

The Aggregate Income Losses from Childhood Stunting and the Returns to a Nutrition Intervention Aimed at Reducing Stunting

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Abstract

This paper undertakes two calculations, one for all developing countries, the other for 34 developing countries that together account for 90 percent of the world's stunted children. The first calculation asks how much lower a country's per capita income is today as a result of some of its workers having been stunted in childhood. The analysis uses a development accounting framework, relying on micro-econometric estimates of the effects of childhood stunting on adult wages, through the effects on years of schooling, cognitive skills, and height, parsing out the relative contribution of each set of returns to avoid double

counting. The estimates show that, on average, the per capita income penalty from stunting is around 7 percent. The second calculation estimates the economic value and the costs associated with scaling up a package of nutrition interventions using the same methodology and set of assumptions used in the first calculation. The analysis considers a package of 10 nutrition interventions for which data are available on the effects and costs. The estimated rate-of-return from gradually introducing this program over a period of 10 years in the 34 countries is 17 percent, and the corresponding benefit-cost ratio is 15:1.

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1. INTRODUCTION

In 2014, 171 million children under the age of five were stunted (UNICEF et al. 2015). Loosely-speaking ‘stunting’ means a child is excessively short for their age; statistically-speaking, it means the child’s height-for-age z-score (or HAZ) is less than 2 standard deviations below the median of a healthy reference population.

Stunting in childhood matters because it is associated with adverse outcomes throughout the life cycle (Dewey and Begum 2011). The undernourishment and disease that cause stunting impair brain development, leading to lower cognitive and socioemotional skills, lower levels of educational attainment, and hence lower incomes. Health problems in terms of non-communicable diseases are more likely in later life, leading to increased health care costs. Stunting in childhood also leads to reduced stature in adulthood, which, due to the persistence of shortness over the lifetime, and the negative (and independent) effect of height on income, further reduces income in adulthood. Yet stunting is not a given: it can be avoided if the child (in utero and after birth) has adequate nutrient intake, and is not exposed to bouts of disease that weaken the body. Programs that increase the flow of nutrients and reduce exposure to disease can reduce the risk of stunting, and potentially eliminate it altogether (de Onis et al. 2013).

In this paper, we undertake two calculations, one for all developing countries, the other for 34 developing countries that together account for 90% of the world’s stunted children. The first asks how much lower a country’s per capita income is today as a result of some of its workers having been stunted in childhood. This is a backward-looking exercise, asking, in effect, what the costs are today of not having eliminated stunting in the past. Very few studies have asked how much lower today’s GDP is as a result of underinvestment in nutrition programs, and only one has looked at stunting

specifically. Martinez and Fernández (2008) estimate the cost of low birth weight and underweight of the members of the current workforce results in a productivity loss to be between 2% and 11% of GDP, but do not look at the aggregate economic penalty associated with stunting. The only paper that does is Steckel and Horton (2013), who use historical data on adult height trends to estimate the cost of adult stunting in the 20th century to be around 8% of GDP.¹ The value-added of the first part of our paper is to estimate the economic cost of stunting using a modeling method commonly used in macroeconomics – a development accounting framework (Caselli 2005; Hsieh 2010; Caselli and Ciccone 2013) – that allows to quantify how much childhood stunting among today’s workers can account for cross-country differences in today’s GDP. To do so, we rely on micro-econometric estimates, and factor in the effects of childhood stunting on adult wages through their effects on years of schooling, cognitive skills, and height, parsing out the relative contribution of each set of returns to avoid double counting. We estimate that, on average, the per capita income penalty from stunting is around 7%, i.e. per capita income in the developing world would have been 7% higher if nobody currently working had been stunted in childhood. Africa and South Asia incur larger penalties: around 9-10% of GDP per capita.

In the second part of our paper, we perform a forward-looking exercise, assessing the economic value and the costs associated with scaling up a package of nutrition interventions using the same methodology and set of assumptions used in the first calculation. If the per capita GDP penalty of stunting is so large, a program or intervention that reduces stunting might have an appreciable rate-of-return, providing its costs are not too large, and/or its effects on stunting are not too small. There is a sizable literature (synthesized in a series of systematic reviews and meta-analyses) on the effects of various nutrition-specific programs (e.g. breastfeeding promotion) and nutrition-sensitive

¹ The economic losses in terms of productivity are computed only for those cm of height lost below 170cm.

programs (e.g. water, sanitation and hygiene interventions). The vast majority of this literature focuses on the effects of the programs and ignores the costs. In our second calculation we take one program (a package of 10 nutrition interventions) that has data on both effects and costs, and we estimate the rate-of-return to gradually introducing this program over a period of 10 years in 34 countries that together account for 90% of the world's stunted children (Bhutta et al. 2013). Three studies have also estimated the cost-benefit ratio of scaling up the same nutrition package, either globally (Hoddinott et al. 2013; Alderman et al. 2017) or in high-burden countries (Hoddinott 2016). All provide an estimate of the economic value of reducing stunting on adult wages, and take into account the fact the costs are incurred now, while the individual is a young child, and the benefits only begin to start flowing when the individual joins the labor market; thus, these studies require discounting to obtain the net present value of the benefit of scaling-up the package of interventions. The value of reducing stunting is obtained either from long-term estimates from a randomized intervention in Guatemala (Hoddinott et al. 2013), or by mapping the benefits from reducing stunting through changes in schooling, and from schooling to earnings (Alderman et al. 2017). One of our contributions to the literature is to use the same development-accounting framework used in our backward-looking exercise to model the benefits of a nutrition intervention. Another is to allow for influences on income occurring through channels other than education – our results allow for effects operating through cognition and height, holding constant the effects operating through education. We also allow for region-specific program costs as calculated by Bhutta et al. Our calculations also allow for the fact that in the absence of the program stunting would likely have been falling anyway, using our estimates of underlying historical trends in stunting reduction.² We estimate a rate-of-return for the 34 countries as a whole of 17%, with a benefit-cost ratio of 15:1. We find the highest

² Alderman et al. (2017) also do so, using projected rates of stunted reductions from past trends by UNICEF.

rate-of-return in East Asia & Pacific (24%), reflecting the low per capita program cost, the high rate of return to education, the high initial GDP per capita, and the high GDP growth rate.

The rest of the paper is organized as follows. Section 2 contains our estimates of the aggregate costs of stunting. Section 3 contains our estimates of the rate-of-return to the package of 10 nutrition interventions. And section 4 contains our conclusions.

2. ESTIMATING THE COSTS OF STUNTING

In any year, the workforce comprises workers of different ages, typically with proportionally more young workers than old workers. Young workers are less likely to have been stunted in childhood than old workers – a worker aged 50, for example, has a probability of being stunted in childhood equal to the childhood stunting rate almost 50 years ago. The average rate of childhood stunting of the workforce will reflect childhood stunting rates over the period from around 50 years ago to around 15 years ago. If those in the current workforce who were stunted in childhood had instead not been stunted in childhood, they would not have suffered impaired cognitive development during childhood, they would not have received less education, and they would have grown to a regular height. Their income today would have been higher by a percentage that reflects the education penalty associated with childhood stunting, the returns to education, the adult height penalty to childhood stunting, the returns to height, the cognitive skills penalty to childhood stunting, and the returns to cognitive skills. By doing a meta-analysis of the relevant literature, we can put numbers on these parameters. And by finding out the age distribution of current workers, we can find out what fraction of current workers were stunted in childhood. Putting the two sets of numbers together, we can quantify the per capita income penalty a country incurs for the fact that some of its current workforce were stunted in childhood.

2.1 Methods

We use a development accounting approach (cf. e.g. Weil 2007; Hsieh and Klenow 2010; Hanushek and Woessmann 2012; Caselli and Ciccone 2013). The method has been used in the growth literature to explain how income differences across countries *at a given point in time* can be explained by its proximate determinants, i.e. differences in factors (human and physical capital) and differences in the efficiency of these factors. This literature uses micro-econometric studies to calibrate the parameters of the production function rather than estimating them using cross-country regressions; the latter are very sensitive to the sample and the estimation method used, and it is hard to credibly address endogeneity concerns.

We follow the literature and assume that aggregate income can be represented by the Cobb-Douglas production function:

$$Y = A \cdot (N_W \cdot hk)^\alpha K^{1-\alpha}$$

where Y is aggregate income (or GDP), A is a shift factor (or residual total factor productivity), N_W is the number of workers, hk is human capital per worker, K is aggregate physical capital, and α is the elasticity of income with respect to aggregate human capital. If N is population, we can rewrite the production function in per capita terms as:

$$\frac{Y}{N} = A \cdot \left(\frac{N_W}{N} hk \right)^\alpha \left(\frac{K}{N} \right)^{1-\alpha}$$

or in log terms as

$$(1) \quad \ln y = \ln A + \alpha \ln(N_W/N) + \alpha \ln hk + (1 - \alpha) \ln k$$

where y is per capita income and k is per capita capital stock. We assume the log of per capita human capital can be written:

$$(2) \quad \ln hk = rE_W + \gamma H_W + \delta C_W$$

where E_W is mean years of education among workers, H_W is mean height among workers (in centimeters), C_W is the mean cognition among workers, r is the rate of return to a year of education, γ is the return to an extra centimeter of height, and δ is the return to an extra unit of cognition (typically measured in standard deviations of the underlying scale). We know that E_W , H_W and C_W are all associated with the fraction of current workers who were stunted as children, S_W . The higher this fraction is, the less educated current workers will be, the shorter they will be, and the lower their cognitive skills will be. Of course, only the second of these is a truly causal relationship; the others reflect the association between stunting and cognitive development in childhood, and the associations between cognitive development in childhood, on the one hand, and educational attainment and cognitive skills in adulthood, on the other.

Substituting eqn (2) in eqn (1) gives:

$$(3) \quad \ln y = \ln A + \alpha \ln(N_W/N) + \alpha[rE_W + \gamma H_W + \delta C_W] + (1 - \alpha) \ln k$$

which is the main equation of our development accounting framework. The percentage effect on per capita income of a change in the rate of childhood stunting among current workers can be derived by taking the total differential of eqn (3) with respect to S_W :

$$(4) \quad \Delta \ln y(t) = \alpha \left[r \frac{\partial E_W(t)}{\partial S_W(t)} + \gamma \frac{\partial H_W(t)}{\partial S_W(t)} + \delta \frac{\partial C_W(t)}{\partial S_W(t)} \right] \Delta S_W(t)$$

In eqn (4), $\partial E_W / \partial S_W$ is the effect on years of schooling achieved by the date of entry into the labor force of being stunted in childhood, $\partial H_W / \partial S_W$ is the effect on height in adulthood of being stunted in childhood, and $\partial C_W / \partial S_W$ is the effect on cognitive skills in adulthood of being stunted in childhood. If we measure ΔS_W by the rate of childhood stunting among current workers, ΔS_W gives us the rate reduction required to eliminate stunting among workers, and therefore the left-hand side of eqn (4) gives us the corresponding change in per capita income.

It is important to note that the comparative statics exercise that we are performing is partial in nature. We are looking at how childhood stunting translates into adult earnings via human capital while holding everything else constant (and importantly A and K). There might be important externalities and spillover effects that arise from human capital formation that are not accounted for by the development accounting approach and that are not captured in the estimates of the private returns to reduction of childhood stunting. More educated and better skilled workers might be better placed to innovate or adopt new technology (Foster and Rosenzweig 2010), hence affecting directly A . There might also be feedback effects due to general equilibrium changes as the relative supply of skilled workers changes in the relative returns to skills (i.e. r), and hence affects firms' decisions to adopt new technologies that are not skill neutral (Caselli and Ciccone 2013). We abstract from these externalities and potential other channels of social returns in this note as the quantitative evidence of such externalities is an area of active research. As a consequence, the estimates presented in this exercise are likely to represent a lower bound of the costs associated with childhood stunting.

2.2 Parameters

We need values for the parameters of eqn (4) to compute the costs of stunting. We searched the literature for estimates of the key parameters: α , the elasticity of income with respect to human capital (i.e. the labor share); r , the returns to education; γ , the return to an extra centimeter of height;

$\partial E_w / \partial S_w$, the effect on years of schooling achieved by the date of entry into the labor force of being stunted in childhood; $\partial H_w / \partial S_w$, the effect on height in adulthood of being stunted in childhood; and $\partial C_w / \partial S_w$, the effect on cognition in adulthood of being stunted in childhood. The results of our literature search are shown in Table A1 in the Annex. The parameter values we decided on based on that literature search are summarized in Table 1.

Table 1: Parameters used in estimating the cost of childhood stunting

<i>Parameter</i>	<i>Assumed value</i>	<i>Explanation / source</i>
<i>Effects of stunting on:</i>		
Education ($\partial E_w / \partial S_w$)	-1.594 fewer years of education	See Table A1
Height ($\partial H_w / \partial S_w$)	-5.981 cm shorter	See Table A1
Cognition ($\partial C_w / \partial S_w$)	-0.625 SD lower cognition	See Table A1
<i>Returns to:</i>		
Education (r)	Region-specific return per extra year of education	Montenegro and Patrinos (2014)
Height (γ)	1.7% extra income per extra cm	See Table A1
Cognition (δ)	4.3% extra income per extra SD	See Table A1
<i>Elasticity of income with respect to human capital, i.e. labor share (α)</i>	0.67	Hanushek and Woessmann (2012)

We set α equal to 0.666 (Hanushek and Woessmann 2012). For the returns to education parameter, r , we use the results from Montenegro and Patrinos (2014); we use their Table 3a which shows average returns across men and women for each World Bank region. For the other parameters, we averaged the parameter estimates across the studies in Table A1, giving a weight of 5 to the estimates based on the COHORTS study since these estimates are derived from data from five developing countries (India, Guatemala, India, Philippines and South Africa). Panel A in Table A1 provides micro estimates of the effect of having been stunted in childhood on adult and adolescent height, in centimeters $\partial H_w / \partial S_w$, as well as the returns to height on earnings in the labor market (γ) conditional on years of schooling. Most estimates are drawn from longitudinal studies that have both stunting at childhood and earnings. The effects of being stunted in childhood on attained adult (or adolescent) height are very similar when looked at as unconditional associations, or as conditional

associations, controlling for years of schooling and other socioeconomic characteristics. We take the mean estimate across all studies: moving from moderate stunting (defined as the height for age z-scores being below 2 standard deviations from the reference population) to non-stunting increases the height on average by 5.98 centimeters.

When looking at the height premium in the labor market, several studies have documented how height gets rewarded in the labor market, over and above schooling and cognition. The results are mainly from middle-income countries, and available only for men, to avoid having to model participation or selection into the labor market by females. On average, an additional centimeter in height translates into 1.7% higher wages in the labor market, after controlling for years of schooling, and sometimes cognition too. The second panel B looks at the association of having been stunted in childhood and completed years of schooling: on average, being stunted in early childhood translates into 1.59 fewer years of schooling completed, which is reduced by about half when controlling for socioeconomic status and maternal education. Finally, the left-hand columns in panel C of Table A1 summarize the estimates of the association between moderate stunting in childhood and cognitive deficits on the left-hand panel: the magnitude of the association is quantitatively important, with an average cognitive deficit of 0.625 standard deviation associated with moderate stunting. The right-side of panel C presents estimates of the conditional returns to cognition in the labor market, controlling for years of schooling and attained height, derived from longitudinal studies in middle-income countries, and available only for men, to avoid having to model participation or selection into the labor market by females.

We want $\Delta \ln y$ to be the percentage difference between actual per capita income today and what it would have been if none of today's workers had been stunted in childhood. We therefore set ΔS_w equal to the average rate of childhood stunting among today's workers, i.e. those working in

2014. We compute this as the (estimated) under-five stunting rate in the year when the median aged worker was aged 2. We estimate the median age of today's workers using the distribution of the population across five-year age bands from 15 through 55 using the population age structure data in the World Bank's World Development Indicators (WDI). Childhood stunting rates are available only for relatively recent years in the Joint Child Malnutrition Estimates (JME) data set jointly prepared by UNICEF, WHO and the World Bank,³ so we used the modeled estimates in the data set of Paciorek et al. (2013). Their data go back only to 1985, so when the median-aged worker was two in an earlier year, we use the 1985 childhood stunting rate.

As an example, take a country like Bangladesh. The median age worker for Bangladesh as from the WDI age structure in 2014 was 30. Even though the stunting prevalence in Bangladesh has almost halved in the past three decades, the relevant stunting prevalence for this exercise is the year when the median age worker was 2, i.e. 1986 (2014-30+2). The childhood stunting in 1986 ($\Delta S_W \sim$ over 70%) among today's workers is used to compute the country-specific income penalty from equation (4) using the estimated effects of stunting on education, height, and cognition as summarized below.

2.3 Results

The results are shown in Table 2 and Figure 1. The rates of childhood stunting among today's workforce vary considerably across countries depending on the historical stunting rate and the age distribution of the population. Only 6% of the workforce in Hong Kong SAR, China, was stunted in childhood. In Chile, the figure was 8%. By contrast, two-thirds of India's current workforce was stunted in childhood. Over 70% of Bangladesh's workforce was stunted in childhood.

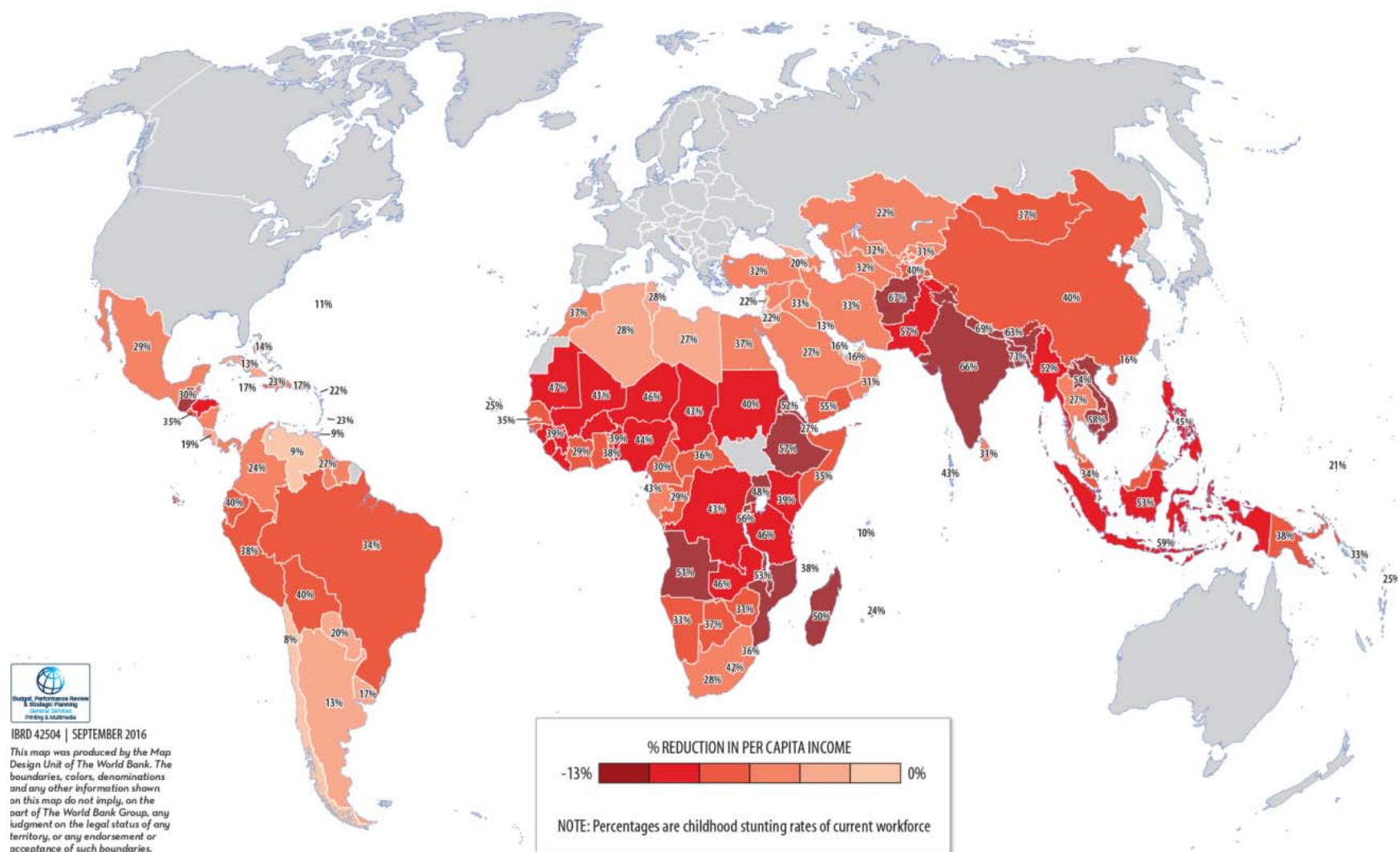
³ See http://data.unicef.org/jme_master_2015_127fcff.xlsx?file=jme_master_2015_127.xlsx&type=topics.

In part, because of these differences, the cost of stunting, in terms of the reduction in per capita income from some of today's workforce being stunted in childhood, varies considerably across countries – from 1% to 13%, with an average of 7%. Africa and South Asia are the regions with the largest average penalties – around 10% of GDP per capita. Countries (and territories) with stunting-induced per capita income reductions less than 2% include Bermuda; Chile; Fiji; Hong Kong SAR, China; Samoa; the Seychelles; Tonga; and Trinidad and Tobago. At the other extreme, Ethiopia's per capita income is 13% less than it would have been if none of its workforce had been stunted in childhood. Other countries with large 'stunting penalties' include Burundi, Guatemala, Malawi, Mozambique, Rwanda, and Vietnam.

Table 2: Costs of childhood stunting among today's workforce

World Bank region	No. countries	Mean
East Asia & Pacific	23	-7%
Europe & Central Asia	9	-5%
Latin America & Caribbean	33	-5%
Middle East & North Africa	19	-4%
North America	1	-2%
South Asia	8	-10%
Sub-Saharan Africa	47	-9%
Total	140	-7%

Figure 1: Per capita GDP effects of childhood stunting among today's workforce



3. THE ECONOMIC RETURNS TO A NUTRITION PROGRAM

The estimates of the previous section suggest there is a sizable economic penalty to not eliminating childhood stunting. This suggests that programs and policies that can reduce stunting may have large benefits. Whether they also have high rates of return depend on their average costs, i.e. the outlays required to reduce stunting by, say, one percentage point. Many studies have been undertaken estimating the effects on stunting of various “nutrition-specific” programs (e.g. breastfeeding promotion, complementary feeding) and “nutrition-sensitive” programs (e.g. agriculture, and water and sanitation), and several systematic reviews and meta-analyses are now available summarizing the effects of these programs.⁴ These reviews find only modest effects of most nutrition-specific and nutrition-sensitive programs on stunting.

This does not mean, however, that the economic returns to such programs are so small as to mean that investing in them is not worthwhile. First, as the results in section 2 make clear, even small changes in stunting can have large economic payoffs by increasing years of schooling, cognition and height. Second, it may be that at least some of the nutrition programs are cheap, so while the effects on stunting may be small, they can nonetheless be obtained at low cost. Regrettably, the systematic reviews and meta-analyses to date, as well as the studies themselves, focus almost universally on the effects of the programs, and ignore their costs.

⁴ The key systematic reviews and meta-analyses for nutrition-specific interventions are Dewey et al. (2008), Giugliani et al. (2015), Imdad et al. (2011) and Ramakrishnan et al. (2009). For nutrition-sensitive interventions, see Berti, et al. (2004), Dangour, et al. (2013), Leroy, et al. (2012), Manley, et al. (2013), Masset, et al.(2012), and Webb Girard, et al. (2012). Both sets of reviews are summarized in Galasso et al. (2017).

In this section we present estimates of the economic returns to implementing a package of nutrition-specific interventions whose costs and stunting impacts have been estimated and reported in a peer-reviewed journal, namely the package devised by Bhutta et al. (2013).⁵ At the time of writing, this is, in fact, the only package for which both region-specific costs and stunting impacts have been reported in a public-domain document. We assume a gradual scale-up of intervention coverage from current rates to 90% (the coverage rate assumed by Bhutta et al.). This package is then implemented each year thereafter at 90% coverage. We estimate the benefits on the assumption that in the absence of the program stunting would have fallen at an annual rate of -1.5% p.a.⁶

3.1 The Bhutta et al. nutrition package

The Bhutta et al. package includes 10 interventions, and we assume each is increased to 90% coverage. We estimate the effects on stunting and costs for 34 countries⁷ that together account for 90% of the world's stunted children. The interventions (with, in parentheses, annual aggregate costs across the 34 countries in 2010 international dollars) are: (i) salt iodization (\$68m), (ii) multiple micronutrient supplementation in pregnancy including iron-folate (\$472m), (iii) calcium supplementation in pregnancy (\$1,914m), (iv) energy-protein supplementation in pregnancy (\$972m), (v) vitamin A supplementation in childhood (\$106m), (vi) zinc supplementation in

⁵ At the time of writing, this is, in fact, the only package for which both region-specific costs and stunting impacts have been reported in a public-domain document.

⁶ We obtain this figure by running a fixed effects growth model (with countries as the fixed effects) on the September 2015 version of the JME data set. The model is of the form: $\ln(S_{it}) = \alpha + \beta t + u_i + e_{it}$, where S_{it} is the number of stunted children in country i in year t , t is the year, u_i is the country fixed effect, and e_{it} the error term. The coefficient β is the growth rate, and the predicted number of stunted under-fives in year t is equal to $\hat{\alpha} + \hat{\beta}t + \hat{u}_i$, where $\hat{\alpha}$ denotes the estimate of α , etc. The country fixed effect model allows us to get an *estimated* stunting figure for every country for every year, including in years after 2014 for which we have no stunting data.

⁷ The countries are: Afghanistan, Angola, Bangladesh, Burkina Faso, Cameroon, Chad, Congo, Dem. Rep., Côte d'Ivoire, Egypt, Arab Rep., Ethiopia, Ghana, Guatemala, India, Indonesia, Iraq, Kenya, Madagascar, Malawi, Mali, Mozambique, Myanmar, Nepal, Niger, Nigeria, Pakistan, Philippines, Rwanda, South Africa, Sudan, Tanzania, Uganda, Vietnam, Yemen, Rep., and Zambia.

childhood (\$1,182), (vii) breastfeeding promotion (\$653m), (viii) complementary feeding education (\$269m), (ix) complementary food supplementation (\$1,359m), and (x) severe acute malnutrition management (\$2,563m). It is important to note that the latter – management of severe acute malnutrition – represents the largest component of the cost, affecting child mortality but not stunting or cognition. Scaling these 10 interventions up to 90% coverage is estimated to reduce stunting across these 34 countries by 20% at an aggregate cost of \$9,559 million.

3.2 Estimating the rate of return to a nutrition program

Suppose we have a nutrition program, like that proposed by Bhutta et al., and we know its costs and its effects on stunting rates and on cognition. We can compute the internal rate of return, i , of the program:

$$(5) \quad \sum_{t=1}^{\infty} \frac{\Delta y(t)}{(1+i)^t} = \sum_{t=1}^{\infty} \frac{C(t)}{(1+i)^t}$$

where $\Delta y(t)$ is the income change due to the program and $C(t)$ is the cost of the program. The internal rate of return is the value of i that equalizes the net present value (NPV) of the benefit stream (the left-hand side) and the NPV of the cost stream (the right-hand side). We can also impose a specific discount rate and compute the NPVs of the benefit and cost streams, and compute the (discounted) benefit-cost ratio.

To get the benefit stream, we can totally differentiate eqn (2) with respect to a nutrition program (D) to get:

$$(6) \quad \frac{d \ln y(t+\tau)}{d D_N(t)} = \alpha \left\{ \left[r \frac{\partial E_W(t+\tau)}{\partial S_W(t+\tau)} + \gamma \frac{\partial H_W(t+\tau)}{\partial S_W(t+\tau)} \right] \frac{\partial S_W(t+\tau)}{\partial S_C(t)} \frac{d S_C(t)}{d D_N(t)} + \delta \frac{\partial C_W(t+\tau)}{\partial C_C(t)} \frac{d C_C(t)}{d D_N(t)} \right\}$$

The nutrition program affects income through three channels. The first two are an education effect and a height effect: the program lowers stunting among children today ($dS_C(t)/dD_N(t)$) which leads to a lower childhood stunting rate among workers in years to come ($\partial S_W(t + \tau)/\partial S_C(t)$) which is associated with a higher level of educational attainment ($\partial E_W(t + \tau)/\partial S_W(t)$) and increased stature ($\partial H_W(t + \tau)/\partial S_W(t)$) among future workers, and this translates into higher future incomes (r and γ). The third channel is a cognition effect: some nutrition interventions increase cognition among children today ($dC_C(t)/dD_N(t)$) without necessarily affecting stunting, and this translates into a higher level of cognition among workers in years to come ($\partial C_W(t + \tau)/\partial C_C(t)$), which translates into higher incomes (δ).

Both $\partial S_W(t + \tau)/\partial S_C(t)$, which captures the transmission of changes in stunting among today's children to the childhood stunting rate among workers τ years in the future, and $\partial C_W(t + \tau)/\partial C_C(t)$, which captures the transmission of changes in cognition among today's children to the cognition among workers τ years in the future, depend on τ . For $\tau < 15$, both will be zero, since the beneficiaries of the nutrition interventions have yet to join the labor force. As τ increases beyond 15, $\partial S_W(t + \tau)/\partial S_C(t)$ and $\partial C_W(t + \tau)/\partial C_C(t)$ become positive. If, for example, the rate of childhood stunting were constant in the absence of the program, $\partial S_W(t + \tau)/\partial S_C(t)$ would eventually reach 1 and stay at 1. In other words, if τ is sufficiently large, a given change in stunting among children at time t will translate into an equal change in the average rate of childhood stunting among workers at time $t + \tau$. The same logic applies to $\partial C_W(t + \tau)/\partial C_C(t)$.

3.3 Parameters

To derive estimates of the rate of return, we need estimates of the various parameters in eqn (6). We summarize our assumptions about their values in Table 3.

Table 3: Assumptions in estimating returns to nutrition program

Parameter	Assumption	Source
<i>Counterfactual trends:</i>		
Stunting (S)	2016 rate from WDI, closest year. Trend before and after follows -1.5% p.a. growth, based on analysis in section II	Authors' assumption
Cognition (C)	2016 z-score assumed to be 0.0 SD. No trend assumed	Authors' assumption
Per capita income (y)	2016 per capita income from WDI, closest year. Country-specific trend thereafter given by country-specific growth rate from IMF World Economic Outlook forecast, with growth rate being reduced over time according to reciprocal function with 2125 growth rate equal to 50% of 2016 growth rate	Authors' assumption
<i>Program effects on:</i>		
Stunting ($dS_C(t)/dD_N(t)$)	20% reduction (assumed relative to counterfactual). Program assumed to be scaled up over 10-year period, 20% reduction below trend being reached in 2025. Program remains in place thereafter so stunting remains 20% below trend thereafter	Bhutta et al. (2013)
Cognition ($dC_C(t)/dD_N(t)$)	0.487 extra SDs of cognition relative to counterfactual. Program assumed to be scaled up over 10-year period, 0.487 increase above trend being reached in 2025. Program remains in place thereafter so cognition remains 0.487 SDs above trend thereafter	See Table A1. For each intervention in Error! Reference source not found. we multiply the estimated cognition effect by 0.9 minus the fraction of children currently covered by the intervention. Current intervention coverage rates from various sources. ⁸
<i>Transmission of effects from childhood to adulthood</i>		
Stunting ($\partial S_W(t + \tau)/\partial S_C(t)$)	Assume 15 years before joining labor force, and adult working life of 40 years	Authors' assumption
Cognition ($\partial C_W(t + \tau)/\partial C_C(t)$)		
<i>Effects of stunting on:</i>		
Education ($\partial E_W/\partial ES_W$)	-1.594 fewer years of education	See Error! Reference source not found.
Height ($\partial H_W/\partial ES_W$)	-5.981 cm shorter	See Error! Reference source not found.
<i>Returns to:</i>		
Education (r)	Region-specific percentage extra income per extra year of education	Montenegro and Patrinos (2014)
Height (γ)	1.7% extra income per extra cm	See Error! Reference source not found.
Cognition (δ)	4.3% extra income per extra SD	See Error! Reference source not found.
<i>Elasticity of income with respect to human capital, i.e. labor share (α)</i>		
Program costs	0.67	Hanushek and Woessmann (2012)
	Aggregate costs for WHO groups of countries divided by aggregate population to get per capita costs for each WHO group. Given program assumed to be scaled up over 10-year period, per capita costs also rise accordingly, reaching full per capita cost only in 2025. Cost stays constant thereafter	Bhutta et al. (2013)
Discount rate	5%	Authors' assumption
Time horizon	2125	Authors' assumption

⁸ The coverage rates for breastfeeding and maternal multiple micronutrient supplementation are the same as those used by Bhutta et al. in the LiST model (Walker et al. 2013). The iodine supplementation coverage indicator is salt iodization; the data are from UNICEF (<http://data.unicef.org/nutrition/iodine.html>).

We compute, for each country, time paths of childhood stunting and cognition without the nutrition program, to which we apply the program effects $dS_C(t)/\partial D_N(t)$ and $dC_C(t)/\partial D_N(t)$. We get the counterfactual childhood stunting time path by setting the 2015 childhood stunting rate equal to the latest JME childhood stunting rate for the country in question, and then assuming that before and after 2015 stunting falls at an annual rate of 1.5% (the rate we computed in section 2 above). For the counterfactual cognition time path, we assume zero change in the absence of the nutrition program, and assume the z-score is initially zero. As in a recent World Bank report (World Bank 2016), we assume the program goes to scale gradually over a 10-year period between 2016 and 2025, achieving Bhutta et al.'s estimated 20% reduction (compared to the counterfactual) in 2025. This gives us, after 10 years, a value of $dS_C(t)/\partial D_N(t)$ (in terms of year-to-year changes) equal to -3.7%. We assume the program is maintained at the same scale thereafter, so the stunting rate remains at 20% below the counterfactual rate for all periods after 2025.

We estimate the change in the cognition z-score attributable to the nutrition program, $dC_C(t)/\partial D_N(t)$, by multiplying, for each intervention in the Bhutta et al. package, the estimated cognition effect of the intervention (obtained from Table 3) by 0.9 minus the fraction of children currently covered by the intervention. (The effect size is relevant for going from 0% to 100%, whereas the program takes intervention coverage from its current rate to 90%.) We use the estimated mean cognition effects from the meta-analyses summarized in Table 3. The current intervention coverage rates are from various sources. We assume the effects are achieved over a 10-year period, in line with the assumption that the program is scaled up gradually over a 10-year period.

To get $\partial S_W(t + \tau)/\partial S_C(t)$ and $\partial C_W(t + \tau)/\partial C_C(t)$ we need to make assumptions about the number of years before a child starts working (we assume 15 given that stunting rates apply to

under-fives) and about the number of years an adult will spend at work (we assume 40). In addition, we need to know the distribution of the population across age groups – not all under-fives will survive through to age 55, some may survive but may migrate elsewhere, etc. We take the age distribution of the population across five-year age bands from 15 through 55 using the WDI population age structure data. These assumptions allow us to quantify how reductions in stunting and increases in cognition among today's children translate into reductions in childhood stunting rates and increases in cognition among the working-age population in years to come.

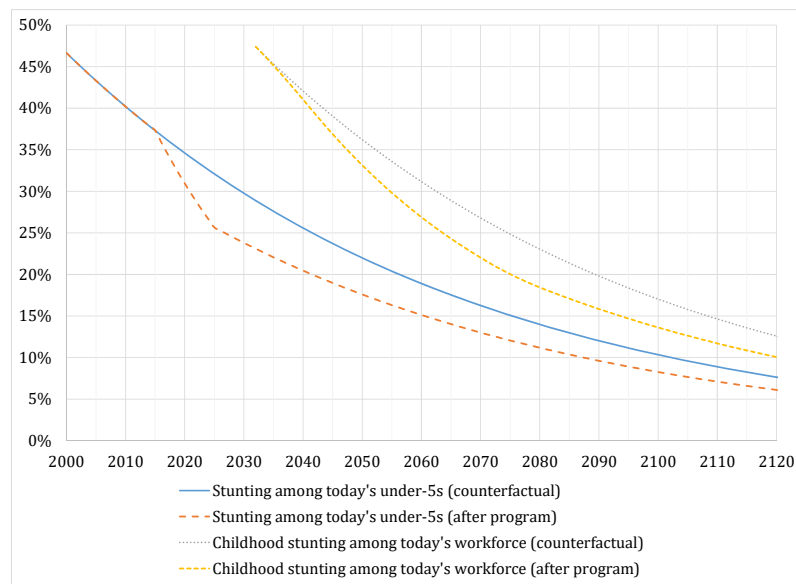
We use the same values of α , r , γ , δ , $\partial E_W / \partial S_W$, and $\partial H_W / \partial S_W$ as in section 2. Applying these assumptions, and the others listed above, we get a time path for $\Delta \ln y(t)$, the percentage change in $y(t)$. To compute the time path for $\Delta y(t)$, and hence the NPV of the benefit stream, we need to estimate the counterfactual time path for per capita income to which we can apply the estimated percentage change due to the program, $\Delta \ln y(t)$. For the counterfactual time path of $y(t)$, we take GNI per capita (converted using PPP) for the latest year from the WDI, and project it forwards, initially using the annual average IMF April 2016 World Economic Outlook (WEO) estimated growth rate over the period 2014-2021, then reducing the growth rate over time asymptotically (via a reciprocal function) until it reaches 50% of the WEO growth rate in 2125.

For costs, we use the program costs computed by Bhutta et al. (2013). To get the program cost per capita (i.e. per person living in the country, not per under-five child), we take the aggregate program costs for each group of countries in Bhutta et al.'s Web Appendix Panel 15 (the groups are WHO regions), and divide the aggregate cost of each group by the aggregate population of that country group (we take the population data from WDI). As already mentioned, we assume that the scaling-up process takes 10 years, so we assume the full cost per capita is reached only in year 10; in year 9, the cost is 9/10th of the full cost, etc.

3.4 Results

Figure 2 shows the results of our assumptions in terms of trends in stunting. The counterfactual rate of stunting among children falls at 1.5% per year. The nutrition program kicks in in 2016 reducing the rate of stunting among children below the counterfactual; the program reaches its full scale in 2025, at which point the reduction in the rate of stunting below the counterfactual reaches 20%. By 2025, stunting has fallen by 36% compared to its 2010 value – 4 percentage points below the 40% target reduction adopted by the 65th World Health Assembly. We assume the nutrition program is sustained at scale and thereafter stunting stays at 20% below the counterfactual.

Figure 2: Reductions in stunting among today's children and their effects on childhood stunting rates among the workforce in later years

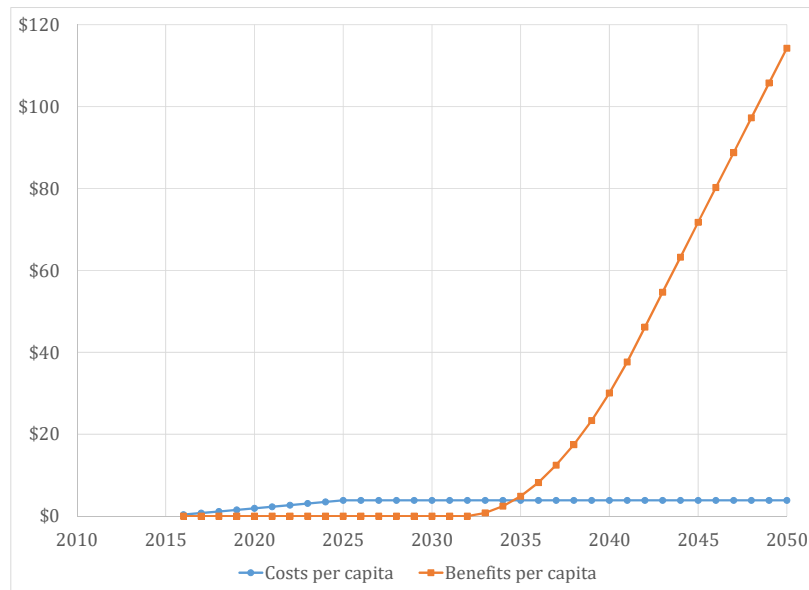


It takes much longer than 10 years for the childhood stunting rate among workers to fall by 20%. The childhood stunting rate among workers in any year is a weighted average of the childhood stunting rates that were prevalent when today's workers were children. Given the lag between childhood and joining the labor force, and the assumed 40-year working life, the childhood stunting

rate among workers today thus exceeds the rate of stunting among today's children by a large margin. For the same reasons, it is 15 years before the effect of the nutrition program is felt on childhood stunting rates among workers. And even then, the decline is slower than the decline 15 years previously in the stunting rate among under-fives: the rate of stunting among children falls to 20% below its counterfactual value within 10 years of the start of the program; by contrast, it takes 55 years for the childhood stunting rate among workers to fall to 20% below its counterfactual rate.

Figure 3 shows the time path of per capita costs and benefits (in terms of income) for the 34 countries on average. Per capita costs rise from zero in 2015 to \$3.85 in 2025 and stay there thereafter. Per capita benefits – in terms of higher incomes – are zero until 2033 when the first cohort benefitting from the scaling-up of the 10 nutrition interventions joins the labor force. Initially the change in per capita income in the country is small, because only the youngest of 40 cohorts in the labor force has benefitted from the scale-up. As time passes, an ever-larger fraction of the labor force has benefitted from the scale-up, and the effect on per capita income grows. In addition, as time passes, the counterfactual per capita income that the percentage effect of the program gets applied to increases (on our assumption that economic growth remains positive), so that the benefit in dollar terms of being well nourished in childhood increases.

Figure 3: Time path of per capita costs and benefits of the nutrition program

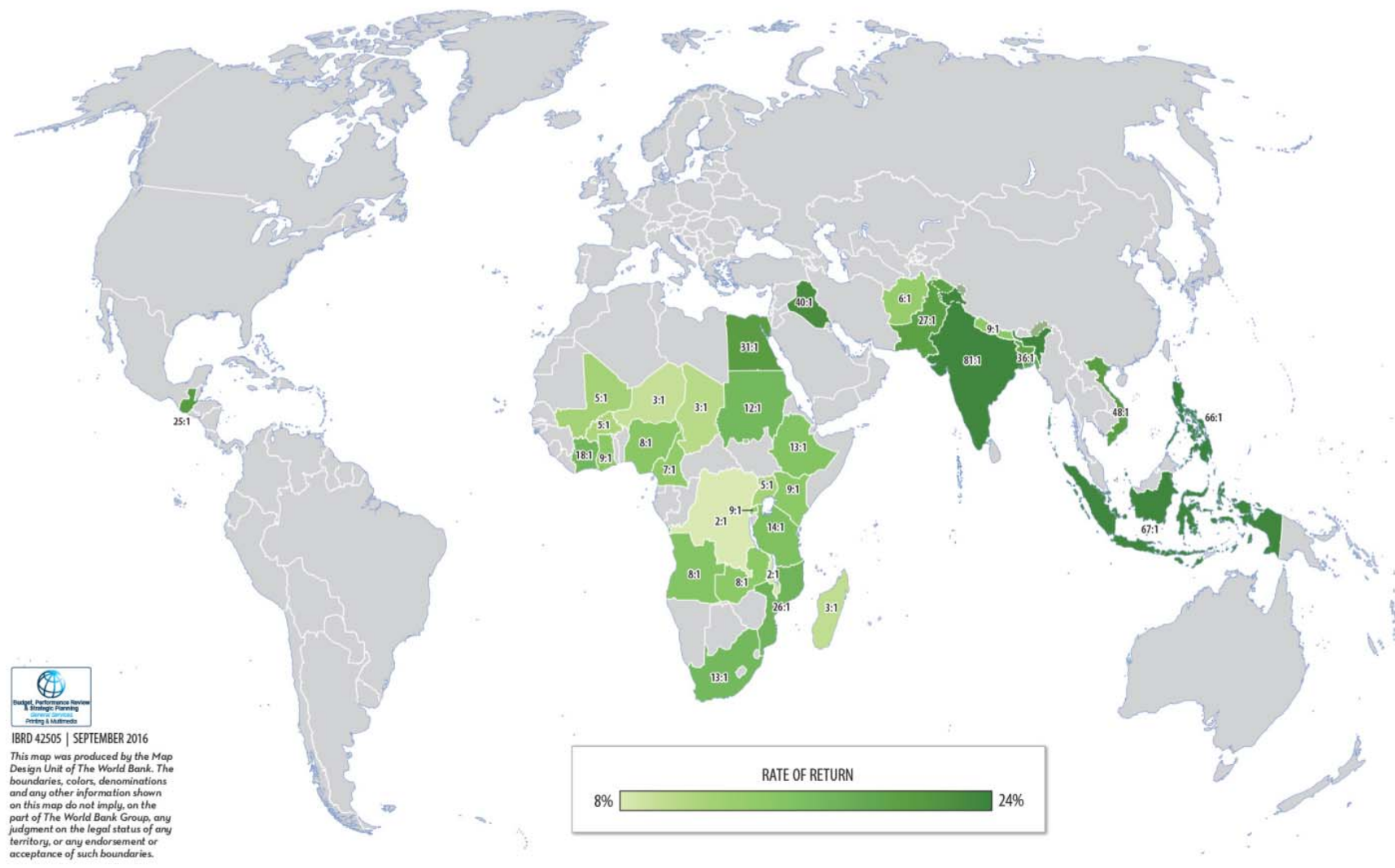


The internal rate of return results are shown in Table 3 and Figure 4. The rate of return varies from 8.5% to 24%. The average is 16%. The East Asia & Pacific region has the highest rate of return (24%) reflecting the low per capita program cost, the high rate of return to education, the high initial GDP per capita, and the high GDP growth rate. Africa is the region with the lowest rate of return (15%) reflecting the high per capita program cost, the relatively low initial GDP per capita, and the relatively low GDP growth rate; these numbers are offset only partly by the relatively high rate of return to education in Africa. There are variations within regions, of course: India, for example, has a rate of return of 23% reflecting in part India's low program cost and its high GDP growth rate.

Table 4: Rates of return to nutrition project, by region

Region	No. countries	Stunting rate	Program cost per capita	Per capita income	Growth of per capita income p.a.	Education rate of return	Benefit-cost ratio	Rate of return
East Asia & Pacific	3	31%	\$2.63	\$8,423	5%	10%	76:1	23.6%
Latin America & Caribbean	1	48%	\$2.72	\$7,510	1%	10%	25:1	20.7%
Middle East & North Africa	2	31%	\$2.61	\$9,733	0%	6%	19:1	19.1%
South Asia	5	46%	\$2.73	\$3,882	4%	7%	23:1	18.7%
Sub-Saharan Africa	21	36%	\$4.59	\$3,119	3%	13%	9:1	14.7%
Total	32	37%	\$3.85	\$4,451	3%	11%	15:1	17.2%

Figure 4: Rates of return to nutrition project, by country



It should also be kept in mind that our results do not capture the effects of the program on mortality, which are estimated to be appreciable (Bhutta et al. 2013). Insofar as the program reduces child mortality, the initial effect will be to reduce the fraction of the population working, i.e. N_W/N in eqn (1) will fall. This will cause per capita income to fall until the children grow up and join the labor force. Reductions in child mortality are also likely, however, to lead to subsequent changes in fertility behavior, with families reducing their family size as children are more likely to survive childhood. This will push N_W/N back up and hence dampen the downward pressure on per capita income.

Finally, we should keep in mind that childhood survival is valued in its own right – a more complete cost-benefit analysis would capture the intrinsic value associated with fewer children dying in childhood because of the nutrition program. All told, our estimates are probably underestimates of the rate-of-return.

3.5 Sensitivity analysis

Table 5 shows how sensitive the estimated rates of return for the 34 countries overall are to the assumptions used, as done in other studies that estimate the cost benefit of the scaled-up nutrition package (Hoddinott et al. 2013; Alderman et al. 2017). It is possible that the costs of the program are underestimated if only because the cost estimates do not take into account that unit costs will likely rise as harder-to-reach groups are covered. Doubling the total cost of the program would cut the benefit-cost ratio by almost half, and would cut the rate of return by 20% or 3.4 percentage points. It is also possible that the program's impacts on stunting are overestimated, in part because many of the effect sizes from the meta-analyses are not statistically significant, and in part because most estimates come from efficacy trials, not at-scale programs. Halving the assumed program effect on stunting from 20% to 10% reduces the benefit-cost ratio by 20% and the rate-of-

return by 8% or 1.3 percentage points; it also cuts the estimated reduction in stunting from 36% to 28%. The cognition impacts of the program may also be overestimated for the same reasons. Halving the assumed cognition effects of the program reduces the rate-of-return by 9% or 1.6 percentage points. We also explore the effects of changes in the assumed effects of stunting on years of education and adult height. Halving the assumed effects of stunting on years of education and adult height reduces the overall effect on adult income of being stunted as a child from 28% to 14%, and cuts the benefit-cost ratio by 20% and the rate-of-return by 8% or 1.3 percentage points. If we make all these changes simultaneously, we end up with an almost 50% reduction in the rate-of-return, equivalent to a reduction of almost 8 percentage points. Finally, reducing the scale-up period from 10 years to one reduces the rate-of-return by 20% or 3.5 percentage points; a 10-year scale-up is considerably more realistic.

Table 5: Sensitivity of results to assumptions

	Stunting reduction 2025 vs. 2010	Benefit-cost ratio	Rate of return
Base estimates	-36.2%	15:1	17.2%
Doubling of program cost	-36.2%	8:1	13.7%
Halving of program effect on stunting	-28.2%	12:1	15.8%
Halving of program effect on cognition	-36.2%	11:1	15.6%
Halving of stunting effects on education & height	-36.2%	12:1	15.9%
All the above	-28.2%	3:1	9.5%
One-year scale-up	-36.2%	7:1	13.7%

3.6 Comparisons with other studies of returns to nutrition investments

Other authors have also reported estimates of the returns to childhood nutrition programs, including the Bhutta et al. program. The studies by Hoddinott et al. (2013) and Hoddinott (2016) are closest to our study. Like us, they estimate the costs and benefits (in terms of higher incomes) of taking the coverage rate of each of the interventions in the Bhutta et al. package from the current rate

to 90%. One difference between the studies is that the others assume immediate scale-up to 90%, and are therefore able to conduct the analysis using just one cohort. By contrast, we scale up over a 10-year period, with each successive cohort born between 2015 and 2025 getting closer and closer to 90% coverage; we then maintain the program at 90% coverage thereafter. There are also differences in the estimates used to estimate the economic value of stunting reduction. Hoddinott et al. focus on the income effects that operate through stunting, whereas we allow for effects that operate through cognition in the case of interventions in the package that do not affect stunting. On the other hand, Hoddinott et al. assume a much larger effect of stunting on income than we do. The median estimate for the benefit to cost ratio in Hoddinott (2013) using a discount rate of 5% is 18:1 (the median country is Bangladesh), which is close to our estimate of 15:1. The benefit-cost ratios in Alderman et al. (2017) range from 4:1 in the Democratic Republic of Congo to 34:1 in India. In addition to assumptions behind the returns to stunting reduction, the benefit-ratios estimated in different studies depend on the assumptions about future income growth, the number of years in the labor force, and the discount rate. All studies provide sensitivity analysis to the various assumptions and come up with favorable ratios. Our study also differs from others in that we report estimates of internal rates of return.

4. Conclusions

There is a large consensus in the public health and economics literatures that chronic malnutrition is associated with adverse outcomes throughout the lifecycle. The undernourishment and disease that cause stunting impair brain development, leading to lower cognitive and socioemotional skills, lower levels of educational attainment, and hence lower incomes. In this paper we rely on a development accounting framework that allows to perform a backward-looking exercise

that estimates how much a country's per capita income today is lower to the extent that some of its workers today were stunted in childhood, and a forward-looking exercise that estimates the net present values of the costs and benefits of a package of interventions aimed at reducing stunting among today's children. We estimate that, on average, GDP per capita globally is 7% lower as a result of some of today's workers being stunted in childhood, and that across 34 countries accounting for 90% of the world's stunted children, the rate-of-return to the package of nutrition interventions is 17%, with a benefit-cost ratio of 15:1.

Our approach has strengths and weaknesses. Among the strengths is that the fact that we conduct the backward- and forward-looking exercises in the same study, using the same methodology and assumptions. By contrast, in the literature to date, the two exercises have been done in different studies, using different methodologies and different assumptions. Another strength of our study is the fact that the methodology we use (development accounting) is in line with other studies that try to pinpoint some or all of the sources of differences across countries in per capita income. The third strength of our study is its comprehensiveness: our methodology allows for three channels by which stunting affects income (years of schooling, cognition and stature), rather than just one or two; we base our parameters on all the relevant micro-econometric studies, rather than just one or two; and our backward-looking estimates are for the entire developing world while our forward-looking estimates are for countries accounting for 90% of the world's stunted children.

There are limitations to this exercise that leave scope for future research. In line with the literature, we are looking at how childhood stunting translates into adult earnings via human capital while holding everything else constant. There might be important externalities and spillover effects that arise from human capital formation that are not captured in the estimates of the private returns to reduction of childhood stunting. Equally, there might be general equilibrium effects from scaling

up a nutrition package to 90% of the populations that are not accounted for in this framework. It should also be kept in mind that our results in the forward-looking exercise do not capture the effects of the program on mortality, which are estimated to be appreciable (Bhutta et al. 2013). Insofar as the program reduces child mortality, the initial effect will be to reduce the fraction of the population working, i.e. N_W/N in eqn (1) will fall. This will cause per capita income to fall until the children grow up and join the labor force. Reductions in child mortality are also likely, however, to lead to subsequent changes in fertility behavior, with families reducing their family size as children are more likely to survive childhood. This will push N_W/N back up and hence dampen the downward pressure on per capita income. Finally, we should keep in mind that childhood survival is valued in its own right – a more complete cost-benefit analysis would capture the intrinsic value associated with fewer children dying in childhood as a result of the nutrition program. All told, our estimates are probably underestimates of the effect of stunting on per capita income and on the rate-of-return to the Bhutta et al. package of nutrition interventions.

The fact that our underestimates are quite large despite likely being underestimates is quite striking. A GDP-per-capita penalty of 7% from extreme smallness in a child's first 1,000 days seems like a big deal. It is true that at 17% our rate-of-return estimate is not as high as the 22% reported by the World Bank's Independent Evaluation Group for World Bank projects over the period 2000-2008 (World Bank Independent Evaluation Group 2010). However, those estimates were not produced using the method that we used, and we suspect ours is more conservative. And as we have already said, our estimates are likely a lower bound, not least because we have not factored in the nonpecuniary benefits associated with better child health and improved survival prospects. A rate-of-return of 17% therefore seems like a good investment.

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Annex Table A1: Review of estimates of effects of stunting on height, schooling and cognition, and their effects on earnings

Panel A: height				Effect of stunting on height (in cm): $\frac{\partial H_W}{\partial S_W}$		Effect of height on earnings γ	
Study	Country	Adult age	M/F	Unconditional	conditional	Unconditional	Conditional
<u>Adult height</u>							
Thomas and Strauss (1997)	Brazil	25-50	M/F	—			0.014*
			M			—	0.015
			F				0.013
LaFave and Thomas (2017)	Indonesia (WISE)	25-65	M	—		0.023	0.012 ^s
Vogl (2014)	Mexico (MFLS)	25-65	M	—		0.023	0.013 ^s
Giles and Witoelar (2016)	Indonesia (IFLS)	21-26	M/F	-3.002	-2.953		0.030 ^s
			M	-4.501	-4.333		0.026
			F	-3.751	-3.623		0.037
Bossavie et al. (2017)	Pakistan	15-64	M			0.009	0.008
Victora et al. {, 2008 #23}	COHORTS study (Brazil, Guatemala, India, the Philippines, and South Africa)	21-23, 26-41, 26-32, 21, 15	M/F	-6.480		—	—
<u>Adolescent height</u>							
Fernald et al. (2016)	Madagascar	7-10	M/F	-5.400		—	—
Coly et al. (2006)	Senegal	18-23	M/F	-7.800		—	—
			M	-9.000			
			F	-6.600			
Alderman et al. (2006)	Zimbabwe	17	M/F	-5.230		—	—
Mean across all studies (weighting COHORTS x 5)				-5.981 cm		0.018	0.015
Median across all studies (weighting COHORTS x 5)				-6.480 cm		0.023	0.013

Panel B: years of schooling				Effect of stunting on years of schooling $\frac{\partial E_W}{\partial S_W}$		Effect of years of schooling on earnings r	
Study	Country	Adult age	M/F	Unconditional	conditional	Unconditional	Conditional [§]
	Indonesia	21-26	M/F	-0.717	-0.583		0.050
Giles and Witoelar (2016)			M		-0.418		
Vogl (2014)			F	-0.620	-0.043		
Pitt, Rosenzweig and Hassan (2012)	Bangladesh	20-49	M/F	—			0.042
LaFave and Thomas (2017)	Indonesia	25-65	M	—			0.083
Vogl (2014)	Mexico (MFLS)	25-65	M				0.073
Martorell et al (2010)	COHORTS study (Brazil, Guatemala, India, the Philippines, and South Africa)	21-23, 26-41, 26-32, 21, 15	M/F	-1.840	-0.920		—
Alderman, Hoddinott and Kinsey (2006)	Zimbabwe	17	M/F	-1.240			—
Mean across all studies (weighting COHORTS x 5)				-1.594 years	-0.864 years		
Median across all studies (weighting COHORTS x 5)				-1.840 years	-0.920 years		

[§] conditional on height and cognition

Panel C: cognition				Effect of stunting on cognition (in SD) $\frac{\partial C_W}{\partial S_W}$		Effect of cognition on earnings δ	
Study	Country	Adult age	M/F	Unconditional	conditional	Unconditional	Conditional
Giles and Witoelar (2016)	Indonesia	21-26	<u>M/F</u>	<u>-0.037</u>	<u>-0.008</u>		<u>0.038</u>
			M	0.066	0.08		0.06
			F	-0.133	-0.123		0.021
LaFave and Thomas (2017)	Indonesia	25-65	M	—			0.077
Vogl (2014)	Mexico (MFLS)	25-65	M	—			0.011
Bossavie et al. (2017)	Pakistan	15-64	M	—			0.024
Glewwe, Jacoby and King (2001)	Philippines	11	<u>M/F</u>	<u>-0.870</u>	—	—	
Walker et al (2005)	Jamaica	17-18	<u>M/F</u>	<u>-0.930</u>	<u>-0.710</u> ^x	—	
Berkman (2002)	Peru	9	<u>M/F</u>	<u>-0.670</u>	<u>-0.367</u> ^x	—	
Grantham McGregor et al(2007)	COHORTS study (Brazil, Guatemala, India, the Philippines, and South Africa)	21-23, 26-41, 26-32, 21, 15	<u>M/F</u>	<u>-0.675</u>	—	—	
Mean across all studies (weighting COHORTS x 5)				-0.625 SD			<i>0.043 (men)</i>
Median across all studies (weighting COHORTS x 5)				-0.685 SD			<i>0.042 (men)</i>

Notes: ^x conditional on SES, ^s conditional on schooling, and height