For Online Publication

Appendix A Economic growth with government provision of health care

The model in the main paper showed that cognitive development affects schooling and economic growth, but it didn't specify the source of cognitive development. This section models the impact of government health spending on the economy through its effect on cognitive development.

Most health spending around the world is by governments (on average 60% in 2017 according to World Bank, 2021). Much of the private spending is only possible due to a government-created network of health facilities, medical training and insurance mandates.

Prenatal care for pregnant women, which is consequential for fetal cognitive development, depends in the first instance on its availability. Undernutrition of young children, a contributor to poor cognitive development, is mostly a reflection of lack of choice. Parents are likely unable to assess whether their children are deficient in crucial micronutrients like iron, iodine and folate without access to blood tests. A strong indication that parents are not making informed decisions in this area is that rates of iron deficiency are very high although adequate iron can be obtained at very low cost. Options include eating iron-rich greens or beans, cooking with iron pots or placing a piece of rusty metal in a water tank (Werner et al., 1992, p. 117). Iodine and folate can also be obtained at low cost from certain natural or fortified foods. On the other hand, governments can provide iron, iodine and folate for the whole population by fortifying foods like salt, rice, or flour at extremely low cost (Ramírez-Luzuriaga et al., 2018; Dietrich et al., 2005). Exposure to important risk factors like contagious disease, clean water, sanitation, pollution, communal violence or war largely depend on government action or inaction.

Define f as the proportion of time a person is healthy. f is the proportion of healthy time that can be devoted to early cognitive development, h_0, human capital development in school, h, or working time, producing income y. Assume that $f(g)$ is an increasing, concave function of government health spending g, where $f(g) > 0 \ \ \forall \ \ g > 0$ and $f'(g) \equiv \frac{\partial f(g_0)}{\partial g_0} > 0$. The level of annual health spending on young children during the fetal and early childhood period is g_0, and health spending on children in school and adults is g. Since the period of cognitive development after which many deficiencies are irreversible starts at conception and ends at about age two, take the period during which initial human capital h_0 develops to be about 3 years, so that cognitive potential at conception is h_{-3}, normalized to equal 1.

If $f = 1$, a person realizes a full year of early development, learning in school, or productive work. When $f < 1$, they are only healthy enough for productive activities for the fraction f of a year. Initial human capital h_0 and completed human capital h are

$$h_0 = f(g_0)h_{-3} = f(g_0)$$
$$h = h_0 e^{\eta h_0 f(g) s}$$

where initial human capital, h_0, a parameter $\eta > 0$, and years of school, s, affect the human capital growth rate. η can be interpreted as a measure of the quality of schooling because it alters the human capital produced by each year of schooling.

Output per worker in the economy, y, is a function of the level of technology A, healthy work time, $f(g)$, and human capital per worker, h:

$$y = A[f(g)h]^{\alpha}.$$

The parameter $0 < \alpha \leq 1$ represents constant or diminishing returns to human capital in production. Technology is a function of the average human capital of workers while they are healthy,

$$A = A_w[f(g)h]^{\beta}.$$

Substituting,

$$y = A_w \left[f(g) f(g_0) e^{\eta f(g_0) f(g) s} \right]^{\alpha+\beta}$$

Keeping people healthy during working years (the first $f(g)$) and during gestation and infancy (the first $f(g_0)$) each have the same impact on income (ignoring for the moment the impact of g_0 and g on learning in $e^{\eta f(g_0) f(g) s}$). The symmetry of $f(g)$ and $f(g_0)$ means that keeping people healthy during working years or during infancy are equally economically beneficial. However, they have very different lengths and very different costs. Infancy is short, about three years, and working years is longer longer, say 48 years to make the ratios simple. If the level of healthcare expenditure per person g were the same for adults and infants,[14] the total cost to the government of providing healthcare to workers is $48g$, twelves times the lifetime spending on infant healthcare ($3g$).

This is the main intuition of the model. Keeping infants healthy from inception to age two is equally economically productive as keeping adults healthy. Keeping an infant healthy is vastly cheaper because infancy is a much shorter time period, so the government should be spending more on the health of an infant than an adult. Accounting for the impact of infant and student health spending on the rate of learning provides an additional impetus to prioritize infant health, since infancy is typically shorter than years in school.[15]

An optimizing government would invest substantially *more* per person for maternal and early childhood health than for working adults because it is much more economically productive per dollar spent. Exactly how much more should be spent per year on infants depends on the concavity of the health function $f(\cdot)$.

To show this formally, the government will maximize the lifetime utility of

[14]In the U.S. the annual cost of healthcare for working adults is, if anything, higher than the cost for children. The cost for infants 0-3 years old 79% of the cost of adults aged 19-64 and the cost of school-age children aged 4-18 only 35% of adults (Table 3 of Herrera & Nelson, 2012)

[15]By the same logic, governments should spend more on school children than adults for economic reasons, since school years are fewer than work years, but for simplicity, in this model the government spends the same amount g on both students and workers each year.

the representative person by choosing health spending for each age group, g_0 for infants and g for school children and workers, conditional on the parents' choice of education s.

Parents choose schooling s to maximize their child's lifetime utility subject to the budget constraint:

$$\max_s u = T\frac{c^\sigma}{\sigma} \quad s.t. \quad Tc = (1-\tau)(T-s)y$$

where c is consumption, σ is a diminishing marginal utility parameter, $(1-\tau)(T-s)y$ is post-tax income during working years and $0 < \tau < 1$ is the tax rate. The parents' choice of schooling is

$$s = T - \tfrac{1}{\alpha\eta h_0}.$$

Note that parents choose more schooling when the government spends more on the health of infants since $h_0 = f(g_0)$, making people more productive their whole lives. The parents' choice of schooling is unaffected by health spending for school age children and workers, g:

$$\frac{\partial s}{\partial g_0} = (T-s)\frac{f'(g_0)}{f(g_0)} > 0; \qquad \frac{\partial s}{\partial g} = 0.$$

The government maximizes the utility of the representative person subject to the individual's post-tax lifetime budget constraint and the government's budget constraint. Health spending, $3g_0 + Tg$, must equal tax revenues $\tau(T-s)y$ from a tax rate τ:

$$\begin{aligned} \max_{g_0,g} u &= T\frac{c^\sigma}{\sigma} \\ s.t. \quad Tc &= (1-\tau)(T-s)y \\ \tau(T-s)y &= 3g_0 + Tg \end{aligned}$$

The maximization provides a relationship between health spending g and g_0:

$$\frac{f'(g)}{f(g)} = \frac{T}{3} B \frac{f'(g_0)}{f(g_0)}$$

where

$$B \equiv 1 + \frac{\frac{f(g)}{\alpha} - \frac{1}{\alpha+\beta}}{1 + \eta h_0 s f(g)}.$$

B reflects the complicated tradeoffs from better cognitive development improving the rate of learning, causing children to stay in school longer, which raises their productivity and income, but also reduces their years working. The magnitude of B depends on the value of its parameters, but for plausible real world values, $B \approx 1$.[16]

$f(\cdot)$ is an increasing function, so $f'(g) > 0$. $\frac{f'(g)}{f(g)} \approx \frac{T}{3} \frac{f'(g_0)}{f(g_0)}$ means that optimal government spending on maternal and infant health, g_0, will be substantially higher than spending on student and worker health, g:

$$g_0 > g$$

If the health spending function $f(g)$ is linear, school (including preschool) and working years after age 2 is $T = 60$ years, and gestation and infancy is 3

[16] $B \approx 1$ if $\frac{f(g)}{\alpha} \approx \frac{1}{\alpha+\beta}$ or if $\frac{f(g)}{\alpha} - \frac{1}{\alpha+\beta}$ is small relative to $1 + \eta h_0 s f(g)$. $\frac{f(g)}{\alpha} = \frac{1}{\alpha+\beta}$ if $f(g)\frac{\alpha+\beta}{\alpha} = 1$. Since we are denominating g as annual per person health expenditures, $1 - f(g)$ is the average annual work lost due to poor health. Empirical estimates for these losses are low in percentage terms, at less than 1% for Great Britain (less than 2 work days lost per 252 working days per year, HSE, 2022), 1.1% in Japan (Chimed-Ochir et al., 2019, p. 682), and 4.5% in a high-disease area of rural Nigeria (8.2 days lost during a 6 month growing season Unekwu, 2014, p. 8489). So it is likely that $f(g) > 0.95$. If β, the impact of average human capital on the level of technology adoption is at least 5% of α, the labor share of income going to workers in a competitive economy, then $B \geq 1$.

If alternatively $\beta = 0$ and $f(g)$ is still 0.95, then $\frac{f(g)}{\alpha} - \frac{1}{\alpha+\beta}$ is still likely to be small relative to $1 + \eta h_0 s f(g)$. As in the previous section, the private return to education is still $R_p = \alpha \eta h_0$, so $1 + \eta h_0 s f(g) = 1 + \frac{R_p s f(g)}{\alpha}$. Most estimates for private returns to education R_p are at least 7% with higher rates in lower income countries (Card, 1999; Psacharopoulos, 1994). Average years of schooling across countries is 9 years in 2015 (Barro & Lee, 2013) plus 3 years of preschool would make $s = 12$. Karabarbounis and Neiman (2014) estimate α, the labor share, at 0.52 or higher. With these parameters, $B = 1 + \frac{f(g)-1}{\alpha + R_p s f(g)} = 1 + \frac{0.95-1}{0.52+0.07\times 12\times 0.95} =$ .96, which is still reasonably close to 1 (relative to $\frac{T}{3}$).

years, then

$$\frac{f'(g)}{f(g)} = \frac{1}{g} \text{ and } g_0 = 20g$$

so the government should optimally spend 20 dollars on early child health for every dollar spent on adult and school age health.

In reality, $f(g)$ is almost certainly concave due to diminishing returns to health spending, so the differences in optimal health spending across age groups would be less dramatic. The effects of health on economic productivity would still mean that substantially more should be spent on maternal and early childhood health per person than on working adults.

References

Barro, R. J., & Lee, J. W. (2013). A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics*, *104*, 184–198. https://doi.org/10.1016/j.jdeveco.2012.10.001

Card, D. (1999). The Causal Effect of Education on Earnings. *Handbook of Labor Economics* (pp. 1801–1863). Elsevier. https://doi.org/10.1016/S1573-4463(99)03011-4

Chimed-Ochir, O., Nagata, T., Nagata, M., Kajiki, S., Mori, K., & Fujino, Y. (2019). Potential Work Time Lost Due to Sickness Absence and Presence Among Japanese Workers. *Journal of Occupational & Environmental Medicine*, *61*(8), 682–688. https://doi.org/10.1097/JOM.0000000000001646

Dietrich, M., Brown, C. J., & Block, G. (2005). The Effect of Folate Fortification of Cereal-Grain Products on Blood Folate Status, Dietary Folate Intake, and Dietary Folate Sources among Adult Non-Supplement Users in the United States. *Journal of the American College of Nutrition*, *24*(4), 266–274. https://doi.org/10.1080/07315724.2005.10719474

Herrera, C., & Nelson, J. (2012). Differences in Health Care Spending of Children and Adults, 2007—2010. Retrieved September 11, 2020, from https://healthcostinstitute.org/images/pdfs/Issue-Brief-2-Children_Adult_Differences.pdf

HSE. (2022). *Statistics - Working days lost in Great Britain*. Retrieved August 2, 2022, from https://www.hse.gov.uk/statistics/dayslost.htm

Karabarbounis, L., & Neiman, B. (2014). The global decline of the labor share. *The Quarterly Journal of Economics*, *129*(1), 61–104. Retrieved July 23, 2022, from http://www.jstor.org/stable/26372544

Psacharopoulos, G. (1994). Returns to investment in education: A global update. *World Development*, *22*(9), 1325–1343. https://doi.org/10.1016/0305-750X(94)90007-8

Ramírez-Luzuriaga, M. J., Larson, L. M., Mannar, V., & Martorell, R. (2018). Impact of Double-Fortified Salt with Iron and Iodine on Hemoglobin, Anemia, and Iron Deficiency Anemia: A Systematic Review and Meta-Analysis. *Advances in Nutrition*, *9*(3), 207–218. https://doi.org/10.1093/advances/nmy008

Unekwu, O. (2014). Ill health and agricultural production: Evidence from kogi state of nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, *14*(1), 8488–8503.

Werner, D., Thuman, C., & Maxwell, J. (1992). *Where there is no doctor: A village health care handbook* (Rev. ed). Hesperian Foundation.

World Bank. (2021). *World Development Indicators*. http://wdi.worldbank.org

Appendix B Proximate determinants of child survival

If child cognitive development plays a causal role in economic growth, it would be useful to know the relative importance of different risk factors of child development. Since data covering many countries for most causes of mortality are only available since year 2000, their coverage is too sparse to include directly in the economic growth regressions. However, we can look at the correlations of different causes of mortality with overall child survival.

Table 7: Correlates of child survival

	Fixed Effects	Shapley % of R^2	Including GDP	Shapley % of R^2
Anemia (% of children < 5)	-1.672	33.3	-1.549	33.4
	[0.069]***		[0.074]***	
Safe water (% of households)	1.039	25.7	0.951	25.6
	[0.055]***		[0.064]***	
Sanitation (% of households)	0.102	13.8	-0.022	
	[0.044]*		[0.049]	
Immunization, DPT (% of children < 2)	0.305	9.5	0.284	9.5
	[0.037]***		[0.040]***	
Undernutrition (% of pop.)	-0.306	9.1	-0.361	9.4
	[0.047]***		[0.051]***	
Immunization, Measles (% of children < 2)	0.047	5.9	0.045	6.2
	[0.036]		[0.038]	
Immunization, TB (% of children < 2)	-0.019	2.7	-0.011	3.0
	[0.030]		[0.032]	
log GDP per capita, lagged 10 yrs			5.317	12.9
			[1.041]***	
Constant	905.177		785.952	
	[6.094]***		[24.807]***	
N	2,371		2,193	
Countries	131		124	
$R^2(Corr(\hat{y}, y)^2)$	0.97		0.96	

+ $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

The risk factor data which are both available for most countries and likely to be important proximate determinants of child survival include child anemia, safe water and sanitation, undernutrition and child immunizations. All data are from the World Bank (2021).

Anemia reflects not only the lack of iron in the diet, but also the incidence of malaria, helminth infections (24% of the world population, WHO, 2021b), tuberculosis (23% of the world, CDC, 2020) and schistosomiasis (3% of the world, WHO, 2021a). Unsafe water and poor sanitation transmit gastrointestinal disease causing diarrhea, a major source of undernutrition. Poor sanitation also transmits helminths and schistosomes, which cause undernutrition and anemia.

Table 7 shows regressions of national child survival rates on risk factors using annual data from 2001 to 2019. Country fixed effects are included to account for geographical and other time-invariant omitted factors. For example the burden of disease tends to be higher in tropical areas due to a more conducive climate for pathogens (State of the Tropics, 2019).

All the risk factors except tuberculosis and measles immunizations are statistically significantly correlated with child survival at the 5% level or lower. The R^2 is very high at 0.97. A test for serial correlation in the errors (Drukker, 2003) accepts the absence of an AR(1) process with a p value of 0.24.

To assess the relative importance of the risk factors, column 2 shows the Shapley decomposition which attributes the contribution of each risk factor to the R^2 (Shorrocks, 2013). Anemia alone accounts for a third of the variation in child survival not explained by the country fixed effects. Anemia together with safe water and sanitation accounts for 72% of the variation. Undernutrition has a smaller share (8%), but it is closely related to access to sanitation and safe water. The three immunizations together account for 20% of the variation, which is notable given their modest cost.

It could be that the levels of risk factors just reflect income levels, which are really responsible for good child survival. The regression in column 3 includes the natural log of GDP per capita, lagged ten years to avoid possible reverse causality and because it is likely that higher income levels require some time to impact health conditions. The results show that income level is unlikely to drive the relation between the risk factors and child survival. The only substantial change to the estimated coefficients due to including income is for sanitation, which becomes statistically insignificant. The other risk factors are not highly correlated with income levels with the highest correlation coefficient for safe water of 0.36. The Shapley decomposition in column 4 is also largely unchanged, where sanitation is excluded due to the illogical negative but insignificant correlation. The estimated contribution of GDP per capita is only 12% of the explained variation in child survival, indicating that it plays a small additional role in child health.

The country fixed effects reveal lower rates of child survival in the tropics which is not explained by the included risk factors. The child survival rate in tropical countries is 36/1000 lower than in non-tropical countries. After accounting for the risk factors, including GDP per capita, the average difference in tropical versus nontropical country effects is still 31/1000 (statistically different from zero at a 0.1% level), or 86% of the raw difference.

The decomposition of child survival into risk factors on a world scale is not a subtle exercise, but it may still be a useful indication of the relative importance of different risk factors for child cognitive development. The correlations indicate that changes in anemia, water, vaccinations and sanitation, in order of importance, account for more than 90% of the improvements in child survival.

References

CDC. (2020). *Tuberculosis*. Retrieved December 22, 2021, from https://www.cdc.gov/globalhealth/newsroom/topics/tb/index.html

Drukker, D. M. (2003). Testing for Serial Correlation in Linear Panel-data Models. *The Stata Journal*, *3*(2), 168–177. https://doi.org/10.1177/1536867X0300300206

Shorrocks, A. F. (2013). Decomposition procedures for distributional analysis: A unified framework based on the Shapley value. *The Journal of Eco-*

nomic Inequality, *11*(1), 99–126. https://doi.org/10.1007/s10888-011-9214-z

State of the Tropics. (2019). Health in the Tropics. https://www.jcu.edu.au/__data/assets/pdf_file/0012/864993/SOTT-Health-Report-2019-Webv02.pdf

WHO. (2021a). *Schistosomiasis*. Retrieved November 29, 2021, from https://www.who.int/news-room/fact-sheets/detail/schistosomiasis

WHO. (2021b). *Soil-transmitted helminth infections*. Retrieved November 29, 2021, from https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections

World Bank. (2021). *World Development Indicators*. http://wdi.worldbank.org