Economic costs of childhood stunting to the private sector in low- and middle-income countries

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eClinicalMedicine
2022;45: 101320
Published online xxx
https://doi.org/10.1016/j.eclinm.2022.101320

Summary

Background Stunting during childhood has long-term consequences on human capital, including decreased physical growth, and lower educational attainment, cognition, workforce productivity and wages. Previous research has quantified the costs of stunting to national economies however beyond a few single-country datasets there has been a limited number of which have used diverse datasets and have had a dedicated focus on the private sector, which employs nearly 90% of the workforce in many low- and middle-income countries (LMICs). We aimed to examine (i) the impact of childhood stunting on income loss of private sector workforce in LMICs; (ii) to quantify losses in sales to private firms in LMICs due to childhood stunting; and (iii) to estimate potential gains (benefit-cost ratios) if stunting levels are reduced in select high prevalence countries.

Methods This multiple-methods study engaged multi-disciplinary technical advisers, executed several literature reviews, used innovative statistical methods, and implemented health and labor economic models. We analyzed data from seven longitudinal datasets (up to 30+ years of follow-up; 1982–2016; Peru, Ethiopia, India, Vietnam, Philippines, Tanzania, Brazil), 108 private firm datasets (spanning 2008–2020), and many global datasets including Joint Malnutrition Estimates, and World Development Indicators to produce estimates for 120+ LMICs (with estimates up to 2021). We studied the impact of childhood stunting on adult cognition, education, and height as pathways to wages/productivity in adulthood. We employed cloud-based artificial intelligence (AI) platforms, and conducted comparative analyses using three analytic approaches: traditional frequentist statistics, Bayesian inferential statistics and machine learning. We employed labour and health economic models to estimate wage losses to the private sector worker and firm revenue losses due to stunting. We also estimated benefit-cost ratios for countries investing in nutrition-specific interventions to prevent stunting.

Findings Across 95 LMICs, childhood stunting costs the private sector at least US$135.4 billion in sales annually. Firms from countries in Latin America and the Caribbean and East Asia and Pacific regions had the greatest losses. Totals sales losses to the private sector accumulated to 0.01% to 1.2% of national GDP across countries. Sectors most affected by childhood stunting were manufacturing (non-metallic mineral, fabricated metal, other), garments and food sectors. Sale losses were highest for larger sized private firms. Across regions (representing 123 LMICs), US$700 million (Middle East and North Africa) to US$16.5 billion (East Asia and Pacific) monthly income was lost among private sector workers. Investing in stunting reduction interventions yields gains from US$2 to US$81 per $1 invested annually (or 100% to 8000% across countries). Across sectors, the highest returns were in elementary occupations (US$46) and the lowest were among agricultural workers (US$8). By gender, women incurred a higher income penalty from childhood stunting and earned less than men; due to their relatively higher earnings, the returns for investing in stunting reduction were consistently higher for men across most countries studied.

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Interpretation Childhood stunting costs the private sector in LMICs billions of dollars in sales and earnings for the workforce annually. Returns to nutrition interventions show that there is an economic case to be made for investing in childhood nutrition, alongside a moral one for both the public and private sector. This research could be used to motivate strong public-private sector partnerships to invest in childhood undernutrition for benefits in the short and long-term.

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Keywords: Stunting; Children; Economy; Private sector; Costs; Low and middle income

Research in context

Evidence before this study

We searched several peer-reviewed published literature and grey literature databases using search terms related to early childhood nutrition, private sector, employment, and economic outcomes in low-and middle-income countries (LMICs) between April and August 2020. Search terms included (Linear growth, growth faltering, short stature, HAZ, height-for-age, stunting, stunt*, private sector, business*, present*, absent*, product*, primary, secondary school, education, financial gains, financial losses, economic cost). Previous studies show that stunting does cost economies through its impact on educational attainment, height attainment and cognitive attainment in adulthood, however, these studies often focused on single-country datasets, that were smaller sample sizes, observational and/or longitudinal, and made inferences to broader countries based on these limited data. Moreover, few studies specifically studied the private sector costs related to stunting or early childhood undernutrition, with the exception of one recent study that studied other forms of malnutrition but did not focus on stunting.

Added value of this study

Our findings add to the existing literature on the connection between early childhood undernutrition and employment outcomes in adulthood, specifically focused on the private sector. We use diverse sets of data (longitudinal/birth cohorts from seven LMICs, national-level survey datasets on private firms from over 100 countries, and global data repositories (e.g., World Bank etc.) to produce estimates for all LMICs where data permitted. Additionally, we compare and contrast results using 3 core analytic approaches: the traditional ordinary least squares (OLS), Bayesian inference and AI-based machine learning algorithms, with the aim of determining the similarities of inferences and value of employing simplistic to more complex approaches for estimating the stunting effect. We find that early childhood undernutrition has negative financial consequences for the private sector workforce and productivity loss of private firms/businesses in LMICs, and estimates vary across settings and subpopulations.

Implications of all the available evidence

Stunting and poor nutrition in early childhood has long lasting effects on adulthood, which in turn impacts the private sector workforce income potential and firm productivity. Using diverse datasets and innovative methodological approaches, our study quantifies the financial penalties incurred by individuals and corporations. We hope our data can be used by governments and private sector actors in LMICs to develop strong partnerships for collective action for reducing undernutrition in the workforce and communities.

Introduction

Globally over 149 million children, or 21% of children, under five years of age, are stunted with 91% living in low- and middle-income countries (LMICs).[1] Stunting refers to children who experience long-term nutritional deprivation and is defined as height-for-age <-2 standard deviations in the WHO Child Growth Standards median.[2] Private sector actors and organizations have been recognized increasingly as critical stakeholders in efforts to achieve the Sustainable Development Goals (SDGs), including ending malnutrition (SDG 2), through investments in the workplace, community and economic market.[3–7] The private sector consists of organisations that engage in profit-seeking activities and have a majority private ownership (e.g., not owned or operated by a government). This term includes financial institutions and intermediaries, multinational companies, micro, small and medium-sized enterprises, co-operatives, individual entrepreneurs, and farmers who operate in the formal and informal sectors. It excludes actors with a non-profit focus, such as private foundations and civil society organisations.[8–10] The private sector has considerable potential to be engaged in providing direct nutrition (e.g., micronutrient supplements) and indirect nutrition interventions (e.g., technological innovations in agriculture, health or education).[4,5,11]

Despite notable reductions in stunting globally,[1] chronic malnutrition during childhood has social, human and economic consequences across the life course, including restricted physical growth/stature, lower educational attainment, cognitive impairments, and reduced workforce productivity (Figure 1).[12–28] Literature shows that per capita income losses (penalty) due to stunting range from 5 to 7% in many low- and middle-income countries (LMICs).[27] Meanwhile, reductions in stunting are projected to improve countries' economic productivity by increasing gross domestic product (GDP) by 4–11% across African and Asian regions.[5,29] Although these national level macroeconomic estimates offer an understanding of the value and cost of stunting to countries, they have often relied on single-country observational datasets with smaller sample sizes which limit in their applicability to LMICs around the world. Importantly, there was not a specific focus on the private sector (though the private sector provides up to 90% of employment opportunities in many LMICs.[30]) and analyses were often conducting using classical ordinary least squares (OLS) statistical frameworks – which are valuable but have its limitations. Overall, there exists a dearth of evidence on income losses incurred specifically by private sector workers, firms or sectors due to childhood stunting across diverse LMIC settings, using diverse datasets and methodological approaches (see *Research in Context* panel). A recent study estimated that malnutrition costs multinational corporations approximately $130–850 billion annually, an equivalent of 0.4–2.9% of countries' collective gross domestic product, however the economic burden of stunting was underestimated given data limitations.[3] Generating empirical data on the costs of stunting to the individual private sector worker (e.g. through impact on human capital markers and wages), to the private firms' bottom line, and to the return on investment of scaling-up stunting relevant interventions offers country governments and corporations financial incentives (in the long term) to improve the nutrition, health, and performance of their workforce and local communities.

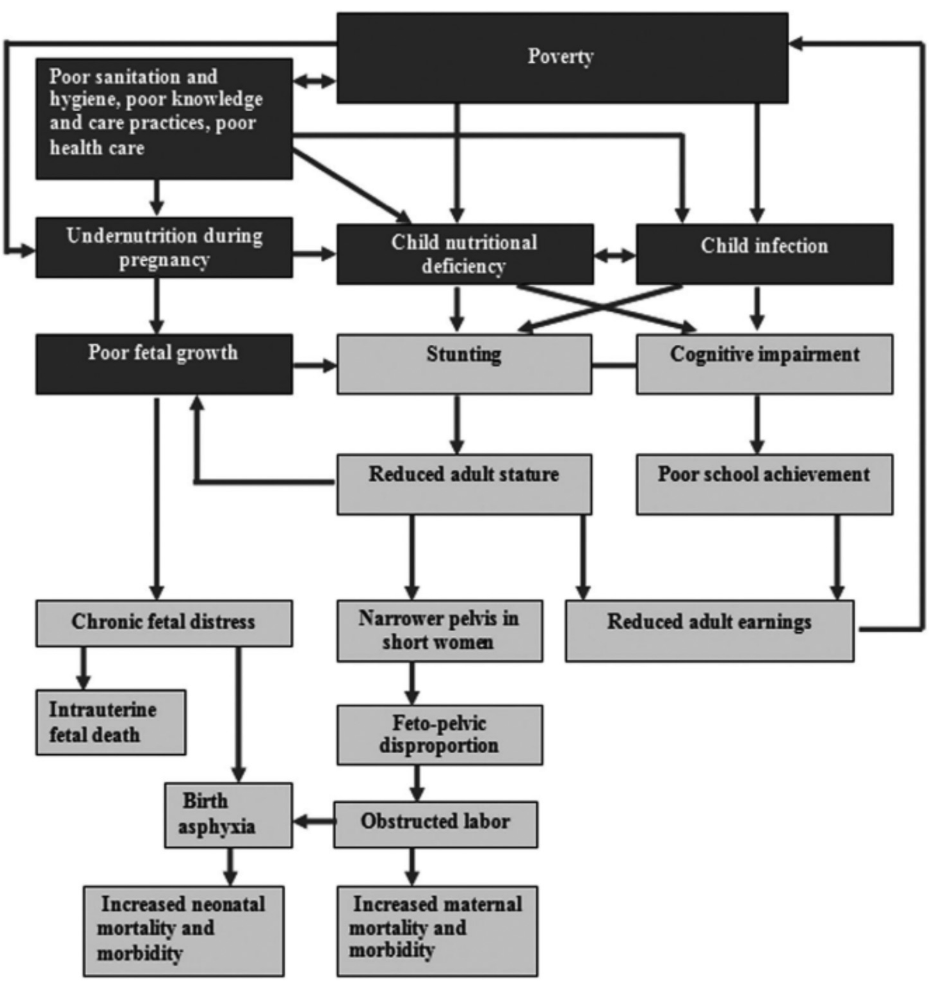

Fig. 1. Childhood stunting pathways to adulthood outcomes*Source: Dewey, 2011*.

Using diverse datasets and rigorous comparative statistical methods, this study aims to address existing knowledge gaps to produce estimates focused on the private sector in all LMICs where data permitted. We studied the following research questions: (i) to examine the impact of childhood stunting (physical and cognitive) on the human capital markers (adulthood height, education, and cognition) and income loss of private sector workforce in LMICs; (ii) quantify losses in sales to private firms in LMICs due to childhood stunting; and (iii) estimate potential gains (benefit-cost ratios) if stunting levels are reduced in select high prevalence countries. Analyses are presented by global region, country, firm size, sector, and gender, as applicable and/or available in datasets.

Methods

Approach

To estimate childhood stunting effect on the human capital markers, we used data from seven longitudinal cohort datasets representing different countries (Peru, India, Ethiopia, Vietnam, Brazil, Philippines, Tanzania; described below) and used estimates from literature (at the regional level) for remaining LMICs. To estimate income loss of the private sector workforce in LMICs due to stunting, we used data from the seven countries and reliable national estimates from global data repositories for the remaining LMICs. To quantify losses in sales to private firms, we used original World Bank Enterprise survey datasets for all LMICs where available. Benefit-cost ratios for investing in stunting reduction were produced for the seven countries as representative high prevalence countries with learnings applicable to other countries in the region.

Study design

We used a multiple-methods design inclusive of targeted and scoping literature reviews, using cloud-based technologies to conduct descriptive and advanced analytics such as Bayesian, Frequentist and Machine Learning modeling approaches, and executing health and labour economic modeling and estimation. We also consulted a technical advisory group (TAG) (representing key nutrition experts from academia, industry, donors, etc.) and informal advisors for advice on research design, interpretation of results, and dissemination plans. (see experts in *Supplementary Technical Annex-Supplementary Supplementary Technical Annex 1*).

Literature reviews

We conducted a series of scoping and topic-specific targeted reviews using systemized approaches to identify, triage, abstract and synthesize literature. Reviews aimed to understand the current evidence related to: (1) stunting and education/economic outcomes; (2) private sector and nutrition outcomes; (3) private sector advocacy efforts focused on the impact on a firm's bottom line/sales/productivity, (4) methodologies for estimating childhood stunting effect on human capital and for estimating the stunting-related income and productivity penalties, and (5) estimates of average height, cognition, and education for key LMICs. Details on databases used, time frame (any restrictions to language), search terms, overall number of results and papers used, and exclusion/inclusion criteria are provided in *Supplementary Technical Annex 2 & 3* for each review.

Data sources

To estimate the actual effect of childhood stunting on human capital markers (adult height, cognition, and education), we obtained and analyzed original datasets from seven longitudinal studies representing diverse global regions. These included the Peru, Ethiopia, Vietnam, and India Young Lives studies conducted from 2002 to 2016, the Brazil (Pelotas) birth cohort study from 1982 to 2013, the Philippines Cebu Longitudinal Health and Nutrition Survey from 1983 to 2005, and the Tanzania Kagera Health and Development Survey from 1991 to 2010. The longest-running dataset was the Pelotas Birth Cohort spanning 30 years. Sample sizes varied from 714 participants in Peru to 5914 participants in Brazil. Childhood stunting (at approximately age 5 years) was prevalent in 11−60% of children across these cohorts, and between 87 and 98% of the children ended up working in the private sector in adulthood (between 22 and 40 years of age). Where available, we obtained data on sociodemographics, anthropometry in childhood, cognition in adolescence or adulthood, educational achievement, and adulthood height, employment, and income. As we obtained de-identified datasets from research teams who had already sought ethical approval for data collection, we did not need to seek ethical approval or participant consent. Further detail on each dataset is provided in *Supplementary Technical Annex 4*.

We relied on data from multiple sources for estimating the income penalty (loss) attributable to childhood stunting on the private sector workforce. We obtained private sector population data from the International Labour Organisation database,[31] and the median age of workers from the World Development Indicators (WDI).[32] To estimate the stunting prevalence at age five, we relied on the Joint Child Malnutrition Estimates,[33] and country-specific Gross Domestic Product estimates from the WDI. We obtained the median and mean monthly income from the World Bank's PovcalNet database,[34] and relied on our targeted reviews for parameters on the stunting effect on human capital.

Enterprise surveys are firm-level surveys representative of the non-agricultural, non-extractive private sector economy. We analyzed data from approximately 71,716 firms from 108 countries within six regions between years 2007–2020 (*Supplementary Technical Annex 5*). Firms are representative of six sectors: Food, Garments, Non-Metallic Mineral, Fabricated Metal, Other Manufacturing, Retail and Other Services. Since manufacturing and services are the primary business sectors of interest for the Enterprise Surveys, neither agricultural enterprises nor informal businesses were captured, and thus are not part of this analysis.

Specific surveys for unregistered business are reported by "Informal Surveys" conducted by the World Bank.[35]

Outcomes and covariates

Childhood stunting was estimated as 2 standard deviations (SD) below the median height-for-age derived from the WHO child growth standards. Adulthood height was measured in centimetres after 21 years of age. Education achievement was estimated as total years of formal schooling obtained. Cognition was estimated using diverse tools such as CLOZE (reading comprehension test), PPVT (Peabody Picture Vocabulary Test), and Wechsler Adult Intelligence Scale (WAIS), and were thus converted to z-scores for analysis. Detail on constructing education and cognition outcomes for each dataset are provided in *Supplementary Technical Annex 6*. Average adult height, education and cognition obtained from the literature review for each of the 7 focus countries are presented in *Supplementary Results Annex 1–3*.

We organized private sector occupations into categories based on the ILO International Standards of Occupation Classification (ISCO) and the types of jobs available in the datasets. For the longitudinal datasets, occupations were organized into agriculture, crafts and trade, services and sales, elementary workers, and unclassified wage workers. For the Enterprise Survey datasets (with more occupations available), categories used included food, garments, non-metallic mineral, fabricated metal, other manufacturing, retail, and other services. For longitudinal datasets, income was presented in local currency units in the dataset, and we aggregated estimates to monthly figures. We then converted estimates to 2019 US$ using appropriate exchange rates from the World Bank.[36] For Tanzania, we utilised income data from the World Bank's PovecalNet[34] as data on income was missing in the dataset. For the Enterprise Survey datasets, labour productivity was estimated as the amount of goods and services produced by a group of workers in a given time (total sales/workforce), the workforce age was estimated as median age of workforce in given year, stunting prevalence was calculated for the median age worker at 5 years, the stunting effect was estimated as the unconditional effects of stunting on human capital and returns to improved human capital (education, cognition, height), and labour share as the elasticity of income with respect to human capital.

Additional covariates used in conditional (adjusted) analyses of longitudinal datasets included the individual's age in years, sex, age gap between parents in years, mother's total years of formal education, household size (total number of residents) and wealth index estimated using principal components analysis of household assets.

Analysis

We estimated the cost of childhood stunting on both individuals and firms for 123 and 146 LMICs, respectively. We estimated the return on investing in stunting prevention using benefit-cost ratios (BCRs) for seven countries with longitudinal cohort datasets. For these seven countries, we also calculated the stunting effect on cognition, education and height in adulthood using three distinct methods.

Cost estimation

Our estimation approach is based on the additive nature of the stunting effect (through adulthood education, cognition and height) on human capital (Fig. 1, *Supplementary Technical Annex 8).*[22,24,25,27,37,38] We argue that any single human capital marker (e.g. education) might not adequately capture all possible pathways to adulthood earnings, and thus applied the additive approach that has been used in literature (see Galasso and Wagstaff[27]). We used unconditional estimates of the effect of stunting on human capital combined with conditional estimates of the returns to a unit gain in the human capital indicators. We provide two sets of estimates based on our main (method 1 - conservative) and alternative (method 2 -less conservative) assumptions (*Supplementary Technical Annex 8*). We present median estimates in the main paper and mean estimates in the appendix. Where possible, estimates are produced for all LMICs.

To estimate income losses to the individual private sector worker for the seven longitudinal datasets, we obtained the unconditional effects of stunting on human capital from the longitudinal data and combined this with conditional returns on human capital from the literature. We utilised the average of the five imputation models discussed above. These estimates were applied to monthly incomes to estimate the income loss attributable to stunting after adjusting for income elasticity (labour share fixed parameter of 0.67).[39] For all other countries (116 with available data), we applied the "Calibration approach' (*Supplementary Technical Annex 8)* which relies on a backwards accounting methodology. This approach used by Galasso et al. (2016) explains how income differences across countries at one point in time can be explained by proximate determinants (human capital). We examined what "current" earnings would be if stunting were eliminated by tracing backward to examine the stunting status for a determined workforce. A current private sector worker who was stunted at five-years-old would have human capital deficits that impact current earnings. This approach allowed us to estimate unit income losses per stunted worker. We obtained national estimates by multiplying unit losses with the determined stunted private sector workforce.

To estimate productivity losses to the firm, we also applied a backward accounting methodology since productivity losses through income can be applied to the firm as labour input in a production function (*Supplementary Technical Annex 9*).[37,38,40–51] We applied the stunting effect to a subset of full-time employees per firm to account for employee and employer choice in workforce selection and participation. We estimated productivity losses through loss in annual sales per stunted worker and determined annual loss in sales per firm by the proportion of full-time employees that were stunted at age five. These estimates were produced based on firms' sector and size. We then estimated national and regional estimates of annual loss in sales and share of GDP loss (*Supplementary Technical Annex 9*).

We estimated the return on investing in stunting prevention using benefit-cost ratios (BCRs) (*Supplementary Technical Annex 10*). We used the cost, effect, and coverage of 10 nutrition-specific interventions[52] to provide preliminary estimates for the one nutrition-specific intervention with estimated cost and impact by Dewey, Stewart et al.[53,54] We applied a 3% and 5% discount rate and aggregated monthly income to annual income; we present estimates for the seven study countries overall, pooled by sector and by gender within each country.[27,44,53–56] All analyses were performed using Python (v3.8) on the CDP and Stata version 15 (StataCorp).

Stunting effect modeling

Various approaches including Frequentist or Bayesian estimation have been applied to develop estimates and prediction models for childhood stunting. However, few studies have considered the comparative use of Frequentist, Bayesian, and ML techniques. Given these approaches offer tradeoffs in terms of complexity to implement, ease of interpretation, and other features, we studied the implementation of each of the 3 approaches when estimating childhood stunting's effect on cognitive status, years of education attained and adulthood height.

We implemented the three approaches with imputation (k-nearest neighbour, or KNN) and without imputation and compared the estimates. The Frequentist approach used a traditional OLS framework to fit the model. For the Bayesian model, Markov chain Monte Carlo (MCMC) was applied in the estimation and inference of model parameters. We conducted a targeted search of databases, including PubMed, GoogleScholar and Google, for national estimates for height, education, and cognition to be included as priors (*Supplementary Results Annex 1*). Priors were assumed to follow a normal distribution in the Bayesian model. For machine learning (ML) approaches, seven well-known ML algorithms were used: SVM, Decision Tree, RF, AdaBoost, Gaussian Process, Linear Regression and NN (MLP). Complete ML training information is described in *Supplementary Technical Annex 7*. The predictive performance of the seven ML algorithms was compared using mean absolute error (MAE), root mean square error (RMSE), and R-squared. To avoid overfitting or underfitting, model fit is evaluated by similar model metrics in training and test sets. Based on various ML predictive performance parameters, the best results have been accomplished by the ML-LR algorithm, which demonstrated a low MAE, RMSE and high R-squared in the training and test set for both crude and adjusted estimates in both by country and sector analysis.

Stunting effect estimates for each of Frequentist, Bayesian, ML models are shown with coefficients, standard errors/standard deviation, and credible intervals/confidence intervals in *Supplementary Technical Annex 7*. We produce estimates for the whole dataset and also stratified by gender (male vs female). All data processing and modeling were performed using Python (v3.8) on the Cloudera Data Platform. (CDP) Additional information on the CDP and Python libraries can be found in *Supplementary Technical Annex 7*.

This study adhered to CHEERS and STROBE reporting guidelines.

Role of funding sources

The Power of Nutrition and the Patrick J McGovern Foundation (formerly Cloudera Foundation) provided funding for the study. The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. They did provide critical review and feedback on the work.

Results

Stunting effect modeling

Generally, there were no notable differences between the Bayesian, frequentist, and ML stunting effect estimates in crude and adjusted analyses. Across the seven countries, the conservative income penalty (i.e., share of income lost) attributable to stunting ranged from about 4.0% (Tanzania) to 19.5% (Brazil) and between 8.4% (service/sales workers) to 16.9% (elementary occupations, crafts/trades workers) across identified sectors(*detailed results* in *Supplementary Results Annex 4*).

In terms of median monthly income lost, amounts ranged from US$2 in Tanzania to US$113 in Brazil; across sectors it ranged from US$9 for agricultural workers to US$48 loss for workers in elementary occupations. Mean estimates are available in *Supplementary Results Annex 4*.

We present and discuss estimates for global regions below and highlight key country estimates. Full country-level data is provided in the annex. We focus on median estimates using method 1 in the narrative (conservative) and provide mean estimates and estimates based on method 2 (less conservative) in the annex. All analyses are conducted using observational data and thus are associational however are likely an underestimate of the true causal effect.

Income losses to private sector workforce

Across the six World Bank regions representing 123 LMICs, the percentage of income lost associated with a stunted worker as was about 15% (Table 1). While we do not have estimates for all LMICs, Europe and Central Asia recorded the smallest total median monthly income loss to the private sector workforce (conservative vs less conservative figures) (US$899– US$1167 million) while East Asia and the Pacific had the largest (US $16,523–US$21,505 million) followed by Latin America and the Caribbean (US$3022–US$5051 million (Table 1). One country in South Asia (India) and Middle East and North Africa (Yemen) regions, and 13 countries in sub-Saharan Africa region recorded loss in median monthly income of less than US$10 per stunted worker, while Malaysia recorded the highest loss per stunted worker (US$115) (Table 2). The magnitude of monthly income loss associated with stunting at national level is a factor of the population size, monthly per capita income, and stunting prevalence at age five for the 2019 private sector workforce. Results should be interpreted within the given context. For example, Malaysia has some of the highest reported monthly incomes across countries and thus even with lower stunting %, the average stunted worker will lose more in absolute dollars. Though China and India are both large countries in terms of population size, income loss differences per stunted worker are largely due to the average earnings in India being less than 60% of earnings in China. Hence even with lower stunting rates, income losses are substantially higher in China.

Three countries, Brazil, India, and Indonesia lost more than US$1 billion in median income per month and China lost about US$12 billion (Table 2). In Sub-Saharan Africa, total monthly income losses associated with stunting were generally lower for most countries (relative to other regions) but Ethiopia (US$ 214·26 million) and Nigeria (US$ 177·10 million) had the highest

Country	OLS before imputation			OLS after imputation			Bayesian before imputation			Bayesian after imputation			Machine learning		
	Cognition (Z score)	Height (cm)	Education (years)	Cognition (Z score)	Height (cm)	Education (years)	Cognition (Z score)	Height (cm)	Education (years)	Cognition (Z score)	Height (cm)	Education (years)	Cognition (Z score)	Height (cm)	Education (years)
Brazil	0·55	8·8	2·49	0·56	8·12	2·37	0·54	8·74	2·47	0·55	8·07	2·36	0·55	7·86	2·28
Ethiopia	0·37	4·26	1·23	0·35	4·06	1·20	0·36	4·17	1·21	0·34	3·96	1·19	0·36	4·60	1·25
Peru	0·51	6·33	0·22	0·45	6·14	0·16	0·5	6·19	0·22	0·43	6·1	0·15	0·37	6·26	0·2
India	0·22	4·06	0·32	0·21	4·07	0·32	0·21	3·96	0·31	0·21	3·99	0·31	0·15	4·55	0·17
Vietnam	0·54	5·09	1·29	0·51	4·99	1·29	0·53	5·03	1·28	0·5	4·92	1·28	0·48	4·49	1·38
Philippines	0·34	5·15	1·43	0·26	5·23	1·16	0·34	5·12	1·42	0·26	5·20	1·16	0·29	5·35	1·15
Tanzania	0·28	3·12	0·33	0·28	2·92	0·01	0·28	3·08	0·33	0·28	2·83	0·02	0·28	1·39	0·27

Table 1: **Cognition, height, education estimates using OLS, Bayesian, and Machine Learning methods, longitudinal study countries.**

Economy	N	Income penalty I (%)	Income penalty II (%)	Individual income lost per month I	Individual income lost per month II	Total income lost per month I (million)	Total income lost per month II (million)
South Asia	7	14·07	20·81	31·40	44·81	2348·08	4624·70
Europe and Central Asia	19	15·48	20·10	51·97	67·48	898·91	1167·24
East Asia and the Pacific	20	14·32	20·30	33·59	46·18	16,522·46	21,504·88
North Africa/Middle East	12	15·48	20·03	35·22	45·57	1034·75	1338·66
Sub-Saharan Africa	46	15·10	23·30	15·69	23·78	1258·07	2099·44
Latin America and the Caribbean	24	15·30	20·29	51·38	66·82	3021·76	5050·91

***Table 2*: Median monthly income lost to the private sector workforce attributable to childhood stunting, by region (US$), N=128.**
N= number of countries; Income penalty I and Total income lost per month I based on main assumptions with smaller effect size and parameters obtained from one source: Galasso and Wagstaff (2019); Income penalty II and Total income lost per month II based on alternative assumptions with larger effect size and parameters multiple sources including region-specific estimates (see data sources for details); Note: The following countries are missing data for total income lost per month: Federated States of Micronesia, Kosovo, Montenegro, Turkmenistan, Djibouti, Syrian Arab Republic, West Bank and Gaza, Somalia, South Sudan..

losses. Estimates by country and based on means are available in *Supplementary Results Annex 5*.

Sales losses to private sector firms by worker, sector, and firm size

Across 108 LMICs, the average amount in sales each stunted worker costs the firm annually is shown in *Supplementary Results Annex 6*. Figures vary notably by country, and the highest values are seen for Mauritania (US$38,124·79), Syria (US$18,389·22), Venezuela (US $16,788·14) and Turkey (US$14,443·10). Generally, amounts are lowest for countries in Sub-Saharan Africa and highest for countries in Latin America and the Caribbean. Full country estimates are available in *Supplementary Results Annex 6*.

While we do not have estimates for all firms and LMICs, the losses in sales per firm associated with stunting in childhood are significant (Figure 2). Firms in East Asia and the Pacific have largest losses in annual sales ranging from US$332,420 (non-fabricated metal manufacturing sector) to US$79,980 (retail sector) for the average firm. Firms in Europe and Central Asia generally have the smallest losses. Across regions, firms in the retail sector have the lowest losses while manufacturing, garments and food sectors have the highest. Country-level losses by sector can be found in *Supplementary Results Annex 6*. Sectors with the highest and lowest losses vary notably across countries; differences across sectors are generally a reflection of sales and number of permanent workers.

The annual losses in sales for each of small, medium, and large size private firms by region is shown in Table 3, and country-level estimates can be found in *Supplementary Results Annex 6*. These figures vary by region and country but as expected, costs are higher for larger size firms. Large firms in Latin America and the Caribbean lost the most, with a regional median of the median loss in annual sales associated with stunting reaching US$91,125, while the smallest losses occur in small firms in Sub-Saharan Africa (US$421.57) (Table 2). For our seven case study countries, losses were lowest in Tanzania (US$176 - US$11,076 for small - large firms); and were highest in Peru (US$2933—US $185,681).

These average annual sale losses by firm/sector accumulate to large losses by region and country (Figure 3& *Supplementary Results Annex 6*). Across the 95 LMICs for which we had representative national private sector data, childhood stunting is associated with costs to the private sector of a minimum of US$135.4 billion annually (conservative estimate). Middle East and North Africa had the lowest sales losses (US$ 0.712 billion) while East Asia and the Pacific (US$65.9 billion) and Latin America and the Caribbean (US$46.8 billion) had the largest (Figure 3). Countries with highest losses included China (US$57.9 billion), Peru (US$21.3 billion), Brazil (US$11.0 billion), Mexico (US$8.2 billion), Colombia (US$4.2 billion), Philippines (US$2.6 billion), Vietnam (US$2.2 billion) and Thailand (US$1.4 billion). These losses to the private sector amount to a significant proportion of annual GDP. Values ranged from 0.01% to 1.2% of annual GDPs lost due to stunting although some outliers existed, e.g., countries that with estimates less than 0.01% GDP (e.g., Liberia) and larger than 1.2% (e.g., Peru, 10.1%).

Returns to investment in nutrition-specific interventions

The returns to investing in the 10 nutrition-specific intervention packages across the seven study countries provide estimates ranging from a high of US$37 (3600% return on every dollar invested) in Vietnam to a low of US$2 (100% return) in Tanzania using 5% discount. Across sectors, the highest returns were in

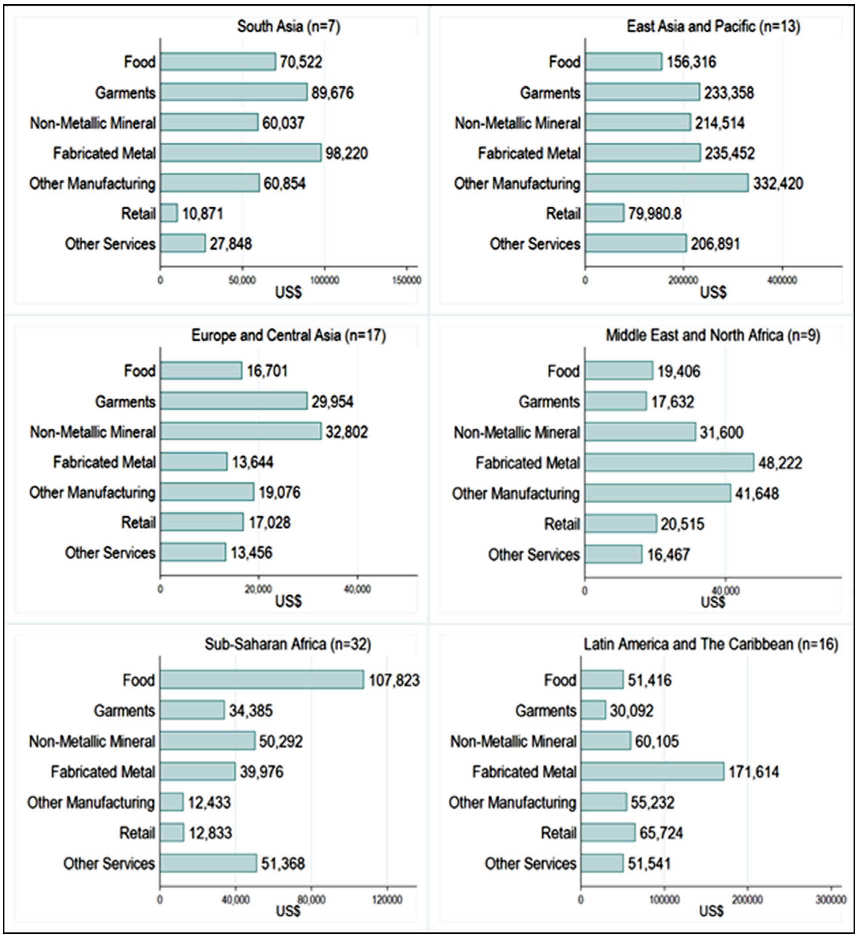

Figure 2. Revenue loss (revenue loss/stunted workforce) attributable to a stunted workforce for the average firm
Note: *n*=number of countries, N=94.

elementary occupations (US$46) and the lowest were among agricultural workers (US$8). The BCRs for the country-level and pooled data increases between US$4 and US$81, and US$17 and US$95, respectively when we applied a 3% discount rate (see Table 5).

We present returns (Benefit-Cost Ratios [BCRs]) to investing in stunting reduction for the private sector in LMICs through the implementation of the Bhutta et al. 10 nutrition-specific intervention and comment on the potential returns to investing in the Lipid Nutrient Supplement Paste Small Quantity (LNS-SQ) using estimates from Dewey et al.[52–54] As has been noted by Hoddinott, BCRs are sensitive to the discount rate, the costing of interventions, assumptions regarding the magnitude of the impact, and the duration over which benefits are calculated.[44] We present CBRs based on a low (3%) and high (5%) discount rate and use unconditional effects of stunting on human capital and conditional returns in improvement on human capital.

Investing in the 10 nutrition-specific intervention packages across our seven study countries provides returns ranging from US$2 to US$81 per $1 investment per annum (Table 4). BCRs that are above 1 are considered a good investment with positive returns hence, the 10 nutrition invention packages are very good investments in the select countries, providing returns from 100% to 8100% for every dollar invested. The returns are highest in Vietnam and lowest in Tanzania, although our income data for Tanzania was from a secondary source which might not reflect the actual private sector earnings in Tanzania. Pooled country data stratified by five sectors suggests that highest returns are in elementary occupations (US$45–US$95) and lowest returns are among agricultural workers (US$8–US$17) using median annual incomes. Considering that elementary occupations are low-skilled workers that engage in occupations including farm and house servants, eliminating stunting and its associated effects on human capital for this occupation would produce the best returns in this scenario. We provide estimates based on means in the *Supplementary Results Annex 4*.

Economy	Monthly income lost per stunted worker				Total lost in monthly income for private sector population	
	Share of income lost I (%)	Share of income lost II (%)	Income lost I US$	Income lost II, US$	Total income lost I, US$ (millions)	Total income lost II, US$ (millions)
Latin America and the Caribbean	**15.30**	**20.95**	**50.93**	**69.47**	**3021.76**	**5050.91**
Bolivia	15·48	21·79	48·23	67·90	105·69	148·79
Colombia	15·48	21·79	41·61	58·58	520·11	732·18
Ecuador	15·48	21·79	44·40	62·51	89·84	126·48
Mexico	15·48	21·79	42·57	59·92	520·58	732·84
Peru	7·38	18·77	23·15	58·85	142·82	363·09
Dominican Republic	15·48	20·01	55·10	71·20	29·95	38·71
Haiti	15·48	20·01	16·78	21·68	25·07	32·40
Jamaica	15·48	20·01	36·95	47·75	4·61	5·96
St· Lucia	15·48	20·01	62·05	80·18	1·31	1·70
Trinidad and Tobago	15·48	20·01	85·63	110·66	2·45	3·17
Belize	15·48	20·68	23·92	31·96	0·80	1·07
Costa Rica	15·48	20·68	69·25	92·53	10·64	14·21
El Salvador	15·48	20·68	42·67	57·01	36·22	48·39
Guatemala	15·48	20·68	29·54	39·46	108·47	144·93
Honduras	15·48	20·68	26·64	35·59	43·60	58·25
Nicaragua	15·48	20·68	34·74	46·41	27·53	36·79
Panama	15·48	20·68	82·30	109·96	21·26	28·41
Argentina	15·48	18·84	64·89	78·95	46·11	56·10
Chile	15·48	18·84	82·95	100·92	25·94	31·56
Uruguay	15·48	18·84	95·87	116·63	27·72	33·72
Brazil	19·20	38·02	74·48	147·46	1197·22	2370·38
Guyana	15·48	19·14	43·87	54·25	1·22	1·50
Paraguay	15·48	19·14	57·23	70·76	31·86	39·39
Suriname	15·48	19·14	37·41	46·26	0·73	0·91
South Asia	**14.07**	**20.81**	**29.68**	**43.25**	**2348.08**	**4624.70**
Bangladesh	22·09	22·09	17.59	25.09	202.00	288.19
Bhutan	22·09	22·09	37.54	53.56	6.19	8.83
India	5·58	13.18	6.82	16.10	1362.89	3219.09
Maldives	22·09	22·09	76.58	109.26	3.14	4.48
Nepal	22·09	22·09	20.03	28.58	87.24	124.47
Pakistan	22·09	22·09	17.93	25.58	620.01	884.59
Sri Lanka	22·09	22·09	31.24	44.57	66.62	95.05
East Asia and the Pacific	**14.32**	**20.30**	**31.63**	**44.16**	**16,522.46**	**21,504.88**
China	15·48	19·60	52·73	66·77	12,896·67	16,331·11
Fiji	15·48	22·44	37·52	54·38	0·58	0·85
Indonesia	15·48	19·60	24·71	31·29	1614·18	2044·05
Kiribati	15·48	22·44	20·74	30·06	0·12	0·17
Lao People's Democratic Republic	15·48	19·60	18·36	23·25	37·32	47·26
Malaysia	15·48	19·60	114·66	145·20	374·56	474·31
Micronesia, Federated States of	15·48	22·44	18·39	26·66	—	—
Mongolia	15·48	19·60	39·34	49·81	5·15	6·52
Myanmar	15·48	19·60	26·72	33·84	358·09	453·45
Nauru	15·48	22·44	35·93	52·08	0·01	0·02
Papua New Guinea	15·48	22·44	14·80	21·45	17·29	25·06
Philippines	10·45	22·09	15·83	33·45	319·26	674·75
Samoa	15·48	22·44	36·68	53·17	0·08	0·11
Solomon Islands	15·48	22·44	13·82	20·04	1·57	2·27
Thailand	15·48	19·60	57·36	72·64	467·80	592·38
Timor-Leste	15·48	19·60	12·74	16·13	3·87	4·90

Table 3 *(Continued)*

Economy	Monthly income lost per stunted worker				Total lost in monthly income for private sector population	
	Share of income lost I (%)	Share of income lost II (%)	Income lost I US$	Income lost II, US$	Total income lost I, US$ (millions)	Total income lost II, US$ (millions)
Tonga	15·48	22·44	38·51	55·82	0·03	0·04
Tuvalu	15·48	22·44	35·34	51·22	0·02	0·03
Vanuatu	15·48	22·44	17·33	25·11	0·33	0·48
Vietnam	11·55	23·00	32·70	65·09	425·54	847·13
Europe and Central Asia	**15.48**	**20.10**	**51.97**	**67.48**	**898.91**	**1167.24**
Albania	15·48	20·10	35·64	46·28	7·87	10·22
Armenia	15·48	20·10	27·65	35·90	3·36	4·36
Azerbaijan	15·48	20·10	82·21	106·75	22·63	29·39
Belarus	15·48	20·10	89·63	116·38	9·79	12·71
Bosnia and Herzegovina	15·48	20·10	94·68	122·95	6·11	7·94
Georgia	15·48	20·10	29·25	37·98	5·29	6·87
Kazakhstan	15·48	20·10	51·98	67·50	42·00	54·54
Kosovo	15·48	20·10	37·41	48·57	–	–
Kyrgyz Republic	15·48	20·10	25·14	32·65	17·21	22·35
Moldova	15·48	20·10	42·48	55·16	2·58	3·35
Montenegro	15·48	20·10	66·45	86·28	–	–
North Macedonia	15·48	20·10	53·00	68·82	2·04	2·65
Romania	15·48	20·10	78·11	101·43	63·76	82·79
Serbia	15·48	20·10	59·33	77·04	10·44	13·56
Tajikistan	15·48	20·10	30·82	40·02	18·47	23·98
Turkey	15·48	20·10	67·31	87·40	382·39	496·53
Turkmenistan	15·48	20·10	36·19	46·99	–	–
Ukraine	15·48	20·10	62·45	81·09	227·85	295·86
Uzbekistan	15·48	20·10	17·63	22·89	77·12	100·15
Middle East and North Africa	**15.48**	**20.03**	**35.22**	**45.57**	**705.17**	**912.28**
Algeria	15.48	20.03	37.71	48.79	107.44	138.99
Djibouti	15.48	20.03	19.96	25.82	–	–
Egypt, Arab Republic of	15.48	20.03	18.91	24.46	134.99	174.63
Iran, Islamic Republic of	15.48	20.03	49.25	63.72	245.88	318.09
Iraq	15.48	20.03	26.44	34.21	34.27	44.33
Jordan	15.48	20.03	42.15	54.53	14.65	18.95
Lebanon	15.48	20.03	83.33	107.80	19.58	25.33
Morocco	15.48	20.03	38.90	50.32	111.87	144.72
Syrian Arab Republic	15.48	20.03	11.23	14.53	–	–
Tunisia	15.48	20.03	44.40	57.44	22.23	28.76
West Bank and Gaza	15.48	20.03	41.99	54.32	–	–
Yemen, Republic of	15.48	20.03	8.38	10.84	14.28	18.48
Sub-Saharan Africa	**15.12**	**23.36**	**15.4**	**23.6**	**1258.07**	**2099.44**
Angola	15.48	23.82	8.7	13.3	23·95	36·85
Benin	15.48	23.48	10.1	15.3	11·25	17·06
Botswana	15.48	22.83	21.5	31.6	4·39	6·47
Burkina Faso	15.48	23.48	11.0	16.7	17·02	25·80
Burundi	15.48	24.56	5.2	8.3	10·47	16·60
Cabo Verde	15.48	23.48	34.8	52.7	1·22	1·85
Cameroon	15.48	23.48	17.4	26.4	43·42	65·85
Central African Republic	15.48	23.48	5.5	8.4	3·89	5·91
Chad	15.48	23.48	10.7	16.2	19·76	29·96
Comoros	15.48	24.56	18.5	29.3	1·00	1·58
Congo, Democratic Republic of	15.48	23.82	5.9	9.1	75·71	116·49

***Table 3** (Continued)*

Economy	Monthly income lost per stunted worker				Total lost in monthly income for private sector population	
	Share of income lost I (%)	Share of income lost II (%)	Income lost I US$	Income lost II, US$	Total income lost I, US$ (millions)	Total income lost II, US$ (millions)
Congo, Republic of	15.48	23.82	7.9	12.1	0·99	1·53
Cote d'Ivoire	15.48	23.48	15.0	22.8	33·12	50·22
Eswatini	15.48	22.83	14.6	21.6	1·23	1·81
Ethiopia	9.87	21.88	9.2	20.5	214·26	474·81
Gabon	15.48	23.48	35.7	54.2	7·59	11·51
Gambia, The	15.48	23.48	19.3	29.3	2·52	3·81
Ghana	15.48	23.48	25.7	39.0	93·35	141·57
Guinea-Bissau	15.48	23.48	7.1	10.8	0·93	1·41
Guinea	15.48	23.48	13.9	21.1	23·80	36·10
Kenya	15.48	24.56	12.5	19.8	89·78	142·41
Lesotho	15.48	22.83	14.7	21.7	2·55	3·76
Liberia	15.48	23.48	9.2	13.9	6·88	10·44
Madagascar	15.48	24.56	5.3	8.4	30·92	49·05
Malawi	15.48	24.56	6.6	10.5	21·00	33·31
Mali	15.48	23.48	9.9	15.1	22·84	34·63
Mauritania	15.48	23.48	23.6	35.7	8·64	13·10
Mauritius	15.48	22.96	52.8	78.3	3·24	4·80
Mozambique	15.48	24.56	7.1	11.2	32·41	51·41
Namibia	15.48	22.83	23.4	34.5	5·04	7·43
Niger	15.48	23.48	10.3	15.7	28·49	43·21
Nigeria	15.48	23.48	10.6	16.1	177·10	268·58
Rwanda	15.48	24.56	9.1	14.4	8·03	12·74
Sao Tome and Principe	15.48	24.56	11.7	18.5	0·28	0·45
Senegal	15.48	23.48	13.6	20.6	14·65	22·22
Seychelles	15.48	22.96	87.3	129.4	0·19	0·28
Sierra Leone	15.48	23.48	10.2	15.5	6·47	9·81
Somalia	15.48	23.48	6.8	10.4	—	—
South Africa	15.48	22.83	20.4	30.0	80·17	118·24
South Sudan	15.48	24.56	7·81	7·81	—	—
Sudan	15.48	24.56	25·29	25·29	35·90	56·95
Tanzania	4.28	10.49	2·6	6·3	25·97	63·70
Togo	15.48	23.48	14·76	14·76	5·38	8·16
Uganda	15.48	24.56	17·40	17·40	42·52	67·44
Zambia	15.48	24.56	11·25	11·25	8·35	13·25
Zimbabwe	15.48	22.83	23·31	23·31	11·44	16·87

***Table 3*: Median monthly income lost to the private sector attributable to childhood stunting, by country and region, calibration estimates N=128.**
Share of income lost I and Total income lost per month I based on main assumptions with smaller effect size and parameters obtained from one source: Galasso and Wagstaff (2019) (see data sources for details); US$ is 2019 United States dollars.

The LNS-SQ is estimated to reduce stunting by 12% per annum at about $63.88 per child. Although the coverage level of the intervention that results in the 12% reduction in stunting is not stated, the BCR estimates for the seven countries could potentially be high enough to also suggest good returns on investment.

Supplementary Results Appendix 4 shows analyses by gender. Women incur a higher income penalty associated with childhood stunting and earn less than men; due to their relatively higher earnings, the returns for investing in stunting reduction are consistently higher for men across most countries studied.

Discussion

This is the first global study, to our knowledge, that quantifies the economic burden of childhood stunting on the private sector workforce earnings, firms' annual sales, and losses incurred by specific economic sectors for up 123 LMICs and uses diverse datasets

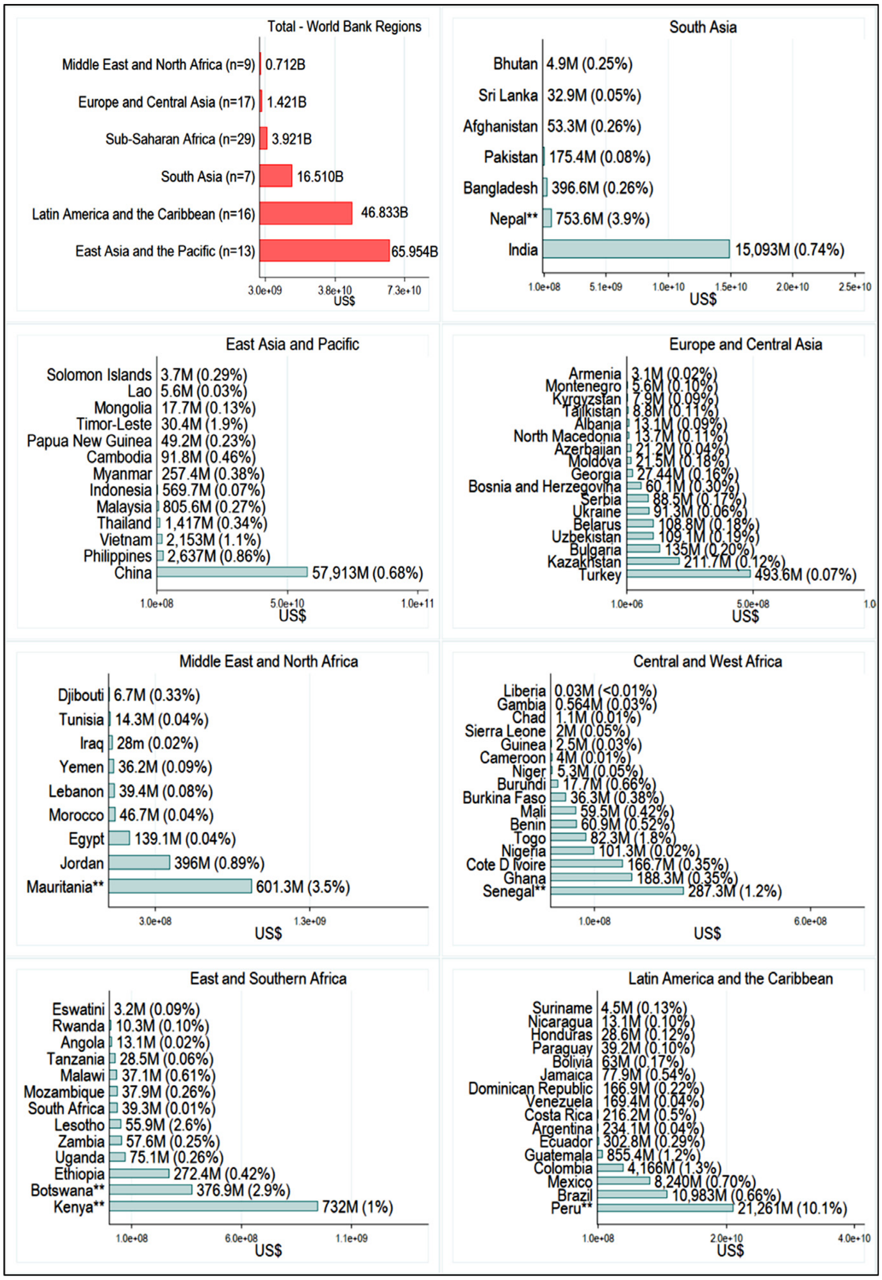

Figure 3. Regional and country level annual loss in sales attributable to childhood stunting as a proportion of the workforce (share of national GDP in parenthesis), N=91.

**Countries had significantly higher number of private sector firms relative to other countries and produced higher penalties. Note: There were 17 countries with missing data that could not be aggregated to include in total estimates. 12 countries (Belize, Cabo Verde, Central African Republic, Eritrea, Fiji, Gabon, Guyana, Madagascar, Saint Lucia, Samoa, Tonga, Vanuatu) have missing firm aggregates, and additional 5 countries (Syria, Namibia, South Sudan, El Salvador, and Algeria) did not have estimates for the total number of firms in the country's Enterprise Survey, and thus we could not generate aggregate estimates to national levels.

(longitudinal cohorts, national surveys) and comparative statistical methodologies.

Findings across 95 LMICs show that childhood stunting costs the private sector at least US$135.4 billion in sales annually. The greatest losses were experienced by countries in Latin America and the Caribbean and East Asia and Pacific regions, representing a loss of 0.01% to 1.2% in GDP. While estimates vary across regions, countries, sectors, and firms, these losses in potential revenue are large enough to act as financial

Region[b]	Loss in annual sales by firm size, US$		
	Small	Medium	Large
East Asia and Pacific (N=13)	707.62	4026.75	36,765.92
Europe and Central Asia (N=17)	771.82	4389.21	23,911.90
Latin America and the Caribbean (N=16)	1008.26	8258.61	91,125.41
Middle East and North Africa (N=10)	1913.48	7637.60	29,682.07
South Asia (N=7)	1087.47	5522.01	51,308.19
Sub-Saharan Africa (N=32)	421.57	4401.22	37,851.48

***Table 4*: Regional median of median loss in annual sales attributable to childhood stunting by firm size, Method I, all Enterprise Survey countries, N=95.**

[b] Note that the following countries were missing relevant data to produce these estimates: Belize, Cabo Verde, Central African Republic, El Salvador, Eritrea, Fiji, Gabon, Guyana, Madagascar, Saint Lucia, Samoa, Tonga, Vanuatu.

boosters for regional and country economies and GDPs. Sectors most affected by childhood stunting were manufacturing (non-metallic mineral, fabricated metal, other), garments and food sectors. Losses in monthly income resulted in large unearned income at the regional level ranging from US$700 million (Middle East and North Africa) to US$16.5 billion (East Asia and Pacific). These funds could be at the disposal of individuals to inject into their economies if stunting was eliminated in childhood. For the average stunted worker, the loss in monthly income circumscribes their financial resources and personal/household capacity to purchase and consume adequate nutrients. Estimates from the longitudinal analysis illustrate that most individuals are not "high income" earners and even small increases in earnings would significantly support their access to essential resources. Reducing stunting during childhood is projected to increase employees' human capital, improve their employment opportunities, and stimulate economic activity within the private sector, as well as national/global economies. Investing in effective direct nutrition interventions[57] also yields substantial returns, from US$2 to US$81 per $1 invested annually (or 100% to 8000% across countries), reinforcing that investing in early-life nutrition interventions represents "value-for-money".[5]

Data from this study could motivate strong partnerships between public and private sector to continue and strengthen investments in undernutrition. The private sector inherently shapes community nutrition via their roles in nutrition-sensitive initiatives and sectors.[4,58] Private sector actors particularly within countries (e.g., Brazil, India, Indonesia and China), industries and regions (e.g., Latin America and Caribbean and East

	By country estimates			BCR	
	Annual income, US$, median	Share of income lost (%)	Intervention cost	5% discount	3% discount
Brazil	7008·72	19·45	120·20	35·94	69·17
Ethiopia	718·08	10·09	121·43	11·63	25·52
India	1180·44	5·47	114·84	6·19	13·08
Peru	3683·40	7·57	120·20	15·49	31·59
Philippines	802·68	11·00	121·43	10·54	22·70
Tanzania	722·40	4·03	121·51	2·00	4·14
Vietnam	2407·08	11·55	121·60	37·45	81·32
By sector estimates (pooled)					
Agricultural workers	1087·68	9·97	120·17	8·17	17·04
Craft/trades workers	1140·60	16·94	120·17	14·42	30·06
Elementary occupation	3428·40	16·91	120·17	45·72	95·34
Not classified	2188·32	9·34	120·17	15·39	32·10
Service/Sales workers	4624·44	8·35	120·17	28·80	60·06

***Table 5*: Benefit-cost ratios for investing in stunting reduction.**

Note: as has been noted by Hoddinott (2016), BCRs are sensitive to the discount rate, the costing of interventions, assumptions regarding the magnitude of the impact, and the duration over which benefits are calculated. We present CBRs based on a low (3%) and high (5%) discount rate and use unconditional effects of stunting on human capital and conditional returns in improvement on human capital.

Asia and Pacific) most impacted by stunting should also consider targeted investments that address underlying determinants of nutrition, including access to education, early childhood development, agriculture productivity, access to water, sanitation and hygiene, gender equality, as well as establishing social safety nets and protection programs.[59] Although we found that across Sub-Saharan Africa, countries have a high stunting burden, the costs due to stunting appear lower than other regions; this does not imply that we should not focus on these countries. Indeed, a constraint on growth in these countries could be due to a lack of an educated workforce,[60] and investments prioritizing universal foundational cognitive and socioemotional skills, as well as investments in technical skills tied to growing sectors would be highly impactful.[61]

The private sector also substantially shapes food systems, supply chains, and populations' diet globally.[4,7,62,63] Prevention of childhood malnutrition by food and agricultural sectors will require investment to integrate smallholder farms into global supply chains, improve quality assurance and food distribution, food fortification, promote sustainable practices to reduce food waste and build nutrition science capacity within LMICs. Moreover, engagement in advocacy for nutrition-friendly trade policies, use of social business models, and innovative use of existing technologies represent promising strategies to engage the private sector.[4,58,64–75] A new self-assessment tool for SMEs created by the Scaling Up Nutrition Business Network (SBN), Access to Nutrition Initiative, and the Global Alliance for Improved Nutrition (GAIN) supports firms to assess the availability, affordability and nutritious value of food produced, and offers recommendations for improved their performance and accountability.[76] Further research is needed to build a case for investment to prioritize scaling-up commercial financing food value chains, which seek to produce and promote safe and affordable nutrition foods.[6]

Our findings also illustrate that women experience higher income penalties due to childhood stunting than their male counterparts; yet men earn higher monthly incomes and the income lost is greater for men than women. Reducing stunting among men and women offers promising returns on investments (with a benefit-cost ratio >1, whereby $1 invested to reduce stunting in Brazil generates a $92 increase in median earnings per annum for men and $62 for women). In contrast, McGovern et al. found that nutrition interventions resulting in a 1 cm increase in height are associated with 4% and 6% increases in wages for men and women, respectively.[38] Health economists assert that gender inequalities in adult wages due to stunting should be interpreted with caution as labour participation rates, types of employment and earnings vary substantially by gender.[20,28] Interventions that aim to improve gender equality and support women's education, sexual and reproductive health, and nutrition (during adolescences and pre-conception)[77] represent important opportunities for nutrition-sensitive investments by all stakeholders, including the private sector. Introducing fee waivers or cash transfer programs to improve access to education[59] or supports for breastfeeding in the workplace (e.g., paid maternity leave, appropriate facilities/equipment, flexible work schedule/policies and increased awareness of breastfeeding among workers)[78] represent evidence-based strategies for the private sector to boost female workforce productivity and create sustainable improvements in community health and nutrition.

The conservative nature of our estimation approach does not account for possible and substantial externalities and spillover effects from human capital development attributable to childhood stunting reduction. This also extends to our BCR estimates since investing in stunting reduction could also have positive externalities. For some secondary parameters, we rely on best available estimates (e.g., stunting prevalence). The generalisability of our longitudinal data country-level and pooled estimates might be limited due to small sample size restrictions, however we improved on this by using other imputation and regression models. The enterprise surveys focus on non-agriculture and formal sectors, hence our estimates may not adequately capture other sectors in LMICs. Using conservative numbers of firms within countries may also have underestimated the of loss in sales. The targeted review of literature on national estimates of adult height, education and cognition aimed to synthesize effects sizes to complement the regional data from longitudinal studies. However, the lack of standard deviation for estimates on educational attainment represents a potential study consideration. Moreover, studies examining adult cognition largely provided subnational, regional, or city-specific estimates that may not adequately reflect national variation. Modelled estimates for cognition were also included,[79,80] generated using international student assessment scores and intelligence test studies, yet critiques of study sample representativeness and cross-country comparability are noted in literature.[81] The outcome variables of years of education and cognition were derived from proxy variables for Ethiopia, India, Peru and Vietnam. Since stunting status at five years old was not available, HAZ at age eight was accounted for. For Tanzania, there were no proxy variables related to cognition. Proxy variables were also used to estimate years of education. Few longitudinal datasets exist from LMICs that span two or more decades and thus the number of countries for which we could conduct in-depth analyses was limited. Our results should also be interpreted with caution as findings may not be causal given the reliance on longitudinal cohort datasets to estimate the stunting effect. However, we do feel our work satisfied five of the nine Bradford Hill's criteria,[82–85] importantly, the temporality element (i.e. that childhood stunting precedes adulthood outcomes in the same individual). Additionally, previous studies that established causation through use of instrumental variables have found that OLS estimation as we have done is an underestimate of the true effect.[12,24] Therefore, we feel confident that our study findings provide valuable insights into causality and will not be overestimating impacts. Finally, we used statistical significance to judge the strength of associations in our longitudinal study analyses, and although this is standard practice, it may not be the best metric to use as it is dependent on sample size.

While long-term financial benefits of investing in stunting reduction are an important motivator for countries, many private firms/corporations are also interested in the more immediate or short-term benefits to their organizations. Our group is currently pursuing follow-on research to estimate the costs and benefits in the short-term to multinational corporations for investing in stunting reduction; we hope the current data and estimates from the follow-up research will provide enable a powerful policy dialogue for action. Additional avenues for further research in this space include an exploration of the variance in the returns on investment in interventions to improve childhood nutrition. In particular, countries with high ROI could be studied to determine the driving force. An extension of the research presented could include country case studies for countries which have longitudinal cohort studies, such that country-specific recommendations can be made. Research can also be conducted to test the impact of the recommendations proposed, and whether gains have been achieved when investments in childhood nutrition have been made. Future work can also focus on critically reviewing public-private partnerships to reduce stunting including identification of challenges and lessons learned.

Given the private sector's omnipresence in LMICs[30,86] which contributes overwhelmingly to the GDP,[87] our results underscore the importance of childhood stunting on the private sector workforce and firms. While our data reinforces the importance of continued government focus on undernutrition, such data that aligns businesses' profit incentives with nutritional outcomes can also motivate private sector stakeholders to invest in childhood stunting reduction interventions.[88] Ensuring alignment between private sector direct and indirect nutrition interventions and national priorities, policies, and programs is necessary. Notwithstanding substantial commitments by SMEs and multinational corporations to reduce malnutrition, including the global Nutrition for Growth Food Systems Summit or their engagement in global platforms (e.g., SBN or GAIN), achieving the SDGs is not feasible without further investment, engagement and mobilization of the private sector — in partnership with the public sector.[4,6] Critically, the COVID-19 pandemic threatens to reverse progress towards the SDGs, including traction gained to improve health and nutrition worldwide.[89] However, it has also exposed unique opportunities for private sector innovation and investment to address social and health inequalities, and reduce childhood stunting.[90]

Contributors

NA and KW conceptualised the study and wrote the proposal for funding. NA designed the approach for the broader study. MNO designed the economic methods with input from JH. RR designed the machine learning and Bayesian methods with input from NA. Deidentified data were accessed and handled by HT, RR, DSH, MNO, and NA. Analyses were conducted by HT, DS, MNO and RR. HT, JW and MNO implemented the literature reviews. JA, REB, BLH, NN, RS, NJ, MS, KW and JH provided critical technical inputs to methodology, inferences and results communication and dissemination. NA took the decision to submit the manuscript for publishing. The first draft of the manuscript was drafted by NA, HT, MNO, JW, DS and RR. After input from all other authors, the second draft was prepared by NA, HT and JW. All authors reviewed and agreed to the analyses, results interpretation, and write up of the final draft.

Data sharing statement

Data used in this study was either publicly available or obtained with special permission from original study research teams who had collected the data. All data obtained for study purposes were received already deidentified. Should other researchers wish to obtain data used in this study, they can do so by contacting the original study teams. HT, DSH, RR, NA and MNO accessed and were responsible for the deidentified data used in this study.

Declaration of interests

Nikita Japra is a current employee of Patrick J. McGovern Foundation (funder) and former employee of Cloudera Foundation (funder). NJ served as the program officer for the grant that funded this work while employed by Cloudera Foundation/Patrick J. McGovern Foundation (funder). Kerri Wazny was an employee of The Power of Nutrition (funder) during the work.

Acknowledgments

We acknowledge the technical guidance and support from Sue Horton (health and nutrition economist, University of Waterloo), Harold Alderman (health and nutrition economist, International Food Policy Research Institute) and Christen Meyer (labour economist, University of Oxford). We would also like to acknowledge our generous funders The Power of Nutrition (UK) and Patrick J McGovern Foundation (USA).

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.eclinm.2022.101320.

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