note to Table 6: NS=Not statistically significant at 5% level.

Table 7: Linear Regression Estimates of the Association between Adult Height and Wages

Authors	Location	Data	Design	Year	All (Association)	Men (Association)	Women (Association)	Age exposure (height) and outcome (wages) measured	N	Notes
Böckerman et al. (2010)	Finland	Health 2000 in Finland	OLS	2000-2001		0.67%	0.40%	Mean=44	2,506	Hourly earnings, which the authors calculate as annual wage divided first by 52, and then by the individual's self-reported number of weekly working hours
Case and Paxson (2010, 2008b)	England	NCDS	OLS	1991		0.65%	0.43%	33	5,833	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Case and Paxson (2010, 2008b)	England	NCDS	OLS	2000		0.63%	0.50%	42	5,833	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Case and Paxson (2010)	England	British Cohort Study - BCS	OLS	2000		0.30%	0.28%	30	5,424	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Case and Paxson (2010)	US	Panel Study of Income Dynamics - PSID	OLS	1988-1997		0.38%	0.18%	25-55	31,996	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Case and Paxson (2010)	US	Health and Retirement Study - HRS	OLS	1992-2004		0.70%	0.68%	55-74	27,606	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Case et al. (2009)	England	British Household Panel Survey - BHPS	OLS	1997–2005		0.40%	0.20%	21-60	42,666	Average hourly earnings; Height was measured in inches, coefficient is scaled by 0.4
Haddad and Bouis (1991)	Philippines		OLS	1984-1985	0.7% - 0.8%			Varied	390	Real daily wage, rural agricultural work; Hausman-Taylor IV applied to variables other than height
Heineck (2008)	England	BHPS	OLS	2004		0.60%	1.40%	21-50	4,650	Results without education
Hübler (2009)	Germany	GSOEP	OLS	1985-2004		0.25%	NS	22-55	36,754	Association was found to be non-linear
Kortt and Leigh (2010)	Australia	Household, Income and Labour Dynamics in Australia - HILDA	OLS	2006-2007	0.22%	0.28%	NS	25-54	6,822	Hourly wages
Lindqvist (2012)	Sweden	Longitudinal INdividual DAta for Sweden - LINDA	OLS	2006		0.33%		Varied	13,414	Annual wages; Men born between 1965 and 1974
Lundborg et al. (2014)	Sweden	Swedish males enlisting for the military between 1984 and 1997	Sibling FE	2003		0.42%		28-32	450,000	Annual earnings; height measured at 18; height associations are non-linear
Persico et al. (2004)	US	NLSY79	OLS	1996		0.70%		35	1,577	Annual income. Height was measured in inches, coefficient is scaled by 0.4
Persico et al. (2004)	England	NCDS	OLS	1991		0.88%		33	1,772	Income period varies. Height was measured in inches, coefficient is scaled by 0.4
Rietveld et al. (2015)	Germany	GSOEP	OLS	2002-2012	0.40%	0.50%	0.30%	Varied	92,248	Hourly Earnings
Sargent and Blanchflower (1994)	England	NCDS	OLS	1981		0.20%	0.10%	23	12,537	Height at age 16; hourly earnings
Smith et al. (2012)	China	China Longitudinal Study of Aging - CHARLS	OLS	2012		2.60%	NS	45+	1,179	
Sohn (2014)	Indonesia	IFLS	OLS	2015		7.50%	13%	20-65	9,306	Annual Earnings
Tao (2014)	Taiwan	Taiwan Integrated Postsecondary Education Database - TIPED	OLS, Selection	2006		0.14%		Varied	2,510	Women only; adjusted for selection into the full time labor market
Vogl (2014)	Mexico	Mexican Family Life Survey - MxFLS	OLS	2002, 2005		2.30%		25-65	3,860	Men only; hourly earnings

Note to Table 7: NS=Not statistically significant at 5% level.

Figure 1: Comparison of Median Estimates of the Wage Return to a 1CM Increase in Height from Instrumental Variables (IV) and Linear Regression (OLS)



Note to Figure 1: Error bars show the interquartile range. Data is based on 12 estimates for men and 10 estimates for women.

4 Cost Benefit Analysis of Childhood Nutrition Interventions

A number of papers conduct cost benefit analyses of an intervention or package of interventions targeted at reducing childhood stunting or undernutrition, which requires costing the economic impact. The approach typically adopted in these studies can be summarized as follows. First, the treatment effect of the program in terms of the expected reduction in the exposure (for example, the probability of being stunted), is calculated. Then, the treatment effect is multiplied by the number of affected children to obtain an estimate of the reduction in stunting prevalence induced by the treatment. The economic benefits of this reduction are then usually calculated by calibrating the returns to height using the existing literature. For example, if the intervention increased average height by a centimeter among 100 children, and the estimated return to height is calculated at 3%, the program is valued at 1*100*3%*average wages, potentially with some correction for discounting and estimates of labor supply across the life course. Additional benefits can be included, for example the return to improvements in test scores (Fink et al., 2016), or reductions in direct costs, such as lower treatment costs for illness associated with improvements in health status. Some studies also include the value of lives saved as a result of these interventions.

Using this approach, a micronutrient supplementation and early childhood stimulation program in Nicaragua was found to have a cost-benefit ratio of 1.5. Benefits for program participants were calibrated using estimates from the literature on the returns to test scores which were estimated to be impacted by the program (Boo et al., 2014). In an analysis of a stunting intervention in Indonesia, the program was found to have a cost-benefit ratio of 2.08 on the basis of productivity enhancements from reduced undernutrition, earnings from deaths averted, and household savings from diarrhoea costs avoided (Qureshy et al., 2013). In a review of cost-benefit ratios of nutrition interventions, estimates ranged from 3.5:1 to 42.7:1 per child, with a median of 17.9:1 (Horton and Hoddinott, 2014; Hoddinott et al., 2013a).

A similar methodology has been used to estimate the aggregate burden of stunting worldwide. Instead of considering a particular intervention, these studies calculate the cost savings associated with reducing stunting prevalence to zero in a country. Then, wage returns for each stunted child, under the hypothetical scenario that every currently stunted child was no longer stunted, are aggregated. An early example of a study which attempts to quantify the national costs associated with stunting is Ross et al. (2003), who examine the impact of undernutrition on economic productivity in China. Using estimates of the impact of stunting on productivity from the literature, they conclude that productivity gains due to reductions in child stunting over the period 1991 to 2001 were worth $12 billion (Yuan 101 billion) in 2001. Conducting a similar analysis, Alcázar et al. (2013) found that productivity-related costs of stunting in Peru were also large (2.2% of GDP). Bagriansky et al. (2014) estimated the impact of undernutrition at more than US$400 million annually in Cambodia, or approximately 2.5% of yearly GDP, of which 57% is a result of children being affected.

A similar approach involves aggregating the costs accruing to the population in a country as a whole. For example, add up the direct costs for affected individuals in a country, potentially using different methodologies as a sensitivity analysis, then divide by the total population in that country to obtain an estimate of per capita costs, which could be expressed as a percentage of GDP. Horton and Ross (2003) estimate the productivity costs of anaemia at 0.57% of GDP in 10 countries, and Horton and Steckel (2011) calculate the global economic losses associated with malnutrition by aggregating losses for individual countries. Assuming that the impact of height on productivity is captured by the association of height with wages (earnings), and that this translates into economic growth via the share of wages in national income (approximately 50%), they consider the differential return to height at different levels of mean height based on linear regression and estimates from the literature. At the country level, they obtain estimates of the wage return to a centimeter increase in height of 4.5% at 170 cm, 4% at 171 cm, 3.5% at 172 cm, and 0.5% at 178cm. Aggregating wage impacts, these assumed productivity losses are combined with data on average height to give estimated costs as a % of national income in each country. Results imply that the annual GDP loss due to undernutrition is up to 12% in low and middle income countries. Globally, these losses are estimated to have fallen from 12% of world GDP in 1900 to 6% in 2000. The corresponding projections for 2050 imply that losses will be of the order of 6%. Based on a model originally developed for Latin America (Fernández and Martínez, 2007), the Cost of Hunger in Africa (COHA) study (www.costofhungerafrica.com) aims to provide economic estimates of the costs of hunger in 13 countries. A recent report on Malawi from this study group indicates that the costs associated with stunting were of the order of 10% of GDP per year (African Union Commission/World Food Programme, 2015).

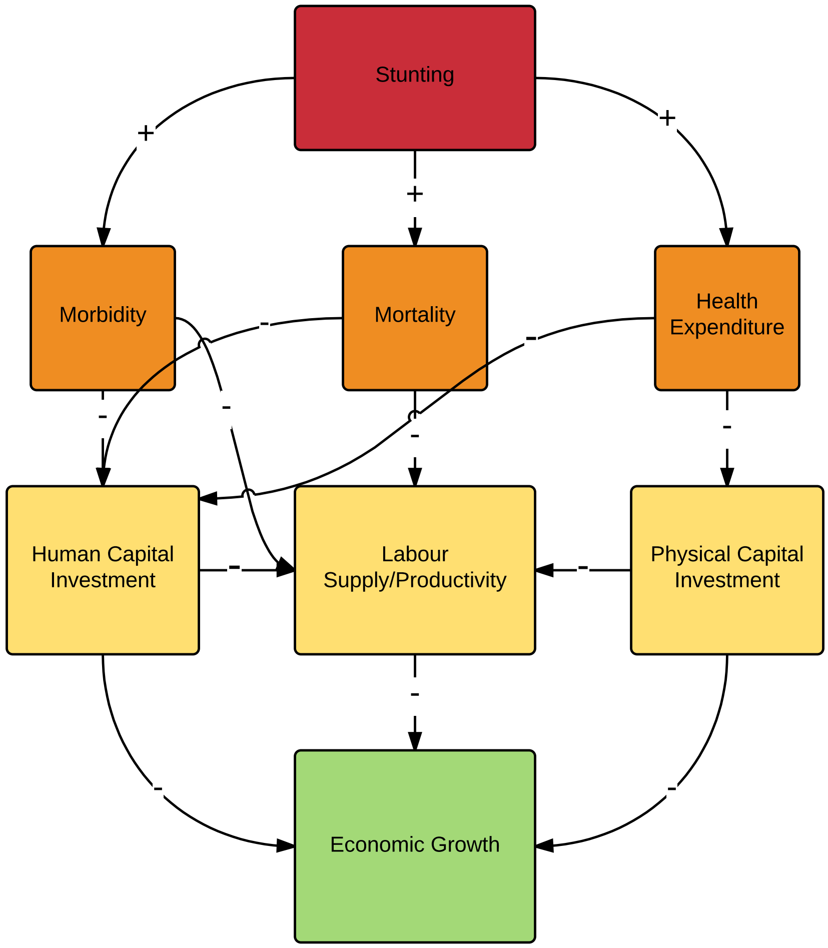
Overall, there is therefore a multitude of evidence that nutrition interventions are highly cost effective, and that the economic burden of undernutrition on society as a whole is likely to be large, however these studies crucially rely on estimates of the economic return to factors such as adult height or reductions in child stunting. In practice, there does not seem to be a consensus in the literature as to what return to height should be used. In addition, studies that aggregate from individual losses may be underestimates of the total economic impact because they do not account for spillover effects on economic growth (Bloom et al., 2014).

5 The Impact of Stunting on Economic Growth

Results in the previous section reflect the potential impact of individual undernutrition on individual economic outcomes, the pathways for which have been discussed previously (Alderman, 2013, 2010; Behrman et al., Forthcoming; Hübler, 2016; Hoddinott et al., 2013a). However, individual level estimates do not take account of effects on aggregate capital formation, labor markets, savings behavior, investment behavior, and other factors which make up the determinants of aggregate output. Estimating the full costs of undernutrition to society requires accounting for all of these potential effects. However, while height and wages tend to be correlated at the aggregate level (Baten, 2000), there has been surprisingly little attention paid to spillover effects of stunting on economic growth in the literature. The potential for such an impact can be informed by considering the standard approach in macroeconomic growth models where national income is a defined as a function of labor, capital, and the efficiency with which labor and capital inputs are combined (or technological progress) Bloom et al. (2004). From this perspective, the pathways through which undernutrition could affect aggregate economic growth include increases in morbidity, mortality and health expenditure, and subsequent reductions in human capital investment (for example, education), physical capital investment, and labor supply. Reductions in productivity because of ill health or work capacity for any given labor supply, and reductions in human capital and technological progress (due to lower levels of educational attainment and infrastructure) are likely to negatively impact not only on the individual themselves, but also on economic growth when a substantial proportion of a country's population are affected by stunting. Other relevant pathways include the impact of undernutrition on chronic disease, which would involve the diversion of productive savings (which boost investment) towards treatment costs (Bloom et al., 2014). These pathways are summarized in Figure 2.

There is a literature in economics which examines whether there is an effect of health on economic growth. However, there are relatively few studies that consider undernutrition specifically (either childhood undernutrition or adult undernutrition) as an input in these production function models of the aggregate economy. Some recent exceptions are Chakraborty et al. (2010), Dalgaard and Strulik (2015), and Piper (2014). Estimating this relationship in practice with currently available data is problematic because it is difficult to assess whether the causal pathway runs from nutrition to economic growth, or from economic growth to nutrition. Most likely the relationship is bi-directional, however this makes it difficult to interpret parameter estimates from models that do not account for this reverse causality because estimates of the impact on growth likely also incorporate some of the effect in the opposite direction, and vice versa. Recent summaries of this literature on health at the macro and micro levels are provided elsewhere (Bleakley, 2010; López-Casasnovas et al., 2005; Weil, 2014). There is a small number of studies that examine the relationship between adult stature specifically and economic growth. Weil (2007) incorporates height alongside other health measures into an augmented production function and finds that health differences worldwide account for a relatively small proportion of differences in GDP (around 10% of the variance in log GDP per worker). Adopting an empirical approach with a co-integrating model to account for reverse causality, Arora (2001) examines whether changes in health, including adult stature, contributed to growth among a group of 10 industrialized countries over the course of the last century, and finds that health contributed between 30%

Figure 2: Summary of the Pathways Linking Stunting to Economic Growth



Adapted from Bloom et al. (2014).

and 40% to the economic growth rates over this period. Also in a co-integration analysis, María-Dolores and Martínez-Carrión (2011) find a bi-directional relationship between height and economic growth among Spanish regions in the period 1850–1958. The evidence demonstrates a strong association between economic growth and health, but because of the difficulties associated with testing theoretical models of how economic growth is produced, it is currently difficult to quantify the magnitude of these effects. However, one recent example of a paper uses an instrumental variables approach in an effort to overcome the problems associated with reverse causality, and finds that each centimeter increase in average population height is expected to raise income per capita by 6% (Akachi and Canning, 2015). This estimate would imply that the magnitude of the return to increases in height at the national level is substantial.

6 The Impact of Economic Growth on Stunting

Some papers in the literature have found that economic growth is associated with a reduction in the prevalence of child stunting, the magnitude of the relationship has generally been found to be small. Interpretation of estimates can be complicated by the fact that some studies report the impact of GDP per capita on stunting prevalence in absolute terms (the association in percentage points), while others report the impact on stunting prevalence in relative terms (the association in percent). Once estimates are rescaled, the magnitude of the reported coefficients appears similar (Bershteyn et al., 2015). Across six studies, the impact of a 10 percent increase in GDP per capita was found to be in the range of a 0-2% reduction in stunting (Bershteyn et al., 2015; Harttgen et al., 2013; Headey, 2013; Heltberg, 2009; Ruel et al., 2013; Vollmer et al., 2014b; Webb and Block, 2012). For example, Harttgen et al. (2013) find that while levels of GDP per capita increased substantially in many low and middle income countries over recent decades, levels of undernutrition showed very little improvement. In this study, a 10 percent increase in GDP per capita was associated with a 1.5 to 1.7 percent reduction in stunting, which is similar to estimates of approximately 2 percent obtained in Heltberg (2009). Ruel et al. (2013) reported that a 10% increase in GDP per capita was associated with a reduction in stunting prevalence of around 6 percentage points. However, their study focused on the long run impacts, as opposed to the other papers which considered more short-term associations with GDP.

There are a number of additional studies, most of which reports similar results to the above. Smith and Haddad (2015) estimate that a 10% increase in GDP per capita is associated with a 1.7% reduction in stunting. Their estimates of the long-run impact of GDP per capita are larger, at around 6%, and comparable to the earlier estimates in Smith and Haddad (2002) and Haddad et al. (2003), where increases in national income over the 25-year period from 1970 to 1995 were found to have led to roughly half of the total reduction in the developing-country prevalence of child undernutrition over the period. In contrast, a recent analysis which adopted a multilevel approach in Indian states, found that economic growth was not associated with reductions in stunting or other measures of undernutrition Subramanyam et al. (2011). As far as we are aware, only one paper has examined whether the timing of economic growth is important for height, and found that economic growth in puberty and in the first year of life were most associated with the adult height of women in sub-Saharan Africa (Moradi, 2010).

Although the magnitude of the relationship between GDP per capita and stunting continues to be debated Alderman et al. (2014b); Vollmer et al. (2014a), there appears to be some agreement that economic growth alone is unlikely to be able to achieve substantial reductions in the prevalence of stunting, and that any effects are too small to rely on national income alone for achieving large reductions in child undernutrition, at least in the short run (Smith and Haddad, 2015). The fact that some countries, such as Sri Lanka, or regions within countries, such as Kerala in India, have lower prevalence of stunting than their incomes would suggest places emphasis on other factors such as the local policy environment and the role of public health nutrition programs. A recent paper suggests that differences in stunting prevalence across Indian states is less due to differences in inputs and more likely due to differences in the predictive power of these inputs for undernutrition (Cavatorta et al., 2015). Moreover, a series of countries have been able to achieve rapid improvements in child nutritional status (Headey, 2013). Recent reports from UNICEF and the International Food Policy Research Institute contain a series of case studies on successful reductions in stunting prevalence in the best performing countries (International Food Policy Research Institute, 2014, 2015; UNICEF, 2013).

Therefore, it seems that other more direct interventions will be required to achieve global targets for reductions in stunting and undernutrition among children. The literature has begun to emphasize that the quality of economic growth is likely to be important for how income gains translate in reductions in child undernutrition (Haddad et al., 2015b). The impact of intermediary factors on stunting, such as sanitation, governance, the roll-out of nutrition programmes, growth in food production, infrastructure, access to health services, infrastructure, governance, education, and fertility have all been investigated previously (Alderman et al., 2006b; Fink et al., 2011; Headey, 2013; Smith and Haddad, 2015; Webb and Block, 2012). Focusing on promoting economic growth that raises the income of the least-well off, and improves the quality and equity of these intermediary inputs, is thus likely to be the most effective way of ensuring that economic growth leads to reductions in the prevalence of child stunting (Haddad, 2015).

7 Discussion

7.1 Summary of the Evidence Linking Childhood Stunting and Undernutrition to Economic Outcomes

The evidence reviewed in this paper supports the hypothesis that children affected by stunting or undernutrition are negatively impacted in terms of a variety of economic outcomes, including productivity, occupational status, and wages. The magnitude of the relationship between stunting and wages is larger in intervention studies (two nutrition programmes were associated with a 25% and a 46% increase in adult wages for affected children) than quasi-experimental studies (where we find that each centimeter increase in adult height is associated with an increase in wages of 4% for men and 6% for women), which is in turn larger than that found in observational data (where the corresponding wage estimate is 1% for men and women).

A theme in this review is that there is a great deal of heterogeneity in terms of coefficient estimates, both across countries and gender, although estimates in low and middle income countries do appear larger on average than those from high income countries such as the UK and the US. This heterogeneity is likely to partly reflect the fact that outcome measures are different (for example, hourly wages versus income), different methodologies are employed, and different control variables are used across the studies. Age and period effects are likely to be important but are not always accounted for. A methodological drawback of almost all the studies we reviewed is that very few adjust for the decision on whether to participate in the labor market, and only consider the earnings of those who are employed. It could be that those who are not currently employed would have lower earnings if they entered the labor market, and those outside the labor market may also be the most likely to be of lower height. An exception is a study of female graduates in Taiwan (Tao, 2014). From that perspective, the results presented here may be underestimates. The studies we report on also use a variety of different exposures to measure the impact of child undernutrition, and it is important to bear in mind that the results are therefore not always directly comparable. Intervention and prospective analyses tend to rely on measuring childhood undernutrition using height-for-age, which is understandable given that this approach provides objectively measured information which is feasible to collect in a variety of contexts, including household surveys. Whereas stunting can be used to identify growth and nutritional deficiencies, along with cumulative undernutrition, these measures also have their disadvantages (for example, they may capture other aspects of early life conditions including disease environment and genetic growth potential, and have a lesser capacity to capture marginally inadequate diets or short-run episodes) (Corsi et al., 2011). Cross-sectional analyses rely on proxying childhood nutritional status with adult height, which also has its limitations. It is difficult to assess the extent to which these issues affect our conclusions without further data from prospective studies which credibly address measurement error, unobserved confounding, and selection into the labor market. An assessment of publication bias in the literature would also be beneficial. It is important to bear in mind that we do not have the same kind of evidence that would be provided by multiple RCTs conducted in a variety of different contexts, and therefore we have tried to summarize the weight of the available evidence across a range of studies from different methodologies and of varying quality. One question is how to reconcile that results from the two experimental studies are substantially higher than median quasi-experimental estimates. It is likely that there are at least two pathways linking stunting to adult outcomes, including a pure stature effect, and the effect of lost growth potential encompassing cognitive impacts of undernutrition. Unlike most quasi-experimental studies, long-run follow up of nutrition interventions can isolate the latter, which we would expect to be larger. It remains to be seen whether the magnitude found in the two existing studies is observed in subsequent trials, but nevertheless, even if we focus solely on the lower quasi-experimental median estimates, the evidence from different sources is still generally consistent with the hypothesis of substantial economic returns to nutrition in early childhood.

Stature in adulthood is also linked to other economic outcomes, including occupational status, and other measures of socioeconomic position. Studies which examine potential mechanisms indicate that there is a direct association of stature with productivity and fatigue (Florêncio et al., 2008; Price, 2013). An alternative set of studies which examine more short-run relationships find that child undernutrition affects cognition and schooling. Controlling for these variables in height regressions generally attenuates coefficient estimates, supporting this interpretation, at least in low and middle income countries. Health effects of stunting across the life cycle are also likely to be substantial, as are effects of in utero environment on health and economic outcomes. Separating out optimal timing of investments in infant and children remains an important direction for future research (Doyle et al., 2009). Intergenerational-transmission of disadvantage is another pathway which we did not cover in this review except insofar as it relates to economic outcomes, but this is also likely to be an important consequence of child undernutrition (Behrman, 2009; Krzyzanowska and Mascie-Taylor, 2011).

Cost benefit analyses that evaluate programs implementing nutrition interventions tend to find that they are cost-beneficial, some very cost-beneficial, and studies which aggregate costs across all affected individuals in a country or set of countries find that the total costs of child stunting and undernutrition are high. Our median quasi-experimental estimate of the return to 1 cm of height of 4% for men is similar to that used in previous cost benefit analysis of 7% (Qureshy et al., 2013), research on economic growth of 3.5% (Weil, 2007), and global estimates of the economic burden of stunting of 0.5% to 4.5% (depending on the country) (Horton and Steckel, 2011). When a high proportion of a cohort within a country are affected, these studies may miss spillover effects on labor markets and technological progress and their consequent impact on economic growth. This is an important direction for future research, and taking account of externalities in the interaction between undernourished individuals, cohorts, and labor markets, potentially using a production function approach such as that taken in more general studies of health and GDP (Bloom et al., 2014), to measure the impact of stunting or childhood undernutrition on economic growth would be of great interest. In contrast to the impact of stunting or undernutrition on economic growth, there are relatively more studies that examine the impact of economic growth on stunting. In this literature, even the studies that do find an association between economic growth agree that the magnitudes involved are not large, at least in the short run. A focus on the quality of economic growth, intermediary inputs including sanitation, education, quality of diets and access to basic health services, and a combination of poverty reduction and direct nutrition interventions, are likely to be most effective at achieving large reductions in stunting (Haddad et al., 2003).

7.2 Implications for Countries with High Stunting Prevalence in the Context of Sustainable Development Goals Post-2015

There has been some progress in reducing child stunting and undernutrition over recent decades, with stunting prevalence falling from 50% in 1970 to 30% in 2010 among low and middle income countries. However, stunting remains high in some regions, and is currently at 38% in South Asia and 37% in sub-Saharan Africa. The current momentum and international agreement on the importance of reducing undernutrition among children is apparent in the proposed inclusion of food security and nutrition as one of the Sustainable Development Goals, the emergence of initiatives such as the Scaling up Nutrition (SUN) movement (scalingupnutrition.org), and the targets for reductions in stunting set by the World Health Assembly and United Nations and endorsed by the SDGs (UNICEF, 2013). However, further evidence is needed to inform how best to prioritize effective and cost effective interventions to reduce stunting in the most adversely affected areas. Reviews of effective treatments for the direct causes of growth restriction have identified promising interventions, including peri-conceptual folic acid supplementation, maternal energy, protein, calcium and micronutrient supplementation, promotion of breastfeeding and appropriate complementary feeding of children, vitamin A and zinc supplementation for children, and management of acute malnutrition (Bhutta et al., 2013). However, to unleash the potential of nutrition programmes, progress is needed in addressing persistent socio-economic inequities (Oruamabo, 2015). Intervention studies suggest that a combination of nutrition and stimulation packages in early childhood may have the greatest impact (Alderman et al., 2014a; Gertler et al., 2014; Yousafzai et al., 2014).

While economic growth in South Asia has been rapid, with more than a doubling of GDP over the past four decades, levels of per-capita GDP remain low. India experienced 8% growth in GDP from 2000-2010, and during the period 1981-2005 India's poverty rate fell from 60% to 42% (Haddad, 2011). Despite this being similar to China's reductions in poverty, stunting fell much more rapidly in China than in India over the period. One potential explanation for this is the low coverage of nutrition interventions. For example, only 25% of vulnerable children benefited from feeding interventions and only 30-40% received vitamin A supplements (Haddad, 2011). Uneven economic growth which does not achieve gains spread equally across the distribution of households is another potential explanation for the lack of improvements observed in India following rising aggregate income per capita (Haddad, 2015; Haddad et al., 2015a).

In a recent assessment of the underlying determinants of stunting in South Asia, Smith and Haddad (2015) point to factors other than economic growth which are likely to be relevant for improving levels of child undernutrition. Access to sanitation, dietary diversity of food supplies, and gender equality have potentially high rates of return because they are farthest below their desired levels. In particular, only 38% in South Asia have adequate sanitation access, while only 40% of the food supply is made up of non-staples, resulting in a poor-quality diet as highlighted by the fact that fewer than 25% of young children are fed diets that meet the minimum adequacy for child growth and development (Aguayo and Menon, 2016). Another area of emphasis is governance and accountability, particularly given that children are especially vulnerable to poor public services, but are not easily heard because of their lack of political voice, and the relative lack of attention paid to undernutrition (Haddad, 2011).

Interventions targeting these factors are largely in the hands of states and provinces in countries such as India and Pakistan respectively, and coupled with the results provided in this paper and the literature, there is therefore the opportunity to view investments in child nutrition as a strategy for economic growth and human capital formation at the state and local levels. States in India and provinces in Pakistan have gained increasing autonomy for administering major family and child programmes over the past three decades with decentralization/devolution of nutrition and other social welfare budgets (Jenkins, 2014).

8 Conclusions

In a review of evidence assessing the economic impacts of stunting and childhood undernutrition, we find that results from intervention studies and quasi-experimental research consistently indicate substantial economic returns to linear growth and reductions in stunting at the individual level. The median return in instrumental variables analyses to a 1cm increase in height was found to be 4% for men and 6% for women. Two long term follow-ups of intervention studies show even more substantial returns to nutrition-related programs (16% per centimeter in a study in Guatemala). On the basis of these estimates, nutrition investments are likely to be cost beneficial, especially if they focus on the one thousand days from conception to age two and adolescence, and they prioritize evidence-based interventions identified in the literature and promoted internationally.

At the national level, progress has been uneven at reducing stunting, and South Asia and sub-Saharan Africa in particular have lagged behind other regions. In India, slow improvement in reducing child undernutrition stands out because of rapid economic growth. Focusing on combinations of nutrition programs and proximal determinants, such as gender equality and sanitation, may provide a more reliable method of reducing child undernutrition than low quality economic growth that is not broad-based and beneficial for poorer or more vulnerable children and households. Because of likely spillover effects of reductions in stunting prevalence on labor markets and productivity, investments targeted at reducing child stunting and undernutrition are likely to have substantial returns to society in terms of increases in economic growth and human capital formation.

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Key Messages

1. Undernutrition in childhood, primarily as measured by stunting or height-for-age, is consistently linked to worse economic outcomes as an adult

2. Although lower than results from the two existing nutrition intervention studies which track affected children across the life course, quasi-experimental estimates of the impact of height on wages are substantial, the median being 4% per CM for men and 6% for women

3. Cost benefit analyses of childhood nutrition interventions typically find them to be cost beneficial or highly cost beneficial

4. At the country-level, there is little evidence that short-run increases in GDP can achieve meaningful reductions in stunting prevalence, if increases in national income are not directed at improving the diets of children, addressing gender inequalities and strengthening the status of women, improving sanitation and reducing poverty and social inequities

5. Few studies examine the impact of undernutrition on economic growth, but spillover effects of health on labor markets and capital accumulation may be substantial

6. Countries facing high stunting prevalence, such as those in South Asia and sub-Saharan Africa, should consider resources used to improve childhood nutrition as cost-beneficial investments in the wellbeing of their populations and their economies

Appendix

Notes on Papers Measuring the Association Between Adult Height And Wages

For studies shown in Tables 6 and 7 which report coefficients associated with height measured in inches, we transform the coefficients by multiplying by 0.4. For studies which use log height instead of height as the measure of exposure, we transform the coefficients so that they refer to a 1cm change at mean height. The final columns of Tables 6 and 7 give details of the studies to which these transformations apply. Where available, we report results for the full sample, men only, and women only. Coefficients are shown in the tables and are donated NS where no statistically significant relationship was found. It is important to note that outcomes were measured at various different ages, and the outcome measure was not always the same, for example sometimes total annual income was used and sometimes hourly wages were used as the outcome. These details are also recorded in the final columns of Tables 6 and 7. Because of the potential for household investment decisions to be made jointly for developmental inputs such as nutritional intake and schooling, and because nutrition may affect educational attainment, there is a debate as to whether education should be included as a control variable in these models (Case et al., 2009). When multiple specifications are reported in these papers, we show results from more parsimonious specifications without these control variables, which tend to reduce the magnitude of the estimates when they are included. Other studies which use categorical height or income measures which are not measured in logs are reported in the next section.

Evidence from Cross-Sectional Studies of Adult Height and other Economic Outcomes in Adulthood

A series of other studies examine adult height and adult economic outcomes, however they are not included in Tables 6 and 7 as they are not directly comparable with the estimates reported in these tables. Countries for which other studies find associations between categorical height and income include the US, Indonesia, Vietnam, France, Norway and the UK (Batty et al., 2009; Deaton and Arora, 2009; Haakon and Selmer, 1999; Harper, 2000; Judge and Cable, 2004; Rashad, 2008; Schick and Steckel, 2015; Singh-Manoux et al., 2010; Thomas and Frankenberg, 2002). One notable study finds that among coalminers in India, workers of above average height earn 9–17% more than their shorter counterparts, and 6–13% more than the average reference height (Dinda et al., 2006). Another notable study is an exception to the general finding that height is related to earnings, and examines stunting among the Tsimane, a foraging–farming society in Bolivia, where there does not appear to be an income or wealth penalty for those with a height deficit (Godoy et al., 2010). Height has been found to be related to occupational grade in Canada (for men, but not for women), the UK, and France, Communist Party membership in China, and social status in East and West Germany, the UK, and Vietnam (Yamamura et al., 2015; Case and Paxson, 2011; Gawley et al., 2009; Herpin, 2005; Komlos and Kriwy, 2002; Kuh et al., 1991; Li et al., 2004; Walker et al., 1988). Height gradients in wealth have been observed across low and middle income countries (Subramanian et al., 2011). Intergenerational mobility is another outcome found to be associated with height in the UK (Krzyzanowska and Mascie-Taylor, 2011). A series of papers examine height and the earnings and socioeconomic position among migrants and minorities in the US and China (Hersch, 2008; Richmond et al., 2013; Wang, 2015). Historical studies of occupational class in Spain, Sweden, and Ireland have also revealed height gradients (Öberg, 2014; Ayuda and Puche-Gil, 2014; Young et al., 2008). Finally, there is a growing literature which uses height to examine socioeconomic inequality more broadly (Moradi and Baten, 2005; Baten, 2000; Baten and Blum, 2012; Blum, 2014; Blum and Baten, 2011).

Methodological Challenges

Assessing the Relationship Between Stunting and Economic Outcomes at Different Levels of Aggregation

Conceptually, there are two levels at which the relationship between stunting and child undernutrition and adult outcomes could be assessed. First, the effect of stunting on that child's economic prospects, specifically whether those children who experience stunting go on to suffer disadvantage throughout their life course. Second, the effect of the prevalence of stunting on the outcomes of a particular country, specifically whether the extent of stunting experienced by that country's children has an impact on subsequent economic growth. There are challenges to identifying the causal effect of stunting in either case. In the former, stunting clearly happens during infancy and early childhood, prior to when adult economic outcomes are realised, and therefore the temporal ordering is clear. However, as we discuss below there are other challenges that must be examined when considering individual level outcomes. In the latter case where we are concerned with country level measures, the same problems as we discuss below generally apply, with the addition of the complication that it is not obvious how we could easily rule out reverse causality because the level of economic development is likely a determinant of the prevalence of undernutrition.

Evaluating the Individual Level Effects of Stunting and Childhood Undernutrition

A number of pathways support the hypothesis of a causal effect of childhood stunting on economic outcomes in later life, however, because undernutrition is not randomly assigned, there may be alternative explanations for an observed association between childhood undernutrition and (for example) wages in later life. For instance, genetic endowment could affect stunting but could also affect labor market outcomes, as could birth weight. More generally, undernutrition could be related to a number of family background variables which are difficult to measure but which could be the real cause of adverse outcomes in later life for stunted children.

Some of the methodological difficulties associated with establishing whether there are economic returns to investments in stunting reduction are general concerns which arise when trying to establish the life cycle impact of early life conditions, and some are unique to the particular exposure of interest. Central to the former is the problem of unobserved confounding. As nutritional status is not randomly assigned, ascribing all differences in the adult outcome of interest to differences in whether those adults were stunted as children is problematic because there are likely to be other factors which affect both, such as, for example, parental involvement in a child's development or genetic endowment. These omitted confounders could operate at the level of the individual, the household, neighborhood, or even the country (although we would hope to be able to account for these at a minimum). It is possible that these background characteristics are positively correlated with stunting and subsequent measures of socioeconomic status in adulthood, such that children who are stunted are also exposed to other disadvantages which are hard to measure, in which case unadjusted estimates of the effects of stunting would be biased upwards because they also incorporate the influence of these other factors. The economics literature also raises concerns about how parents allocate resources within households (Schultz, 2003a). Under the framework of maximizing returns to investments in their children, parents will consider the costs and benefits of these investments over the course of their lifetimes and the lifetimes of their family members. For example, they might prefer to spend less on the education of stunted children because the expected economic return to education may be lower for those who are undernourished. Ideally, when estimating the economic returns to stunting, researchers would separate out factors influencing the investments in human capital from those directly affecting the child's later wage earning capacity. The extent to which households operate in this manner and react to either reinforce or compensate for initial endowments is open to debate (Almond and Mazumder, 2013), however this framework does illustrate how it can be problematic to separate stunting from human capital investments by households which also determine adult outcomes in later life. Without an approach to control for these potential unobserved confounders, it is problematic to describe any relevant associations as causal. Therefore, as in other contexts, evidence from randomized control trials, such as the provision of nutritional supplements, will likely provide the best evidence on the policy relevant effects of interest. However, in the absence of repeated trials in different countries and contexts, the external validity of findings from specific interventions may be difficult to assess.

In addition to the problem of unobserved confounding, another issue which is particularly relevant for studies on undernutrition is the issue of measurement. There are several alternatives to measuring nutrition in childhood, including anthropometric approaches such as height or length for age, weight for age, weight for height, BMI, BMI for age, and leg length, and each may capture a different aspect of nutritional intake (Corsi et al., 2011). Height for age and stunting are more likely to reflect chronic exposure to undernutrition (Smith and Haddad, 2015). However, any one of these measures could be affected by measurement error. First, the exposure of interest may be a noisy proxy for nutritional status because there may be other determinants of, stunting (for example), such as genetic or environmental influences. In this case, assuming the measurement error is random, using an anthropometric measure as the exposure of interest would tend to attenuate coefficient estimates and we would evaluate the effect of undernutrition to be smaller than if we had been able to use an exposure which better captured true nutritional intake. Therefore, the measurement error problem likely biases effect size estimates in the opposite direction to what would be anticipated from omitted confounding. This problem of measurement error is exacerbated in practice because we often do not have prospective data, and instead require a proxy for the childhood anthropometric measure. There are in fact relatively few cohort studies in which the members are sufficiently old to track them into adulthood, and even in these prospective studies the relevant information on childhood characteristics or adult economic outcomes may not have been collected. As shown in Tables 4–6 in the main text, most of the evidence on height and economic outcomes is from cross-sectional data, and many studies in the literature examine the relationship between adult stature and adult outcomes, with the assumption that adult height is sufficiently correlated with height in childhood that it can be used to retrospectively measure childhood conditions. While more direct measures of childhood circumstance would ideally be employed, focusing only on the limited number of prospective studies would substantially limit the available evidence on the economic effects of stunting. The use of adult height in this manner is based on the argument that because height is largely fixed in adolescence (Case and Paxson, 2008b), and childhood growth is a major determinant of adult height (Stein et al., 2010). However, this is likely to induce even more measurement error because we are unable to adopt an exposure measured in childhood.

There are several approaches to dealing with these issues of measurement error and unobserved confounding in the literature outside of randomized control trials. One approach is to use natural experiments, where adults observed contemporaneously are tied to events which occurred in their childhoods which can be reasonably be linked to exposure to undernutrition, for example a famine. These events are termed natural experiments because they assign nutritional status to the exposed cohort or individuals in a manner which is assumed to approximate random allocation. For example, a famine is likely to be unanticipated, and depending on the context, the exposure may be uncorrelated with the characteristics of affected individuals. Drawbacks of this approach are that this assumption of exposure being as good as randomly assigned cannot generally be proven, and there are often questions about external validity arising from very specific events or contexts. For example, estimating the effect of famine exposure may be less policy relevant than exposure to low level chronic undernutrition over the course of childhood. This natural experiment approach is similar to the instrumental variables (IV) method, in the sense that both use sources of variation in undernutrition which are assumed to be unrelated to potential omitted confounders and affect the outcomes of interest only through their effect on nutritional status (Greenland, 2000; Angrist and Krueger, 2001). While there are studies which use the IV method to assess the impact of undernutrition on health (van den Berg et al., 2015), we were unable to locate any studies which used this approach to examine economic outcomes in prospective or retrospective data, other than one paper which used randomized treatment of nutritional supplements as the instrumental variable (Hoddinott et al., 2013b). A conceptually similar approach to account for unobserved confounding is to compare exposure among siblings and twins because this allows the researcher to account for all factors common to either the sibling or twin pair. Although this method does not adjust for measurement error in and of itself, it can be combined with instrumental variables, for example as in Böckerman and Vainiomäki (2013).

A limitation of the IV method is that it can be difficult to find plausible variables which affect the outcome of interest only through the relevant exposure. In the case of using instrumental variables to adjust for measurement error, there is a similar requirement that the measurement error in the instrument is uncorrelated with the measurement error in the exposure variable. In the case of IV studies which examine the effect of height on wages, the instrumental variable must be correlated with height, but unrelated to those background characteristics which also affect wages in later life. Schultz (2003a) suggests the use of the market price of inputs to produce the human capital, or random variation in the local health infrastructure or weather shocks as candidate instruments, and these are typically the type of variables used in the literature. However, there are concerns about the extent to which these factors are simply a reflection of unobserved background characteristics of individuals or households, in which case resulting IV estimates would be biased (Weil, 2014). Nevertheless, to the extent that we expect measurement error to attenuate estimates of the effects of height, it is important to adjust for this in empirical studies, or at least bear in mind that unadjusted estimates may be underestimates.

Plausible Mechanisms Linking Stunting to Economic Outcomes

There are likely to be several channels through which child stunting affects economic outcomes in later life. For example, there is evidence that undernutrition impacts on cognition in childhood (Sudfeld et al., 2015), which has spillover effects on subsequent educational attainment and cognitive ability in adulthood (Alderman et al., 2006a, 2009). Therefore, we would expect earnings to be lower for those who experienced undernutrition in childhood because their educational attainment is lower. Health is another pathway (van den Berg et al., 2015), and those who are undernourished in childhood are likely to have subsequent health problems which may affect their productivity in adulthood. Other potential mechanisms include behavior and risk preference. Some studies provide evidence on these potential pathways linking height to outcomes such as income. These include the productivity of sugarcane laborers in the State of Alagoas, north-eastern Brazil (Florêncio et al., 2008), and worker fatigue in Tanzania (Price, 2013). Other studies examine whether the height coefficient attenuates with the addition of control variables which are potential outcomes of stunting, and this approach can be useful in shedding light on the relevant mechanisms (Case and Paxson, 2008a,b; Lundborg et al., 2014; Persico et al., 2004; Schick and Steckel, 2015). Generally there is evidence supporting the existence of educational and cognition pathways in these studies, however the full effects of stunting which operate through these variables ought to be included in estimating the economic returns to nutrition interventions and not adjusted for, seeing as they at least partly represent outcomes of the adverse effects of undernutrition.

Limitations of the Literature

When interpreting the results presented, it is important to bear in mind a number of limitations of this literature. There are only two randomized control trials on this topic, one from Jamaica, and one from the INCAP study conducted in Guatemala. Both of these studies show large returns to the intervention, and large effects of nutritional supplementation. Further studies are required to establish the extent to which these results are generalizable. Another set of estimates come from prospective studies which measure stature contemporaneously in childhood, but suffer from the drawback that they may be affected by unobserved confounding. Natural experiments offer an opportunity to adjust for this limitation in cross sectional data, however again it is unclear as to the extent to which it is possible to generalize from specific events such as famines. The next set of estimates come from cross-sectional studies which attempt to adjust for measurement error using instrumental variables analysis. However, these require additional assumptions, specifically the existence of a variable which is correlated with the outcome, height for example, but affects the outcome only through its association with height. The validity of this assumption is often open to question and is generally not possible to test empirically. Most of the studies listed in this review use background variables such as characteristics of place of birth as instrumental variables , or other strategies based on correction procedures which make strong assumptions about observed confounding. Therefore, it is unclear whether the requirements for valid instrumental variables estimates are met in practice. While it is plausible that estimates from IV studies should be larger than OLS estimates because measurement error can be expected to attenuate coefficient estimates of effects of exposure to undernutrition using imperfect proxies, often the IV estimates are substantially greater than their OLS counterparts.

Further Details on the Impact of Economic Growth on Stunting

There is a generally a strong cross sectional relationship between measures of national income and nutrition, which is at least suggestive that improvements in economic growth could help reduce prevalence of undernutrition and stunting among children. The association between income and nutrition is also observed at the household level, with wealthier households tending to have lower stunting prevalence (Krishna et al., 2015). A review of studies examining the relationship between per capita household income or expenditure and child height for age Z scores found the median of 14 semi-elasticity estimates to be 8.4%, that is to say a doubling of income was on average expected to raise height for age Z scores by 8.4%, with the other point estimates ranging from 0 to 17% (Haddad et al., 2015b).

There are numerous channels through which poverty, and therefore income per capita, are expected to impact on the nutritional status of children. For example, raising incomes can increase capacity to purchase food, raising both the quantity and the quality of nutrient intake for women and young children. In addition, net nutritional intake (the nutrients available to contribute to child development) is also likely to increase because of reductions in the risk of infection and poor health (Shekar et al., 2006). At the national level, education, infrastructure and health services are all positively associated with GDP. However, from the perspective of families, economic growth may not necessarily translate into improvements in household incomes in the manner expected due to unequal sharing of income gains, lack of access to public and private services, and potential negative externalities (Haddad, 2015; Haddad et al., 2015a). Therefore, whether this relationship holds in practice needs to be estimated empirically in order to better understand whether improvements in economic growth are likely to reduce the prevalence of stunting, and whether public policy aimed at reducing undernutrition among children should focus on reducing poverty more broadly, or instead, or additionally, be targeted at specific nutrition-focused interventions (Haddad et al., 2015b).

Table A1: Notes to Intervention Studies, Prospective Cohorts, and Natural Experiment Papers

Authors	Age at outcome	Year of Outcome	N	Childhood controls	Notes
Intervention Studies					
Gertler et al. (2014)	22	2007-2008	105	Y	Enough for intervention group to catch up with non-stunted; not a nutrition intervention per se
Haas et al. (1995, 1996)	11-27	88-89	364	Y	Mainly in males, effect largest for those exposed in gestation and up to 3 years of age
Hoddinott et al. (2005, 2008); Martorell et al. (2010)	25-42	2002-2004	1,424	Y	Effect present in men only
Hoddinott et al. (2013b)	25-42	2002-2004	1,338	Y	Stunting was instrumented for (IV) with nutrition intervention
Prospective Studies					
Galler et al. (2012)	37-43	2007-2010	123	Y	Effect was attenuated by addition of IQ in childhood
Satyanarayana et al. (1979)	14-17	1976-77	96	N	Effect operated through current weight
Carba et al. (2009)	20-22	2005	1,795	Y	Small number still in school

Barker et al. (2005)	56-66	1990	4,630	Y	Men only; No effect on growth age 1 - 12
Case et al. (2005)	33, 42	2000, 1991	5,339	Y	
Montgomery et al. (1996)	22-32	1981-1991	2,256	Y	Only men were included in the study; Height in adulthood did not predict employment
Persico et al. (2004)	33	1991	1,772	Y	Height was measured in inches, coefficient is scaled by 0.4
Persico et al. (2004)	Mean=35	1996	1,577	Y	Height was measured in inches, coefficient is scaled by 0.4. Self-reported height in NLSY
Sargent and Blanchflower (1994)	23	1981	12,537	Y	
Victora et al. (2008)	2123	2003	4,297	Y	Annual income (log US$); Other exposures including birth weight examined and significant
Victora et al. (2008)	2641	2010	1,571	Y	Annual income (log US$); Other exposures including birth weight examined and significant
Victora et al. (2008)	2632	2011	1,583	Y	Other exposures including birth weight examined and significant

Natural Experiments					
Chen and Zhou (2007)	Mean age=31	1991	1,068 - 1,871	Education only	Effects strongest for those exposed in childhood and in gestation; Income effects were somewhat inconsistent depending on measurement
Jürges (2013)	25	1970	450,000 - 420,000	N	Evidence of effects on education in Germany and supplementary analysis of Austrian Census; Comparison is with adjacent cohorts who also experienced adverse events in childhood; effects stronger for those in utero
Lundborg et al. (2014)	28-32	2003	450,000	Y	Annual earnings; height associations are non-linear
Neelsen and Stratmann (2011)	Mean age=31	71-2001	43,177 - 80,993	N	Effects for cohorts exposed as fetuses are very small and not statistically significant, not significant in all censuses

Maccini and Yang (2009)	Mean age=21	2000	6,295	N	Rainfall in the years after the birth year has no statistically significant relationship with adult outcomes, and there was no effect of rainfall in the years prior to the birth year. Suggests the first year of life is the most important. Affected women were also taller.

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