Essays on Maternal and Child Health, Fertility, and Economic Well-Being in Low- and Middle-Income Countries

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ESSAYS ON MATERNAL AND CHILD HEALTH, FERTILITY, AND ECONOMIC WELL-BEING IN LOW- AND MIDDLE-INCOME COUNTRIES

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Essays on Maternal and Child Health, Fertility, and Economic Well-Being in Low- and Middle-Income Countries

Abstract

This dissertation is comprised of three studies that, together, explore the links between: 1) access to and use of maternal and child health care, family planning, and reproductive health services; 2) fertility and maternal and child health outcomes; and 3) longer-term measures of well-being, in developing country contexts. I utilize both theoretical and empirical methods to explore these relationships of interest. In the first study, I use a large multi-country microeconomic data set to assess the associations between physical access to services and utilization of maternal and child health services as well as child mortality outcomes. I find that living close to a health facility is associated with increased utilization of maternal health services, namely receipt of antenatal care and in-facility delivery, as well as improved child survival, particularly in the neonatal period. In the second study, I adopt a macrosimulation approach to investigate the long-run health and economic effects of a decline in fertility. I construct a model that describes the interrelated evolution of economic and demographic outcomes under a "baseline" scenario, in which fertility declines slowly over time, and I compare these outcomes under a simulated "alternative" scenario in which fertility declines more rapidly. I calibrate the model parameters using findings from well-identified microeconomic studies, and I use baseline data from Nigeria to compare the model's predictions for each of the key outcomes under the two fertility scenarios. Through this modeling exercise, I show that a decline in fertility creates the potential for a demographic dividend and a window of opportunity for economic growth; moreover, the magnitude of this growth factor may be substantially larger than what has been estimated to date. In the third study, I use population-based survey data to identify children growing up in healthy environments in low- and middle-income countries, and I compare the height distribution of these children to the height distribution of the international growth reference sample that was established by the World Health Organization. I find that observed differences in child height across populations are likely not due to innate or genetic differences, but are more likely to reflect children's continued exposure to resource-poor environments, poor maternal education, and lack of access to health and sanitation.

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All errors and omissions are my own.

1. Facility Distance and Child Mortality: A Multi-Country Study of Health Facility Access, Service Utilization, and Child Health Outcomes

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1.1. Abstract

Background

Access to health facilities remains limited in many resource-poor settings, and women and their children often have to travel far to seek care. However, data on distance is scarce, and it is unclear whether distance is associated with worse child health outcomes. We estimate the relationships between distance to facility, service utilization, and child mortality in low- and middle-income countries.

Methods

Population-representative data are pooled from 29 Demographic and Health Surveys across 21 low- and middle-income countries. Multivariable logistic models and meta-analysis regressions are used to estimate associations between facility distance, child mortality, and health care utilization in the pooled sample as well as for each survey.

Results

Compared to children who live within 1 km of a facility, children living within 2 km, 3 km, and 5 km of a facility have a 7.7% (95% CI: 0.927 – 1.251), 16.3% (95% CI: 1.020 – 1.327), and 25% (95% CI: 1.087 – 1.439) higher odds of neonatal mortality, respectively; children living farther than 10 km have a 26.6% (95% CI: 1.108 – 1.445) higher odds of neonatal mortality. Women living farther than 10 km from a facility have a 55.3% lower odds of in-facility delivery compared to women who live within 1 km (OR: 0.447, 95% CI: 0.394 – 0.508).

Conclusions

Even relatively small distances from health facilities are associated with substantial mortality penalties for children. Policies that reduce travel distances and travel times are likely to increase utilization of health services and reduce neonatal mortality.

1.2. Keywords

Distance, antenatal care, facility delivery, child mortality, service availability

1.3. Key Messages

The key contributions of this study to the literature are fivefold:

1. We overcome two key methodological problems faced by previous studies: a) measurement error in estimated distances due to incomplete and geo-scrambled location data; and b) insufficient sample size to be able to detect mortality outcomes.
2. The systematic and standardized collection of distance data across countries allows us to infer the distribution of spatial distances and travel times within and across several low- and middle-income countries.
3. Most of the literature has primarily focused on the most remote areas (> 5 km or > 10 km). We show that such distances are rather rare in most countries.
4. We are able to show that distance to facilities does not only matter when facilities are far, but also within relatively narrow radiuses – relatively minor factors are likely to have substantial effects on health behaviors.
5. We find that reducing distance to facilities may increase health care utilization and, more importantly, improve neonatal survival.

1.4. Introduction

Over the past two decades, low- and middle-income countries have made considerable progress towards reducing child mortality (Wang et al., 2014). In spite of these achievements, however, nearly 18 000 children under the age of five continue to die every day (UNICEF/WHO, World Bank, & UNDP, 2013; World Health Organization, 2014). Many of these deaths might be avoidable if high quality obstetric and medical care was provided to mothers and their children, yet utilization of these services in these settings remains low (Bhutta et al., 2014; UNICEF, 2012; World Health Organization & UNICEF, 2003).

A large theoretical and empirical literature has highlighted the importance of geographical determinants for health care seeking as well as for maternal and child health outcomes (Gabrysch & Campbell, 2009; Målqvist, Sohel, Do, Eriksson, & Persson, 2010; Shannon, Bashshur, & Metzner, 1969; Thaddeus & Maine, 1994; Titaley, Dibley, & Roberts, 2012). Two recent systematic reviews assessed the existing empirical evidence on the link between distance and child survival and found that while a few studies report a significant relationship between facility distance and child health outcomes, the evidence of the associations between distance and child mortality is both limited and mixed (Okwaraji & Edmond, 2012; Rutherford, Mulholland, & Hill, 2010).

We think the existing literature suffers from two potential flaws; firstly, the distances usually contain measurement error by construction, and secondly, the studies have small sample sizes and low power to detect effects. In the absence of direct measures of facility distance and complete facility data, most of the literature to date has relied on imputing straight-line distances from households to facilities, which are subject to a substantial amount of measurement error (Elkies, Fink, & Bärnighausen, 2015), are likely to lead to mismatches between households and facilities, and are not able to capture local differences in topography and travel time (Rutherford et al., 2010). Many previous studies also have attempted to estimate distances to facilities by matching household location data from public use surveys, such as the Demographic and Health Surveys (DHS), to facility data without adjusting for the geo-scrambling of the true household locations in these surveys. In DHS surveys, for example, the geo-scrambling of clusters, which serves to protect respondent confidentiality, is carried out using a displacement algorithm by place of residence, in which urban clusters are displaced by up to two kilometers and rural clusters are displaced by up to five kilometers, with a further, randomly selected one percent of rural clusters being displaced by up to ten kilometers (Burgert, Colston, Roy, & Zachary, 2013). This displacement induces significant measurement error in any imputed distances and also biases the estimated effect of distance (Elkies et al., 2015).

In addition, there is an issue of sample size in reported studies. While health service utilization is reported frequently and is relatively common, child mortality is a relatively rare event, and analyses of the relationship between distance and child mortality using small sample sizes are likely to be insufficiently powered. Furthermore, a low absolute number of deaths in small samples can also give rise to a downward bias in estimates of the true effect size (King & Zeng, 2001).

In this study, we utilize health facility access data that was collected as part of the Service Availability Module in 29 DHS surveys from 21 low- and middle-income countries, and we investigate the relationships between distance to facility, service utilization (receipt of antenatal care and in-facility delivery), and child mortality within and across countries. The Service Availability Module provides, to our knowledge, the first set of population-representative data on both travel time and distance to the nearest health facilities, thereby allowing us to both characterize distances and time to health facilities and estimate the mortality penalty associated with larger distance to facilities in low- and middle income countries. From this module, we extract measures of actual reported distance and travel time from each surveyed cluster to the nearest health facility. This overcomes the measurement issues that arise from estimating straight line distance measures based on geo-scrambled data. In addition, we report both individual and pooled results from the 29 surveys. The pooled results make use of a large sample size, giving us sufficient power to detect child mortality effects.

1.5. Methods

1.5.1. Study Population

We combine data from 29 DHS surveys with Service Availability Modules that were conducted between 1990 and 2011, resulting in a pooled sample of 124 719 mothers and 126 835 births across 7 901 DHS clusters in 21 countries. The DHS surveys are nationally representative cross-sectional surveys that cover a range of health topics (USAID & ICF Macro International, 2014). All surveys employ a two-stage cluster sampling design, stratifying by region and urban/rural residence and interviewing about 20 to 30 women aged 15 to 49 per primary sampling unit, each of which generally corresponds to a census enumeration area and which is randomly selected within each strata. A total of 52 DHS surveys were collected; as described in Supplemental Material Table A2, we excluded 23 surveys because they either did not have information on household wealth (one of the key confounders) or because the Service Availability Module only contained partial information on facility distance. Supplemental Material Figure A1 shows the geographic distribution of the 21 countries that are covered in our sample.

1.5.2. Distance Measures

All distance measures were based on data from the Service Availability Module, a special module that was administered at the cluster level as part of the routine DHS surveys. DHS clusters consist of about 20 to 30 households that are randomly selected from sampled census enumeration areas of approximately 1 000 individuals (ICF International, 2012). In each cluster, three or four key informants with presumed knowledge about local availability of health services were identified and were jointly interviewed. Typical key informants were community leaders, religious leaders, and local health service providers; at least one member had to be female (Rose, Abderrahim, Stanton, & Helsel, 2001; Wilkinson, Wamucci, & Abderrahim, 1993). In the interview, the informants were asked to identify the nearest facility of each type from the sampled cluster. For each type of facility, three questions are asked to identify distance and travel time:

1. “How far in miles/kilometers is the (name of the health facility of interest) located from the center of this village/community/locality?”
2. “What is the most common mode of transportation that is used by people in the village/community/locality to go to this facility?”
3. “How long (minutes/hours) does it take to go to the facility using the most common type of transportation?”

Following the interview, facilities that were mentioned by informants were visited by a DHS enumerator as a means to validate the data that was provided.

We utilize four available distance indicators in the Service Availability Module: 1) distance to the nearest hospital; 2) distance to the nearest dispensary, doctor, or low-tiered clinic, 3) distance to the nearest mid-level clinic or health center; and 4) distance to the nearest maternal and child health center, district-level clinic, or primary health center. We then calculate the minimum distance to any of these four types of facilities. We measure minimum distance to facility as an interval categorical variable with five categories: less than 1 km to a facility, which is our reference category; between 1 km and 2 km; between 2 km and 3 km; between 3 km and 5 km; between 5 km and 10 km; and greater than 10 km to a facility. We also use travel time categories as robustness checks.

1.5.3. Outcome Variables

Our primary outcome of interest is neonatal mortality. We examine neonatal mortality (death within the first 28 days after birth) among all children born who would have been at least 29 days old had they survived to the survey date. We also report results in the Supplemental Material section on additional child mortality measures, including: child mortality (death before age 5); post-neonatal infant mortality (death after 28 days but before age 1); and post-infant child mortality (death after age 1 but before age 5) (UNICEF/WHO et al., 2013). Details about our analytic sample for these additional mortality results are provided in the Supplemental Material section. Finally, we analyze receipt of antenatal care and delivery in a health facility as secondary outcomes. A woman was coded to have received appropriate antenatal care for a given birth if she reported receiving at least four visits during pregnancy, which is the minimum number of visits recommended by the World Health Organization (World Health Organization & UNICEF, 2003).

1.5.4. Statistical Analysis

We use multivariable logistic regressions to estimate the associations between distance to the nearest facility and our binary outcomes of interest. Regressions include mother-, child-, and cluster-level controls. At the mother level, we control for wealth index of the household (in quintiles), mother's educational attainment group (no education, primary, secondary, higher), birth order, maternal age (in five-year age groups), marital status, and place of residence (urban/rural). The neonatal mortality regression also incorporates child-level controls, including the length of time from the child's birthdate to the survey date, child sex, and whether the birth was a single or multiple birth. To control for spatial differences in socioeconomic characteristics, we include average cluster wealth and average cluster educational attainment. Lastly, we include survey and year-of-birth fixed effects in all of our models to ensure our results are not affected by country or temporal trends. Standard errors are clustered at the primary sampling unit level to account for the complex DHS survey design. Regression coefficients are interpreted as odds ratios of the outcome, which in the case of rare outcomes such as child mortality, is approximately equal to the relative risk (Rothman, Greenland, & Lash, 2008). We conduct regression analyses separately for the full sample and for each survey. All analyses were performed using Stata, version 13 (StataCorp LP, 2013).

1.6. Results

Figures 1 and 2 respectively summarize the distances and travel times to the nearest facility across the 21 countries. The fraction of children born to households that are farther than 10 km from a health facility is largest in Burkina Faso (50.2%) and lowest in Vietnam (0.9%); similarly, the fraction of children born to households that are farther than 30 minutes away is highest in Burkina Faso (65.7%) and lowest in Jordan (0.2%). Table 1 describes the distribution of facility distances by DHS cluster, while Table 2 describes the distribution of facility distances by birth. Both tables also separately present the distributions of clusters and births by urban and rural place of residence. As Table 2 indicates, 27.9% of children in our pooled sample are born to households that are within 1 km of a health facility, 9.1% are born to households that are within 2 km of a facility, 15.2% are born to households that are within 3 km, 12.1% are born to households that are within 5 km of a facility, and 15.3% are born to households that are within 10 km of a facility. The remaining 20.4% of children are born to households that do not have a facility within a 10 km radius.

Tables 3 and 4 presents descriptive statistics for our health utilization and child mortality outcomes. In our sample, 3.0% of children died in the neonatal stage, 3.4% died at the post-neonatal infant stage, and 1.7% died in the post-infant child stage. Slightly less than two out of every five women (39.4%) received at least four antenatal care visits, and 42.6% of births were delivered in a health facility.

Results from the pooled analysis for our primary and secondary outcomes are reported in Table 5, and we plot these coefficients in Figure 3. We find that children who are born to households that are located within 2 km, 3 km, and 5 km from a health facility have a 7.7% (95% CI: 0.927 – 1.251), 16.3% (95% CI: 1.020 – 1.327), and 25% (95% CI: 1.087 – 1.439) higher odds of dying in the neonatal period, respectively, when compared to children who are born to households that are within 1 km from a facility. Similarly, increased odds of neonatal mortality were found for children who are born to households within a 5 to 10 km range of a facility (OR: 1.191; 95% CI: 1.042 - 1.363) and to children born in households located farther than 10 km from a facility (OR: 1.266; 95% CI: 1.108 - 1.445).

We find similar results when we use travel time to the nearest facility instead of distance; children born to households that are located more than 60 minutes from a health facility have a 25.6% (OR: 1.256; 95% CI: 1.105 - 1.429) higher odds of dying in the neonatal period than children who are born to households that are within 10 minutes from a health facility.

When compared to women who live less than 1 km from a facility, the odds of receiving at least four antenatal visits for women living more than 10 km from a facility is 38.8% lower (OR = 0.612, 95% CI: 0.559 – 0.671). Similarly, the odds of in-facility delivery are lower at greater distances, with the odds ratio for delivery for women living more than 10 km being 55.3% lower (OR = 0.447; 95% CI: 0.394 – 0.508) relative to women living less than 1 km away. As was the case in the neonatal mortality analysis, we find similar results when using travel time to the nearest facility.

In Figure 4, we plot the estimated effect of distance to facility on the odds of neonatal mortality for each of our 29 surveys. We find being more than 10 km from a facility increases the odds of neonatal mortality in five surveys. In one survey, in Nigeria in 1990, being farther than 10 km from a facility appears to lower the odds of neonatal mortality, while no effect is observed in the remaining 23 surveys. We observe that the confidence intervals on the survey-specific estimates are quite large, and it may be that the lack of significance is a product of small sample sizes rather than a real null effect.

We provide robustness checks and additional results for child mortality at older ages in the Supplemental Material section. We show that our results are robust to: 1) using travel time rather than travel distance; 2) restricting our range of facilities in-patient facilities only, which include: hospitals, mid-level clinics and health centers, maternal and child health centers, district-level clinics, and primary health centers, and 3) controlling for distance to nearest primary school. Our results also confirm that distance appears to have little effect on child mortality after the neonatal period.

1.7. Discussion

In this study, we used detailed health access data across 21 countries to show the empirical relationships between facility distance, child health, and health service utilization. Our analysis has yielded three main results. Firstly, we find that the majority of children in our sample of low- and middle-income countries live relatively close to a facility; on average, 52.2% of children live within 3 km from a health facility. In contrast to prior studies, we show that living farther than 5 km from a facility is relatively rare in most countries. Given that most of our data are from the 1990s and early 2000s, it is likely that such remoteness has become even rarer with increasing urbanization and global economic development. While we find that longer travel distances are associated with lower health care utilization and higher mortality for children, the fact that most women live relatively close to facilities may reduce the case for making travel distance a policy priority. Secondly, the degree of health system access varies remarkably across countries; for example, less than two percent of households living more than 10 km from the nearest facility in Jordan and Vietnam, while around half of all households in Burkina Faso and Nigeria do not have a facility within the same 10 km radius. Finally, and perhaps most importantly from a health systems perspective, we find that even relatively small distances are associated with sizeable increases in utilization and neonatal mortality. While most of the existing literature has focused on relatively large distances, our results suggest that average health outcomes deteriorate rather quickly with small distance increases. Moreover, we find that the differences in outcomes between households that are located within a moderate distance from a facility and more remote households are relatively small. For example, our findings show that estimates of the distance impact for women and children from households that are within 3 to 5 km from a facility for both service utilization and child health outcomes are comparable to estimates for households that are located more than 10 km from the nearest facility.

We find a statistically significant effect on neonatal mortality of being 2 km or more from a facility; for longer distances, however, the point estimates of the effect sizes are all very similar and not statistically different from each other. In contrast, we find that the utilization effects seem to be increasing fairly linearly in distance. While the point estimates for the effect of distance on mortality are similar above 2 km, the confidence intervals are quite wide due to the fact that mortality, unlike utilization, is a fairly rare outcome. Indeed, in Figure 3, it would be possible to draw a linearly increasing relationship between distance and the odds ratio of neonatal mortality that remained within our confidence intervals of the estimated effect. It follows that while a reasonable interpretation of our results is that there is a cutoff in the effect of distance on mortality around the 2 km mark, our findings are also consistent with the possibility of a continuing effect on mortality as distance rises.

A "gold standard" measure of distance would completely reflect the travel burden between locations (Delamater, Messina, Shortridge, & Grady, 2012). We believe that our reported distance measures from the Service Availability Module more accurately quantify the difficulty of traveling to health facilities than previous approaches to estimating distance. Moreover, the spatial and temporal distance data from the Service Availability Module allows us to compare different metrics of distance and travel time to health services against each other. Relative to previous studies, our pooled approach gives us a much larger sample size and the statistical power to estimate both how health care utilization and neonatal mortality vary with distance.

Taken together, our results suggest that while average distances to health facilities in low- and middle-income countries are likely to be smaller than what is commonly perceived, improving access to facilities may still play a considerable role in further improving child health outcomes. One approach to reducing travel distances would be to build more facilities; however, having a large number of facilities, each with a low case load, may increase costs and could lower the quality of service provision.

Improving access to transport would not affect the distance required to travel but can have benefits through reducing travel times. While we identify distance and travel times as a barrier, additional research is required to establish the relative cost effectiveness of different policies that aim to address this issue.

There are several limitations to our study. The only health outcome that we evaluate is child (and more specifically neonatal) mortality. However, access to care is likely to child affect morbidity as well (Ahmed, Sobhan, Islam, & Khuda, 2001), which we do not capture. We argue that the distances reported in the Service Availability Module are more reliable than straight line distances estimated from scrambled coordinate data; however, the Service Availability Module data may have errors. Distances and travel times reported by the community may be subject to measurement error and reporting bias. While the survey protocol is for enumerators to validate reported distances and travel times through visits to facilities, a study of the Service Availability Module found that these facility follow-up visits were not always carried out (Rose et al., 2001). In addition, the Service Availability Module does not contain any data on the quality of services that are received, which is likely to affect both service utilization and mortality outcomes (Ahmed et al., 2001; Akin, Guilkey, & Hazel Denton, 1995; Anwar, Kalim, & Koblinsky, 2009). For example, distances to rural facilities are, on average, farther than distances to urban facilities, but rural facilities may also have different levels of service provision. While we control for urban versus rural place of residence in our regressions, controlling for direct measures of the quality of facility services would be preferable. The same concern holds for other spatial confounders – even though we control for some household and cluster-level covariates, it is possible that distance to other infrastructure types may be correlated with health facility access and will therefore confound the results. Although we show that controlling for school access does not affect our main results in one of our robustness checks, residual confounding cannot be fully excluded. In particular, we acknowledge that our controls may not be sufficiently accounting for other factors that are correlated with both distance to facility and child mortality, including disease environment, access to safe water and sanitation, access to markets, etc. It therefore may be that our distance to facility measure might be a proxy for access more generally, and while we have tried to identify the effect of access to health services more specifically by controlling for access to other types of services (e.g. school, market), we are unable to adequately account for other unobserved dimensions of access in this study.

The DHS wealth index quintiles are a measure of relative wealth of the household within each country. Our use of survey fixed effects implicitly adjusts for any factors, such as average national income per capita, that are the same for all households within the same survey. However, it would be preferable to construct wealth measures that were directly comparable across countries, however such procedures are difficult both conceptually, and because different surveys measure different household assets (Rutstein & Staveteig, 2014).

These measurement problems, and the possibility that they are confounders in our observational study, imply that we must be circumspect about drawing policy conclusions from our results. Direct evidence from policy interventions or experiments would be required to overcome these concerns.

1.8. Conclusions

Our findings suggest that health facility distance remains a key predictor of health service utilization as well as neonatal mortality. Policies and programs that improve access in more remote areas through, for example, increasing the number of facilities or reducing travel times through increased access to transport, are likely to not only yield substantial increases in the coverage rates of critical public health interventions but also may substantially contribute to further reductions in under-5 mortality.

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1.10. Ethics

Ethical approval for the evaluation was granted by the Harvard T.H. Chan School of Public Health Institutional Review Board (IRB), Protocol No. IRB13-2746.

1.11. Author Contributions

MK was responsible for conducting the main statistical analysis, conducting the literature review, drafting and reviewing the main text, and coordinating review among authors; GF contributed substantially to the analysis of the data and write-up of the manuscript; and DC contributed substantially to the conceptual development of the paper, assisted with the review of the manuscript, and supervised the finalization of the results. All named authors contributed to the overall conceptualization, analysis, writing, and finalization of the paper.

1.12. Competing Interests

We have read and understood the *International Journal of Epidemiology*'s policy on declaration of interests and declare that we have no competing interests.

1.13. Funding Statement

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

1.14. Main Figures and Tables

Table 1: Descriptive Statistics, Distance to Facility Variables by Cluster

	Total Mean	No. of Cases	Urban Mean	Rural Mean
Distance				
Distance to facility, < 1 km	0.318	2,514	0.538	0.186
Distance to facility, 1 – 1.9 km	0.111	869	0.169	0.074
Distance to facility, 2 – 2.9 km	0.170	1,340	0.160	0.175
Distance to facility, 3 – 4.9 km	0.116	915	0.058	0.150
Distance to facility, 5 – 9.9 km	0.133	1,052	0.048	0.185
Distance to facility, > 10 km	0.153	1,211	0.027	0.229
N		**7,901**	**3,346**	**4,555**

Notes: All distance to facility measures are collected at the DHS cluster level. Each observation corresponds to a cluster.

Table 2: Descriptive Statistics, Distance to Facility Variables by Birth

	Total Mean	No. of Cases	Urban Mean	Rural Mean
Distance				
Distance to facility, < 1 km	0.279	35,387	0.534	0.177
Distance to facility, 1 – 1.9 km	0.091	11,542	0.160	0.064
Distance to facility, 2 – 2.9 km	0.152	19,279	0.158	0.150
Distance to facility, 3 – 4.9 km	0.121	15,347	0.066	0.143
Distance to facility, 5 – 9.9 km	0.153	19,406	0.050	0.194
Distance to facility, > 10 km	0.204	25,874	0.031	0.272
N		**126,835**	**42,746**	**84,089**

Notes: All distance to facility measures are collected at the DHS cluster level. Each observation corresponds to a birth.

Table 3: Descriptive Statistics, Mother-Level Outcomes and Covariates

	Mean	SD	No. Cases
Mother-Level Outcomes			
WHO Recommended ANC Visits (1 = yes)	0.394		49,186
Delivery in a health facility (1 = yes)	0.426		53,152
Mother-Level Covariates			
Wealth, quintiles	2.893	1.392	
Maternal education, none (1 = yes)	0.532		66,323
Maternal education, primary (1 = yes)	0.271		33,777
Maternal education, secondary (1 = yes)	0.176		21,890
Maternal education, higher (1 = yes)	0.022		2,727
Maternal age, years	28.214	7.041	
Marital status (1 = married)	0.865		107,875
Urban (1 = yes)	0.284		35,399
Cluster-Level Covariates			
Average wealth, quintiles	2.889	1.066	
Average education, highest level	0.682	0.616	
Distance to primary school, km	1.724	4.822	
N	**124,719**		

Notes: Each observation corresponds to a mother.

Table 4: Descriptive Statistics, Child-Level Outcomes and Covariates

	Mean	SD	No. Cases
Birth-Level Outcomes			
Child death (1 = dead)	0.082		10,427
Neonatal death (1 = dead)	0.030		3,806
Post-neonatal infant death (1 = dead)	0.034		4,427
Post infant child death (1 = dead)	0.017		2,189
Birth-Level Covariates			
Birth order	3.876	2.651	
Multiple birth (1 = yes)	0.027		3,383
Child sex (1 = female)	0.494		62,705
Time from birth to survey date, months	24.311	16.115	
N	**126,835**		

Notes: Each observation corresponds to a child.

Table 5: The effect of distance and travel time to a health facility on neonatal death, receipt of antenatal care, and facility delivery: pooled analysis

VARIABLES	(1) Neonatal Death	(2) Four ANC Visits	(3) Facility Delivery
Distance			
Reference Category: < 1 km			
Distance to facility: 1 km – 1.9 km	1.077	0.834***	0.920
	(0.927 - 1.251)	(0.769 - 0.904)	(0.828 - 1.023)
Distance to facility: 2 km – 2.9 km	1.163**	0.825***	0.754***
	(1.020 - 1.327)	(0.767 - 0.887)	(0.681 - 0.835)
Distance to facility: 3 km – 4.9 km	1.250***	0.779***	0.691***
	(1.087 - 1.439)	(0.715 - 0.850)	(0.612 - 0.779)
Distance to facility: 5 km – 9.9 km	1.191**	0.713***	0.547***
	(1.042 - 1.363)	(0.652 - 0.779)	(0.483 - 0.620)
Distance to facility: > 10 km	1.266***	0.612***	0.447***
	(1.108 - 1.445)	(0.559 - 0.671)	(0.394 - 0.508)
Time			
Reference Category: < 10 min			
Time to facility: 10 min – 19.9 min	1.074	0.872***	0.794***
	(0.952 - 1.212)	(0.814 - 0.933)	(0.722 - 0.873)
Time to facility: 20 min – 29.9 min	1.157**	0.807***	0.732***
	(1.015 - 1.319)	(0.745 - 0.874)	(0.659 - 0.814)
Time to facility: 30 min – 59.9 min	1.223***	0.748***	0.602***
	(1.078 - 1.389)	(0.692 - 0.809)	(0.538 - 0.674)
Time to facility: > 60 min	1.256***	0.688***	0.477***
	(1.105 - 1.429)	(0.627 - 0.753)	(0.419 - 0.543)
Observations	**125,167**	**124,719**	**124,719**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: For column 1, the unit of observation is a birth. For columns 2 and 3, the unit of observation is a mother giving birth. The top half of the table reports results when using categorical distance to the nearest health facility as the key exposure variable of interest, while the bottom half of the table reports results when using categorical time to the nearest health facility as the key exposure variable of interest. Odds ratios are presented with 95% confidence intervals in the parentheses below. Neonatal death (column 1) is defined as death between 0 and 28 days of age. Four ANC visits (column 2) reports whether the mother received at least four ANC visits for the birth. Delivery in a facility (column 3) reports whether the mother delivered the birth in a health facility or not. Distance (time) to facility is distance (time) from the cluster to the nearest health facility. Results are from logistic regressions that include cluster-, mother-, and child level controls. Cluster-level covariates are the average wealth index value of mothers in the cluster, and the average educational attainment of mothers in the cluster. Mother-level controls are the household wealth index (in quintiles), educational attainment of the mother (no education, primary, secondary, higher), birth order, age of the mother (in 5-year age groups), mother's marital status, and mother's place of residence (urban/rural). Child-level controls in the neonatal death regression include the length of time from the date of the child's birth to the survey date, the sex of the child, and whether the birth was a single or multiple birth. Survey and year-of-birth fixed effects are included, and standard errors are clustered at the primary sampling unit level.

Figure 1: Distribution of Distances to the Nearest Facility by Country

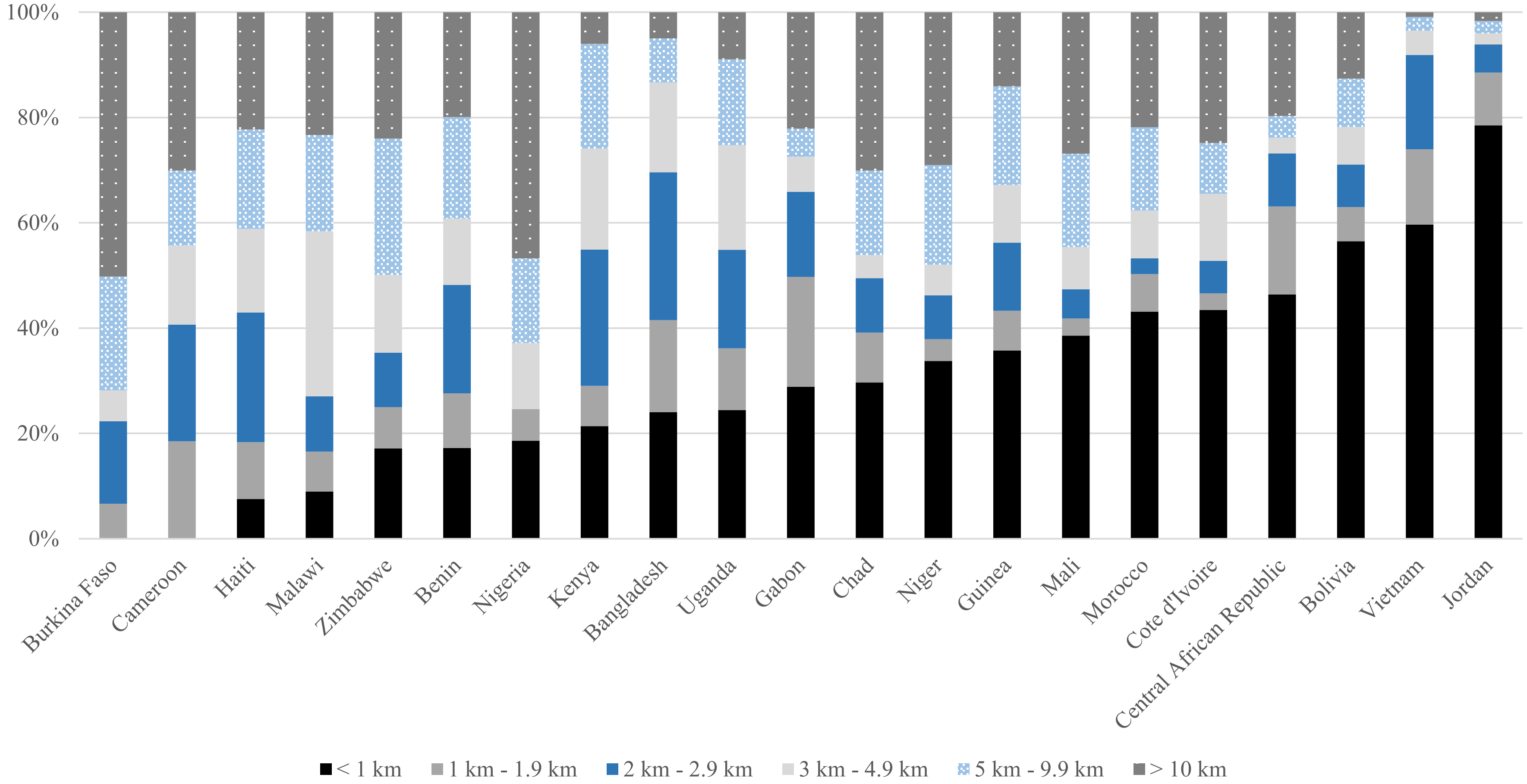


Figure 2: Distribution of Times to the Nearest Facility by Country

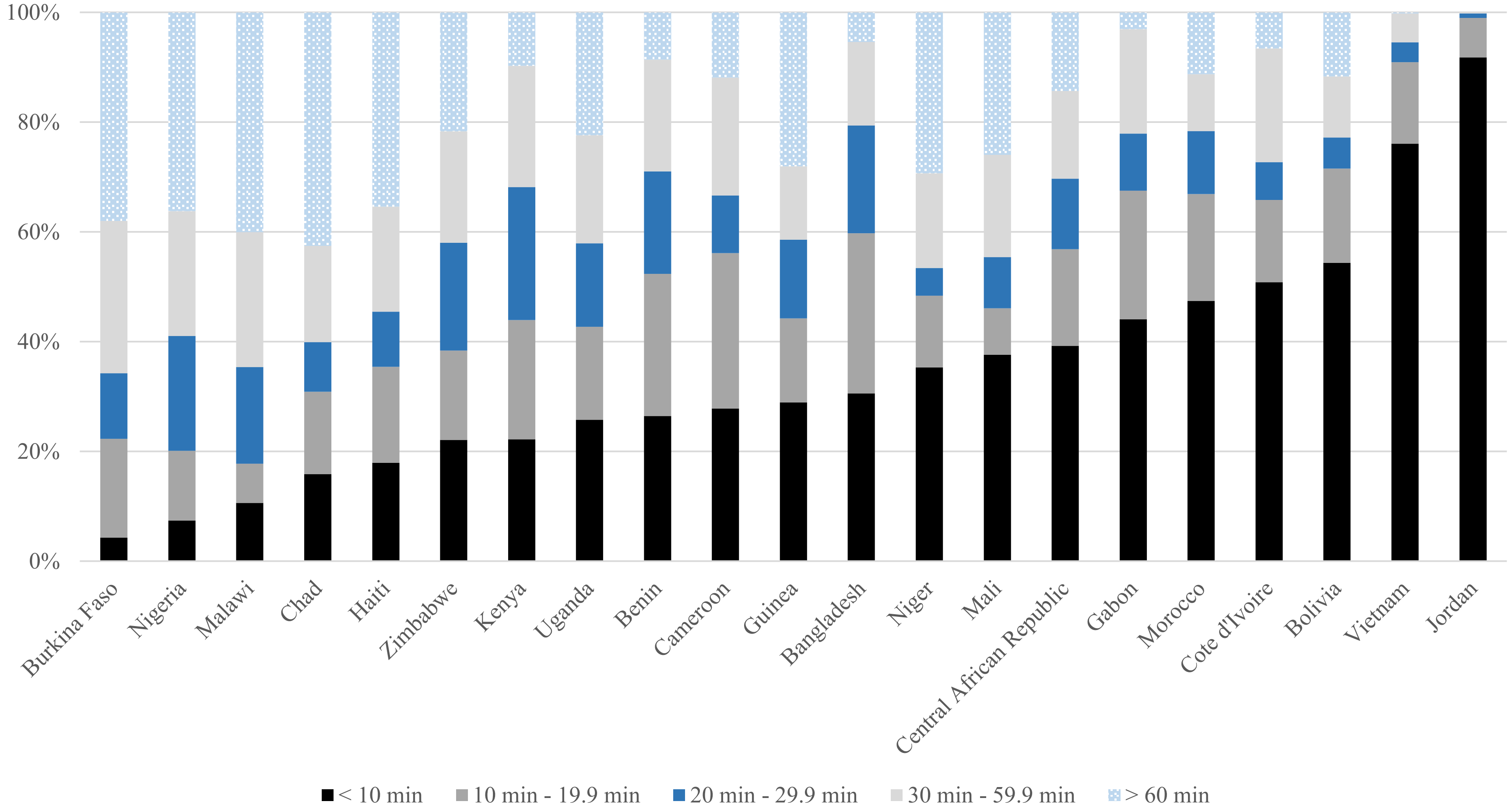
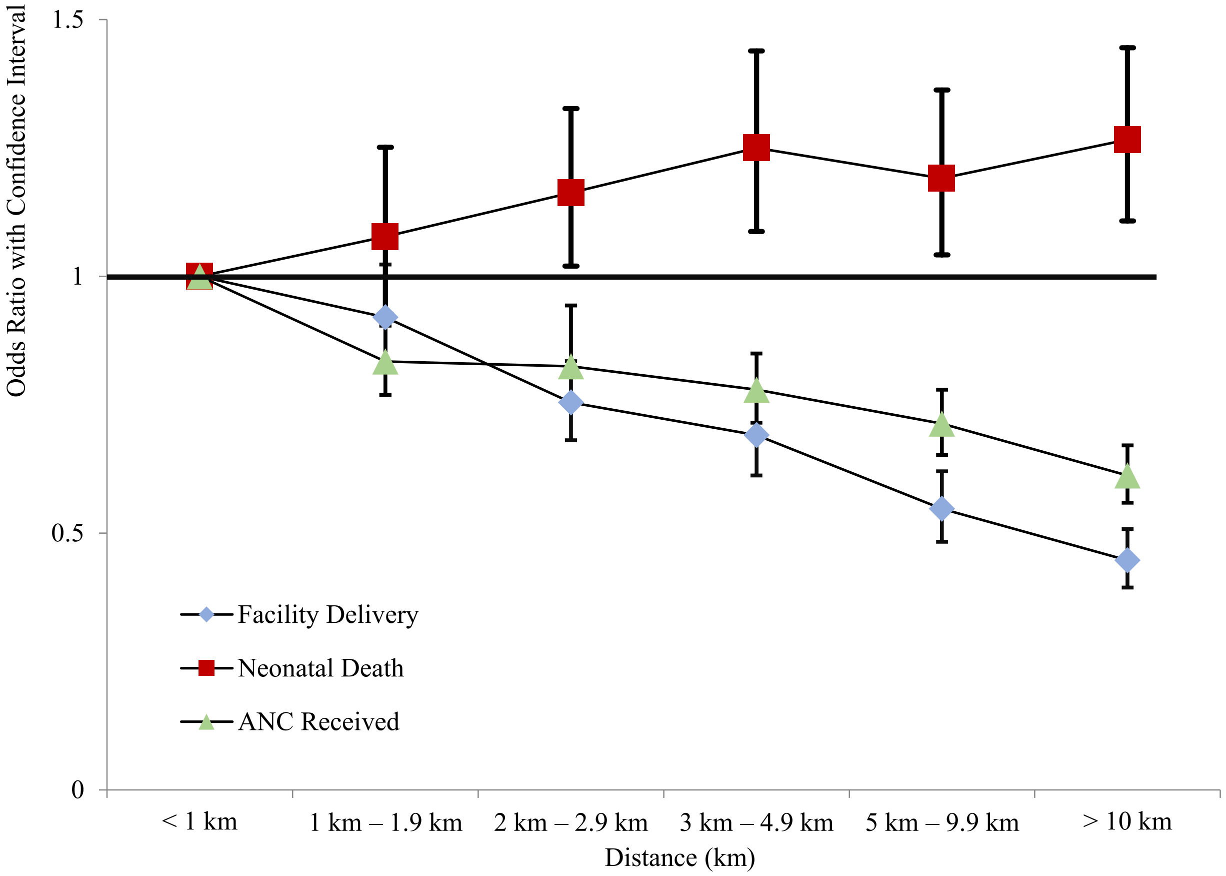
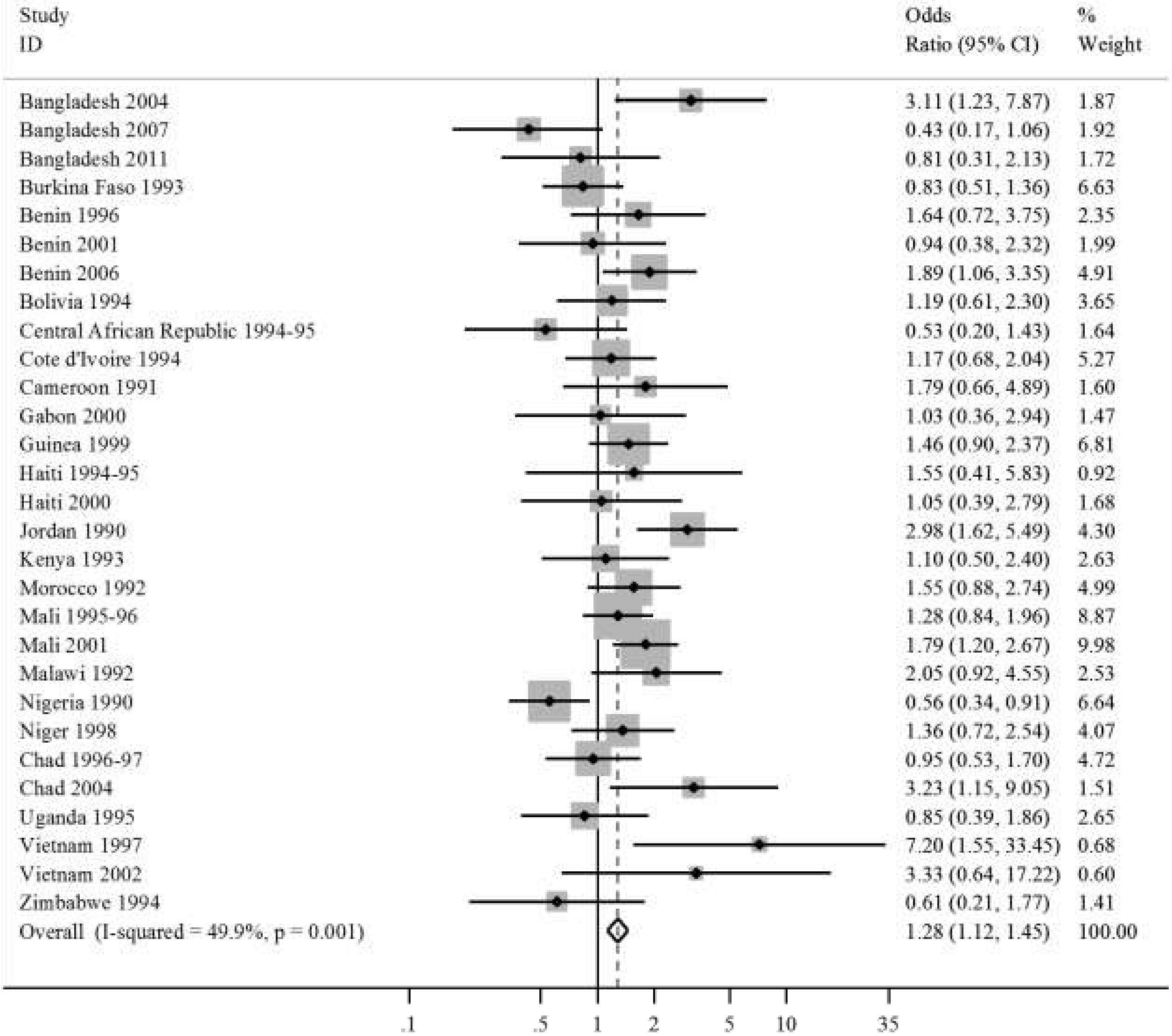


Figure 3: The effect of distance to health facility on antenatal care received, facility delivery, and neonatal death: pooled analysis



Notes: The results are based on the logistic regression results that are reported in Table 1. The odds ratios are for each distance category, compared to the reference group of living within 1 km of a facility. The error bars indicate the 95 percent confidence interval. The horizontal line at 1 represents the odds ratio value under the null hypothesis.

Figure 4: The effect of distance to health facility on neonatal death: survey-specific analysis



Notes: We report odds ratios for those who live farther than 10 km when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 10 km from the nearest facility, so the next maximum categorical distance from the facility was plotted instead. These surveys (with their maximum categorical distances in parentheses) are: Bangladesh 2004 (5 - 9.9 km); Burkina Faso 1993 (5 – 9.9 km); Cameroon 1991 (5- 9.9 km); Vietnam 1997 (3 – 4.9 km); and Vietnam 2002 (3 – 4.9 km). The results are based on survey-specific logistic regression with the same set of covariates as described in Table 1. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

1.15. Supplemental Material

1.15.1. Overview

We removed surveys from consideration that did not have data on our outcomes or distance variables or any of the covariates that are listed in Table A1. The reasons for exclusion for these surveys is given in Table A2. A total of 163,044 birth records were extracted from the remaining 29 DHS surveys that that contained all the variables that we used in the analysis. These surveys span 21 countries; in some cases we have several DHS for the same country in different years. We dropped individual observations from these surveys with missing information on the outcome variables of interest, or the distance to facility measures, or our covariates. Table A3 gives details of the number of observations that were dropped for each reason to obtain the analysis sample of 124,719 mothers and 126,835 births.

For our analysis on post-neonatal infant mortality, our sample includes those children who survived the neonatal period and those children who would have been at least one year old on the survey date had they lived. Thus, all children in our sample for both neonatal and infant deaths are fully exposed. For our analysis on post-infant child mortality, however, many children in our surveys have not yet reached age 5, so we report observed deaths in all children who have at least reached age 1; our sample therefore includes all children born in the five years preceding the survey, independent of their potential age at the time of the survey. We expect post-infant child mortality and all child mortality to be rising in the time from birth to the survey date, since this time period measures the length of exposure. For neonatal and post-neonatal infant death, the exposure times are the same, but we might still expect to observe a higher mortality rate for children born several years before the survey due to secular declining trends in mortality.

In a similar fashion to Tables 1 and 2 in the main text, Table A4 describes the distribution of travel times to the nearest facility by DHS cluster, while Table A5 describes the distribution of travel times to the nearest facility by birth. Figure A2, which plots the distribution of distances to the nearest facility, provides visual evidence that a large proportion of women in our pooled sample (84·7 percent) were located within 10 km of a health facility. Similarly, Figure A3 plots the distribution of travel times to the nearest facility and shows that 85 percent of women in our sample were located within 60 minutes of a health facility.

Results for odds ratios for receipt of antenatal care when the nearest facility is more than 10 km away for each survey, relative to a reference category of being less than 1 km away, together with their respective 95 percent confidence intervals, are reported in Figure A4 for each survey. We find that the decline in receipt of antenatal care with distance is statistically significant at the 5 percent level in ten of the 29 surveys. In the other 19 surveys, the estimated odds ratio is not statistically different from unity. Similarly, Figure A5 shows that while distance significantly reduces the likelihood of in-facility delivery in 11 surveys, no significant effect is found in 17 surveys. In one survey, in Bolivia in 1994, the significant estimate indicates the likelihood of facility delivery actually increases with distance to facility. We presume that even if distance were to truly reduce the likelihood of service utilization, some positive results due to sampling error may be observed when testing the relationship in a large number of surveys, as we do here. We find evidence of a significant negative effect of distance on utilization in about one-third of our surveys, which contrasts the overwhelming finding of significance in the systematic review; this dissimilarity may be evidence of publication bias.

Table A6 provides odds ratio coefficient estimates for all covariates and also report the effects of distance on post-neonatal infant death and well as post-infant child death in the pooled sample. None of our distance measures appear to have a statistically significant effect on child death after the neonatal period. We find significant result for child death overall, but this effect seems to be driven by neonatal mortality. In Table A7, we report results using travel time to facility rather than distance. The magnitude and significance of the time to facility odds ratios for antenatal care, facility delivery, and neonatal mortality are very similar to those found for distance. However, we do find some evidence that time to facility increases the odds of post-infant child death. Figures A6, A7 and A8 show survey specific results using travel time, rather than distance, to facility; again, we find the survey-specific estimates are often not statistically significant. Table A8 shows that our results are robust to including distance to primary school as a covariate, while Table A9 demonstrates that our results are robust to using distance to a higher-level in-patient facility (hospitals, mid-level clinics and health centers, maternal and child health centers, district-level clinics, and primary health centers).

Table A1: Variable Descriptions

	Variable Description
Outcome Variables	
Delivery in a facility	Binary: whether mother delivered the birth in a health facility
Four ANC Visits	Binary: whether mother received at least 4 ANC visits for the birth
Child death	Binary: whether child died before age 5 years of age
Neonatal death	Binary: whether child died on or before 28 days of age
Post-neonatal infant death	Binary: whether child died between 29 days and 1 year of age
Post-infant child death	Binary: whether child died after 1 year but before 5 years of age
Distance Variables	
Distance to facility	Distance from the cluster to the nearest health facility, km
Distance to in-patient facility	Distance from the cluster to the nearest in-patient health facility (hospitals, rural health centers, maternal and child health centers, or second-tier health clinics), km
Time Variables	
Time to facility	Travel time from the cluster to the nearest health facility, minutes
Time to in-patient facility	Travel time from the cluster to the nearest in-patient health facility (hospitals, rural health centers, maternal and child health centers, or second-tier health clinics), minutes
Child-Level Covariates	
Birth order	Birth order of the child
Multiple birth	Binary: whether the child was a multiple birth
Child sex	Whether the child was male or female
Time from birth to survey date	The hypothetical age of the child (in months), irrespective of whether the child is alive or not, at the time of the survey
Mother-Level Covariates	
Wealth	Wealth quintile, derived from DHS household asset index*
Maternal education	Highest level of schooling achieved by mother (none, primary, secondary, higher)
Maternal age	Age of mother, in 5-year age groups
Marital status	Binary: marital status of the mother, either married or not (not married includes single, separated, divorced and widowed)
Urban	Place of residence: either urban or rural
Cluster-Level Covariates	
Average wealth	Average of mother's wealth quintile index score in the cluster (based on lowest=1 to highest=5)
Average education	Average level of maternal education in the cluster (based on none=0, primary=1, secondary=2, higher=3)
Distance to primary school	Distance from the cluster to the nearest primary school, km

*For additional information on the wealth index, see to Filmer and Pritchett (2001) and Rutstein et al (2004) (Filmer & Pritchett, 2001; Rutstein, Johnson, & MEASURE, 2004).

Table A2: Demographic and Health Surveys (DHS) that conducted the Service Availability Module

Country	Year	Included in Analysis	Reason for Exclusion
Bangladesh	1993	N	No time to facility data
Bangladesh	1997	N	No time to facility data
Bangladesh	2004	Y	
Bangladesh	2007	Y	
Bangladesh	2011	Y	
Benin	1996	Y	
Benin	2001	Y	
Benin	2006	Y	
Bolivia	1994	Y	
Burkina Faso	1993	Y	
Burundi	1987	N	No wealth index
Cameroon	1991	Y	
CAR	1994-95	Y	
Chad	1996-97	Y	
Chad	2004	Y	
Colombia	1986	N	No wealth index
Cote d'Ivoire	1994	Y	
Dominican Republic	1986	N	No wealth index
Dominican Republic	1991	N	No wealth index
Ecuador	1987	N	No wealth index
Egypt	1988	N	No wealth index
Gabon	2000	Y	
Guatemala	1987	N	No wealth index
Guinea	1999	Y	
Haiti	1994-95	Y	
Haiti	2000	Y	
India	1992-93	N	No time to facility data
Indonesia	1994	N	No wealth index
Jordan	1990	Y	
Kenya	1993	Y	
Madagascar	1992	N	No wealth index
Malawi	1992	Y	
Mali	1995-96	Y	
Mali	2001	Y	
Morocco	1992	Y	
Niger	1992	N	No wealth index
Niger	1998	Y	
Nigeria	1990	Y	
Nigeria	1999	N	No wealth index
Pakistan	2012-13	N	No SAQ data available
Philippines	1993	N	No time to facility data
Senegal	1992-93	N	No wealth index
Tanzania	1991-92	N	No wealth index
Thailand	1987	N	No wealth index
Togo	1988	N	No wealth index
Tunisia	1988	N	No wealth index
Uganda	1988-89	N	No wealth index
Uganda	1995	Y	
Vietnam	1997	Y	
Vietnam	2002	Y	
Zimbabwe	1988	N	No wealth index
Zimbabwe	1994	Y	

Notes: There were 52 surveys that conducted Service Availability Module questionnaires. We use the 29 surveys labeled as 'Y' in the table for our analysis.

Table A3: Births: observations dropped from analysis due to missing data

Starting Sample	**163,044**	
	No. Obs. Dropped	Pct. of Starting Sample
Outcome Variables		
Delivery in a health facility	603	0.37%
WHO Recommended ANC Visits	24,344	14.93%
Neonatal death	0	0.0%
Post-neonatal infant death	0	0.0%
Post-infant child death	0	0.0%
Distance Variables		
Distance to facility	5,372	3.29%
Distance to in-patient facility	815	0.50%
Time Variables		
Time to facility	4,786	2.94%
Time to in-patient facility	265	0.16%
Mother-Level Covariates		
Wealth	0	0.0%
Maternal education	3	0.0018%
Maternal age	8	0.0049%
Marital status	2	0.0012%
Urban	0	0.0%
Child-Level Covariates		
Birth order	0	0.0%
Child sex	0	0.0%
Time from birth to survey date	0	0.0%
Cluster-Level Covariates		
Average wealth	0	0.0%
Average education	0	0.0%
Sample Probability Weight of 0	11	0.0067%
Final Sample	**126,835**	**77.79%**

Notes: The large number of observations dropped due to missing data on ANC visits is mainly because some surveys only recorded the number of ANC visits for mothers for her last birth and not for all of her births in the previous five years.

Table A4: Descriptive Statistics, Time to Facility Measures by Cluster

	Mean	No. Cases
Time		
Time to facility, < 10 min	0.372	2,934
Time to facility, 10 – 19.9 min	0.186	1,470
Time to facility, 20 – 29.9 min	0.132	1,042
Time to facility, 30 – 59.9 min	0.161	1,270
Time to facility, > 60 min	0.150	1,185
N	**7,901**	

Notes: All time to facility measures are collected at the DHS cluster level. Each observation corresponds to a cluster.

Table A5: Descriptive Statistics, Time to Facility Measures by Birth

	Mean	No. Cases
Time		
Time to facility, < 10 min	0.321	40,714
Time to facility, 10 – 19.9 min	0.170	21,562
Time to facility, 20 – 29.9 min	0.128	16,235
Time to facility, 30 – 59.9 min	0.179	22,703
Time to facility, > 60 min	0.202	25,621
N	**126,835**	

Notes: All time to facility measures are collected at the DHS cluster level. Each observation corresponds to a birth.

Table A6: Estimates of the effect of distance to health facility on service utilization and child death

VARIABLES	(1) Four ANC Visits	(2) Facility Delivery	(3) Child Death	(4) Neonatal Death	(5) Post-Neonatal Infant Death	(6) Post-Infant Child Death
Reference Category: < 1 km						
Distance to facility: 1 km – 1.9 km	0.834***	0.920	1.090*	1.077	1.039	1.067
	(0.769 - 0.904)	(0.828 - 1.023)	(0.991 - 1.199)	(0.927 - 1.251)	(0.888 - 1.214)	(0.879 - 1.295)
Distance to facility: 2 km – 2.9 km	0.825***	0.754***	1.114**	1.163**	1.029	1.106
	(0.767 - 0.887)	(0.681 - 0.835)	(1.021 - 1.216)	(1.020 - 1.327)	(0.893 - 1.185)	(0.929 - 1.318)
Distance to facility: 3 km – 4.9 km	0.779***	0.691***	1.148***	1.250***	1.017	1.183*
	(0.715 - 0.850)	(0.612 - 0.779)	(1.043 - 1.263)	(1.087 - 1.439)	(0.881 - 1.174)	(0.984 - 1.423)
Distance to facility: 5 km – 9.9 km	0.713***	0.547***	1.082*	1.191**	0.955	1.053
	(0.652 - 0.779)	(0.483 - 0.620)	(0.991 - 1.181)	(1.042 - 1.363)	(0.834 - 1.094)	(0.885 - 1.253)
Distance to facility: > 10 km	0.612***	0.447***	1.179***	1.266***	1.084	1.149*
	(0.559 - 0.671)	(0.394 - 0.508)	(1.083 - 1.283)	(1.108 - 1.445)	(0.955 - 1.231)	(0.975 - 1.354)
Wealth, quintile 2	1.172***	1.226***	1.007	1.125**	0.945	0.947
	(1.111 - 1.236)	(1.153 - 1.304)	(0.942 - 1.077)	(1.005 - 1.259)	(0.851 - 1.050)	(0.827 - 1.084)
Wealth, quintile 3	1.353***	1.377***	0.984	1.137**	0.956	0.852**
	(1.280 - 1.430)	(1.294 - 1.466)	(0.916 - 1.056)	(1.010 - 1.280)	(0.852 - 1.072)	(0.732 - 0.992)
Wealth, quintile 4	1.658***	1.767***	0.907**	1.029	0.850**	0.844*
	(1.562 - 1.759)	(1.656 - 1.886)	(0.835 - 0.986)	(0.899 - 1.178)	(0.744 - 0.972)	(0.710 - 1.002)
Wealth, quintile 5	2.389***	2.711***	0.837***	1.008	0.789***	0.698***
	(2.215 - 2.577)	(2.489 - 2.953)	(0.751 - 0.932)	(0.841 - 1.208)	(0.664 - 0.938)	(0.556 - 0.875)
Maternal education, primary	1.466***	1.676***	0.928**	0.922	0.930	1.018
	(1.403 - 1.532)	(1.595 - 1.761)	(0.872 - 0.988)	(0.833 - 1.020)	(0.839 - 1.031)	(0.897 - 1.154)
Maternal education, secondary	2.113***	2.687***	0.729***	0.739***	0.685***	0.774**
	(1.993 - 2.241)	(2.512 - 2.874)	(0.662 - 0.802)	(0.635 - 0.859)	(0.581 - 0.808)	(0.622 - 0.964)
Maternal education, higher	4.788***	7.222***	0.489***	0.630**	0.288***	0.179**
	(4.176 - 5.491)	(6.162 - 8.466)	(0.361 - 0.663)	(0.436 - 0.910)	(0.147 - 0.564)	(0.044 - 0.720)
Maternal age, 20-24	1.225***	0.966	0.663***	0.619***	0.682***	0.786**
	(1.157 - 1.298)	(0.907 - 1.028)	(0.611 - 0.719)	(0.548 - 0.699)	(0.592 - 0.786)	(0.643 - 0.959)
Maternal age, 25-29	1.327***	1.054	0.573***	0.518***	0.606***	0.667***
	(1.249 - 1.410)	(0.985 - 1.128)	(0.523 - 0.627)	(0.451 - 0.595)	(0.522 - 0.705)	(0.541 - 0.821)
Maternal age, 30-34	1.481***	1.217***	0.530***	0.498***	0.539***	0.608***
	(1.379 - 1.590)	(1.122 - 1.320)	(0.477 - 0.589)	(0.423 - 0.587)	(0.454 - 0.640)	(0.480 - 0.771)
Maternal age, 35-39	1.568***	1.492***	0.536***	0.588***	0.523***	0.525***
	(1.441 - 1.707)	(1.355 - 1.643)	(0.473 - 0.609)	(0.484 - 0.714)	(0.426 - 0.642)	(0.400 - 0.690)
Maternal age, 40-44	1.710***	1.818***	0.516***	0.588***	0.459***	0.513***
	(1.541 - 1.898)	(1.609 - 2.054)	(0.441 - 0.603)	(0.461 - 0.750)	(0.357 - 0.591)	(0.367 - 0.716)
Maternal age, 45-49	1.673***	1.839***	0.640***	0.855	0.571***	0.548***
	(1.458 - 1.919)	(1.566 - 2.160)	(0.525 - 0.781)	(0.628 - 1.164)	(0.420 - 0.775)	(0.367 - 0.819)
Time from birth to survey date			1.008**	0.993	0.994	1.014**
			(1.001 - 1.014)	(0.983 - 1.002)	(0.984 - 1.004)	(1.001 - 1.027)
Child sex			0.904***	0.756***	0.972	1.036
			(0.867 - 0.943)	(0.707 - 0.809)	(0.907 - 1.042)	(0.950 - 1.131)
Marital status	1.163***	0.976	0.800***	0.813***	0.824***	0.815***
	(1.102 - 1.227)	(0.916 - 1.040)	(0.747 - 0.858)	(0.726 - 0.911)	(0.736 - 0.922)	(0.710 - 0.935)

VARIABLES	Four ANC Visits	Facility Delivery	Child Death	Neonatal Death	Post-Neonatal Infant Death	Post-Infant Child Death
Birth order	0.922***	0.893***	1.019**	0.987	1.036***	1.042***
	(0.913 - 0.932)	(0.882 - 0.904)	(1.004 - 1.035)	(0.963 - 1.012)	(1.012 - 1.061)	(1.011 - 1.074)
Multiple birth			4.066***	6.737***	2.900***	1.625***
			(3.694 - 4.476)	(5.931 - 7.652)	(2.486 - 3.384)	(1.284 - 2.056)
Urban	1.059*	1.111**	1.107**	1.074	1.045	1.275***
	(0.990 - 1.133)	(1.006 - 1.227)	(1.024 - 1.197)	(0.959 - 1.203)	(0.921 - 1.186)	(1.089 - 1.493)
Average wealth	1.197***	1.510***	0.994	0.965	1.024	1.031
	(1.150 - 1.246)	(1.429 - 1.595)	(0.951 - 1.039)	(0.904 - 1.030)	(0.955 - 1.098)	(0.945 - 1.124)
Average education	1.499***	1.880***	0.785***	0.928	0.724***	0.620***
	(1.386 - 1.622)	(1.683 - 2.100)	(0.713 - 0.863)	(0.804 - 1.070)	(0.623 - 0.843)	(0.506 - 0.761)
Constant	0.0631***	0.00848***	0.583	0.307	0.230	0.232
	(0.044 - 0.091)	(0.005 - 0.014)	(0.148 - 2.304)	(0.035 - 2.726)	(0.024 - 2.193)	(0.013 - 4.187)
Observations	**124,719**	**124,719**	**126,835**	**125,167**	**87,289**	**83,176**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: For columns 1 and 2, the unit of observation is the mother. For columns 3 to 6, the unit of observation is the child. Odds ratios are presented with 95% confidence intervals in the parentheses below. Four ANC visits (column 1) reports whether the mother received at least four ANC visits for the birth. Delivery in a facility (column 2) reports whether the mother delivered the birth in a health facility or not. Child death (column 3) is defined as death before age 5. Neonatal death (column 4) is defined as death between 0 and 28 days of age. Post-neonatal infant death (column 5) is defined as death between 29 and 364 days of age. Post-infant child death (column 6) is defined as death between 1 and 5 years of age. Distance to facility is distance from the cluster to the nearest health facility. Results are from logistic regressions that include cluster, household, and child level controls. Cluster-level covariates are the average wealth index value of mothers in the cluster, and the average educational attainment of mothers in the cluster. Household controls are the household wealth index (in quintiles), educational attainment of the mother (no education, primary, secondary, higher), birth order, age of the mother (in 5-year age groups), mother's marital status, and mother's place of residence (urban/rural). The neonatal death regression controls for the length of time from the date of the child's birth to the survey date, the sex of the child, and whether the birth was a single or multiple birth. Survey and year-of-birth fixed effects are included, and standard errors are clustered at the primary sampling unit level.

Table A7: Estimates of the effect of time to health facility on service utilization and child death

VARIABLES	(1) Four ANC Visits	(2) Facility Delivery	(3) Child Death	(4) Neonatal Death	(5) Post-Neonatal Infant Death	(6) Post-Infant Child Death
Reference Category: < 10 min						
Time to facility: 10 min – 19.9 min	0.872***	0.794***	1.063	1.074	1.030	1.024
	(0.814 - 0.933)	(0.722 - 0.873)	(0.982 - 1.151)	(0.952 - 1.212)	(0.910 - 1.167)	(0.867 - 1.209)
Time to facility: 20 min – 29.9 min	0.807***	0.732***	1.164***	1.157**	1.047	1.342***
	(0.745 - 0.874)	(0.659 - 0.814)	(1.067 - 1.269)	(1.015 - 1.319)	(0.912 - 1.201)	(1.131 - 1.591)
Time to facility: 30 min – 59.9 min	0.748***	0.602***	1.172***	1.223***	1.112	1.182*
	(0.692 - 0.809)	(0.538 - 0.674)	(1.076 - 1.276)	(1.078 - 1.389)	(0.974 - 1.270)	(0.997 - 1.400)
Time to facility: > 60 min	0.688***	0.477***	1.218***	1.256***	1.099	1.235**
	(0.627 - 0.753)	(0.419 - 0.543)	(1.117 - 1.329)	(1.105 - 1.429)	(0.959 - 1.260)	(1.040 - 1.467)
Observations	**124,719**	**124,719**	**126,835**	**125,167**	**87,289**	**83,176**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: For columns 1 and 2, the unit of observation is the mother. For columns 3 to 6, the unit of observation is the child. Odds ratios are presented with 95% confidence intervals in the parentheses below. Four ANC visits (column 1) reports whether the mother received at least four ANC visits for the birth. Delivery in a facility (column 2) reports whether the mother delivered the birth in a health facility or not. Child death (column 3) is defined as death before age 5. Neonatal death (column 4) is defined as death between 0 and 28 days of age. Post-neonatal infant death (column 5) is defined as death between 29 and 364 days of age. Post-infant child death (column 6) is defined as death between 1 and 5 years of age. Time to facility is time from the cluster to the nearest health facility. Results are from logistic regressions that include cluster, household, and child level controls. Cluster-level covariates are the average wealth index value of mothers in the cluster, and the average educational attainment of mothers in the cluster. Household controls are the household wealth index (in quintiles), educational attainment of the mother (no education, primary, secondary, higher), birth order, age of the mother (in 5-year age groups), mother's marital status, and mother's place of residence (urban/rural). The neonatal death regression controls for the length of time from the date of the child's birth to the survey date, the sex of the child, and whether the birth was a single or multiple birth. Survey and year-of-birth fixed effects are included, and standard errors are clustered at the primary sampling unit level.

Table A8: Estimates of the effect of distance to health facility on service utilization and child death, controlling for distance to primary school

VARIABLES	(1) Four ANC Visits	(2) Facility Delivery	(3) Child Death	(4) Neonatal Death	(5) Post-Neonatal Infant Death	(6) Post-Infant Child Death
Reference Category: < 1 km						
Distance to facility: 1 km – 1.9 km	0.855***	0.856***	1.052	1.021	1.058	1.010
	(0.782 - 0.935)	(0.762 - 0.961)	(0.946 - 1.170)	(0.866 - 1.203)	(0.881 - 1.271)	(0.811 - 1.260)
Distance to facility: 2 km – 2.9 km	0.845***	0.707***	1.136**	1.163**	1.079	1.150
	(0.776 - 0.920)	(0.630 - 0.794)	(1.028 - 1.255)	(1.000 - 1.353)	(0.911 - 1.278)	(0.938 - 1.409)
Distance to facility: 3 km – 4.9 km	0.774***	0.603***	1.180***	1.273***	1.043	1.191
	(0.694 - 0.864)	(0.521 - 0.698)	(1.051 - 1.325)	(1.079 - 1.501)	(0.874 - 1.243)	(0.953 - 1.489)
Distance to facility: 5 km – 9.9 km	0.739***	0.529***	1.098*	1.200**	0.993	1.034
	(0.661 - 0.826)	(0.456 - 0.614)	(0.990 - 1.217)	(1.029 - 1.399)	(0.846 - 1.166)	(0.844 - 1.266)
Distance to facility: > 10 km	0.571***	0.416***	1.170***	1.240***	1.091	1.108
	(0.506 - 0.644)	(0.356 - 0.485)	(1.059 - 1.292)	(1.062 - 1.447)	(0.942 - 1.265)	(0.914 - 1.343)
Observations	**95,108**	**95,108**	**96,625**	**95,300**	**66,071**	**62,972**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: For columns 1 and 2, the unit of observation is the mother. For columns 3 to 6, the unit of observation is the child. Odds ratios are presented with 95% confidence intervals in the parentheses below. For post-neonatal infant mortality, our sample includes those children who survived the neonatal period and those children who would have been at least one year old on the survey date had they lived. For our analysis on post-infant child mortality, our sample therefore includes all children born in the five years preceding the survey, independent of their potential age at the time of the survey. Four ANC visits (column 1) reports whether the mother received at least four ANC visits for the birth. Delivery in a facility (column 2) reports whether the mother delivered the birth in a health facility or not. Child death (column 3) is defined as death before age 5. Neonatal death (column 4) is defined as death between 0 and 28 days of age. Post-neonatal infant death (column 5) is defined as death between 29 and 364 days of age. Post-infant child death (column 6) is defined as death between 1 and 5 years of age. Distance to facility is distance from the cluster to the nearest health facility. Results are from logistic regressions that include cluster, household, and child level controls. Cluster-level covariates are the average wealth index value of mothers in the cluster, and the average educational attainment of mothers in the cluster. Household controls are the household wealth index (in quintiles), educational attainment of the mother (no education, primary, secondary, higher), birth order, age of the mother (in 5-year age groups), mother's marital status, and mother's place of residence (urban/rural). The neonatal death regression controls for the length of time from the date of the child's birth to the survey date, the sex of the child, and whether the birth was a single or multiple birth. Survey and year-of-birth fixed effects are included, and standard errors are clustered at the primary sampling unit level.

Table A9: Estimates of the effects of distance and time to in-patient (IP) facility on service utilization and child death

VARIABLES	(1) Completed ANC Visits	(2) Facility Delivery	(3) Child Death, ALL	(4) Neonatal Death	(5) Post-Neonatal Infant Death	(6) Child Death, Age 1-5
Distance						
Adjusted						
Reference Category: < 1 km						
Distance to IP facility: 1 km – 1.9 km	0.825***	0.904*	1.081	1.044	1.034	1.049
	(0.760 - 0.896)	(0.808 - 1.012)	(0.982 - 1.190)	(0.896 - 1.217)	(0.879 - 1.218)	(0.860 - 1.279)
Distance to IP facility: 2 km – 2.9 km	0.801***	0.711***	1.171***	1.211***	1.113	1.094
	(0.742 - 0.865)	(0.638 - 0.793)	(1.070 - 1.281)	(1.054 - 1.392)	(0.964 - 1.285)	(0.913 - 1.310)
Distance to IP facility: 3 km – 4.9 km	0.736***	0.619***	1.192***	1.314***	1.048	1.193*
	(0.673 - 0.805)	(0.546 - 0.701)	(1.079 - 1.317)	(1.134 - 1.523)	(0.901 - 1.220)	(0.988 - 1.441)
Distance to IP facility: 5 km – 9.9 km	0.699***	0.543***	1.057	1.175**	0.931	1.013
	(0.640 - 0.763)	(0.479 - 0.616)	(0.965 - 1.158)	(1.022 - 1.351)	(0.809 - 1.072)	(0.847 - 1.212)
Distance to IP facility: > 10 km	0.587***	0.435***	1.187***	1.295***	1.108	1.108
	(0.538 - 0.640)	(0.385 - 0.492)	(1.090 - 1.292)	(1.132 - 1.481)	(0.972 - 1.262)	(0.941 - 1.305)
Time						
Adjusted						
Reference Category: < 10 min						
Time to IP facility: 10 min – 19.9 min	0.882***	0.770***	1.046	0.988	1.049	1.051
	(0.822 - 0.946)	(0.696 - 0.851)	(0.964 - 1.136)	(0.870 - 1.121)	(0.921 - 1.195)	(0.886 - 1.248)
Time to IP facility: 20 min – 29.9 min	0.792***	0.715***	1.147***	1.120*	1.035	1.344***
	(0.732 - 0.857)	(0.642 - 0.797)	(1.050 - 1.252)	(0.980 - 1.279)	(0.898 - 1.193)	(1.129 - 1.600)
Time to IP facility: 30 min – 59.9 min	0.752***	0.590***	1.177***	1.188***	1.133*	1.206**
	(0.696 - 0.812)	(0.527 - 0.661)	(1.079 - 1.284)	(1.045 - 1.350)	(0.988 - 1.300)	(1.012 - 1.438)
Time to IP facility: > 60 min	0.673***	0.469***	1.213***	1.245***	1.093	1.269***
	(0.617 - 0.735)	(0.413 - 0.533)	(1.112 - 1.323)	(1.096 - 1.415)	(0.951 - 1.256)	(1.066 - 1.512)
Observations	**124,719**	**124,719**	**126,835**	**125,167**	**87,289**	**83,176**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: For columns 1 and 2, the unit of observation is the mother. For columns 3 to 6, the unit of observation is the child. Odds ratios are presented with 95% confidence intervals in the parentheses below. Four ANC visits (column 1) reports whether the mother received at least four ANC visits for the birth. Delivery in a facility (column 2) reports whether the mother delivered the birth in a health facility or not. Child death (column 3) is defined as death before age 5. Neonatal death (column 4) is defined as death between 0 and 28 days of age. Post-neonatal infant death (column 5) is defined as death between 29 and 364 days of age. Post-infant child death (column 6) is defined as death between 1 and 5 years of age. Distance (time) to in-patient facility refers to the distance (time) from the cluster to the nearest in-patient health facility (hospitals, rural health centers, maternal and child health centers, or second-tier health clinics). Results are from logistic regressions that include cluster, household, and child level controls. Cluster-level covariates are the average wealth index value of mothers in the cluster, and the average educational attainment of mothers in the cluster. Household controls are the household wealth index (in quintiles), educational attainment of the mother (no education, primary, secondary, higher), birth order, age of the mother (in 5-year age groups), mother's marital status, and mother's place of residence (urban/rural). The neonatal death regression controls for the length of time from the date of the child's birth to the survey date, the sex of the child, and whether the birth was a single or multiple birth. Survey and year-of-birth fixed effects are included, and standard errors are clustered at the primary sampling unit level.

Figure A1: Map of the countries used in the analysis

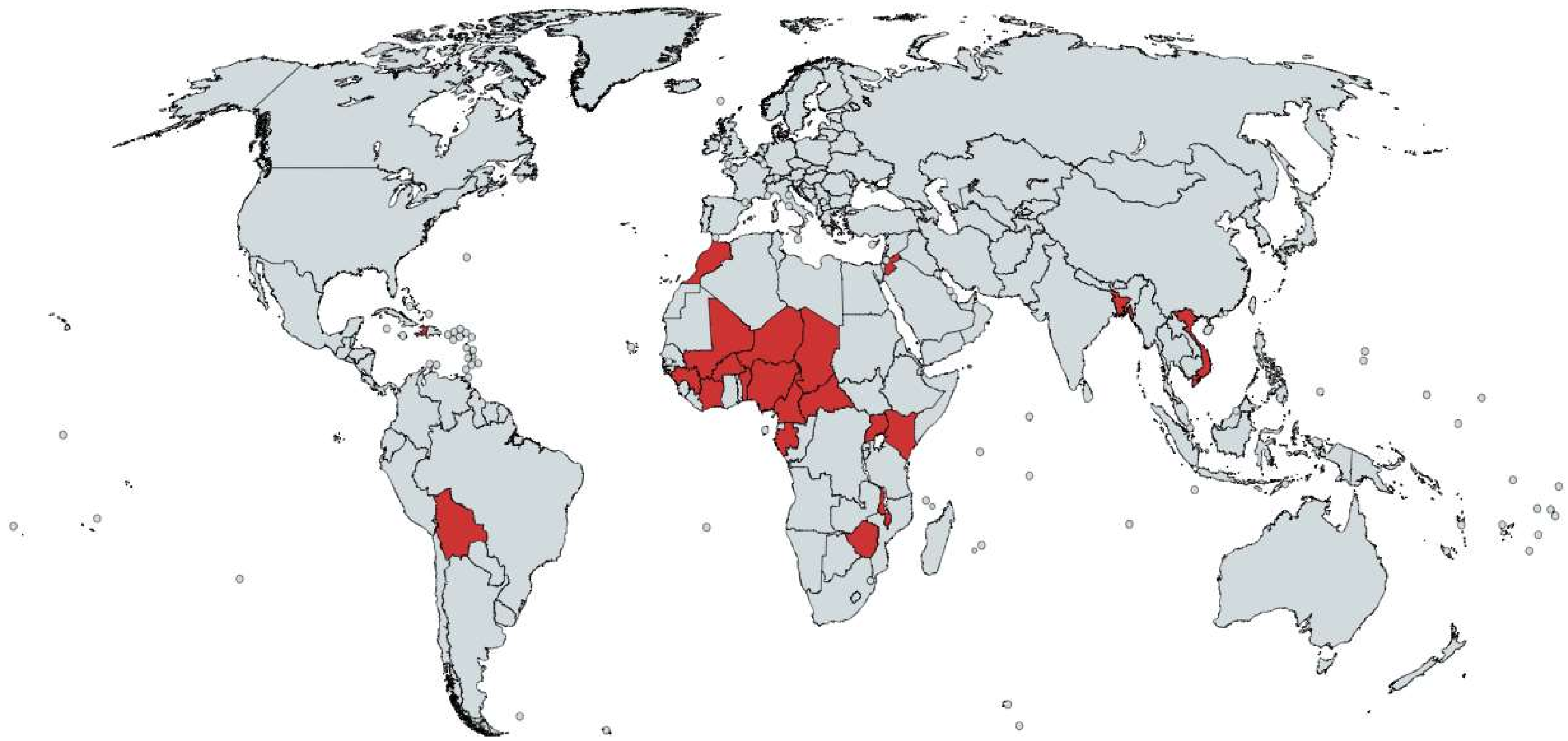


Figure A2: Histogram, distance to facility, km

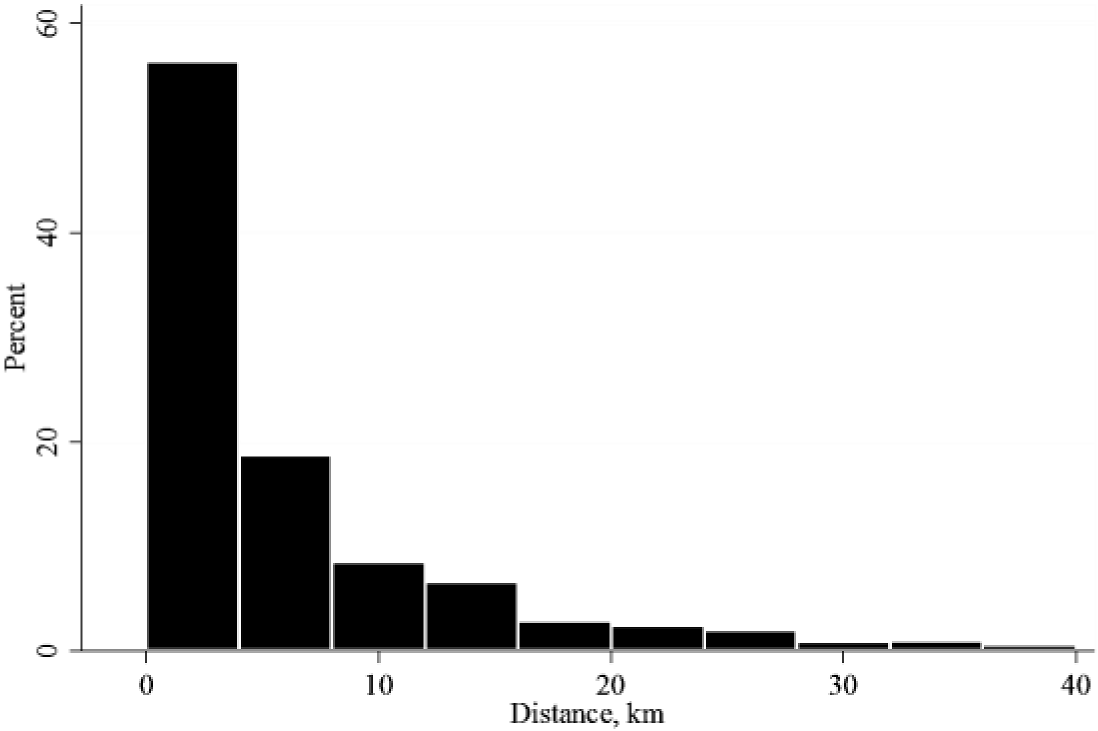


Figure A3 Histogram, time to facility, minutes

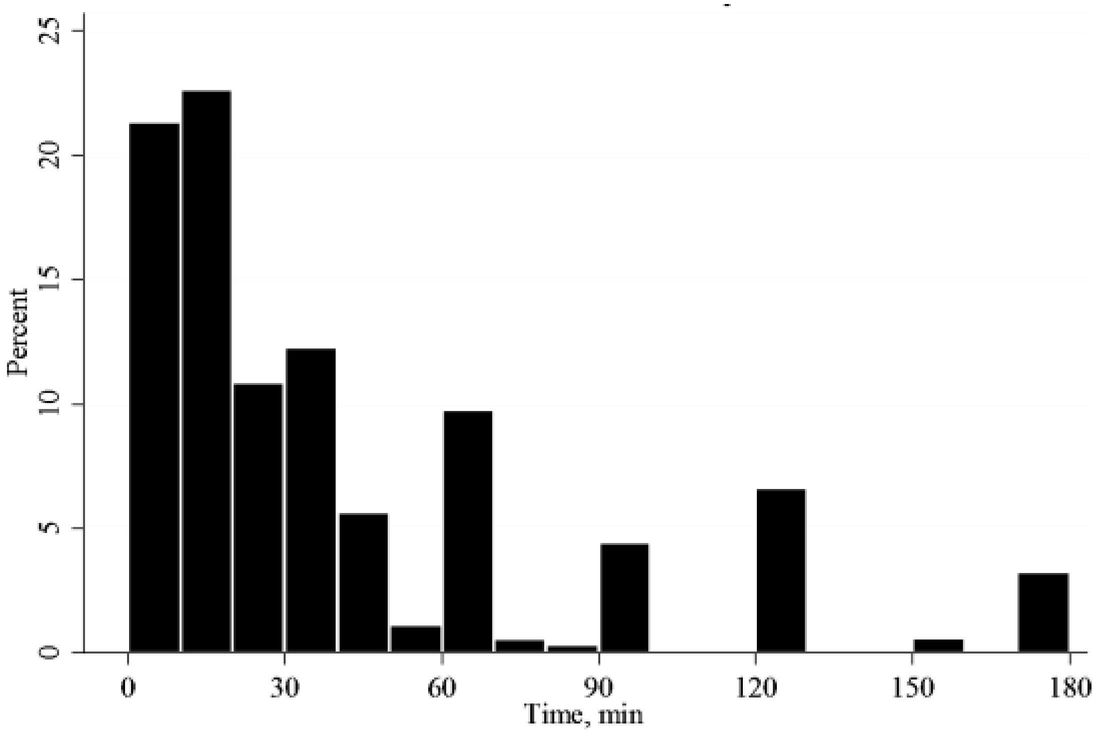
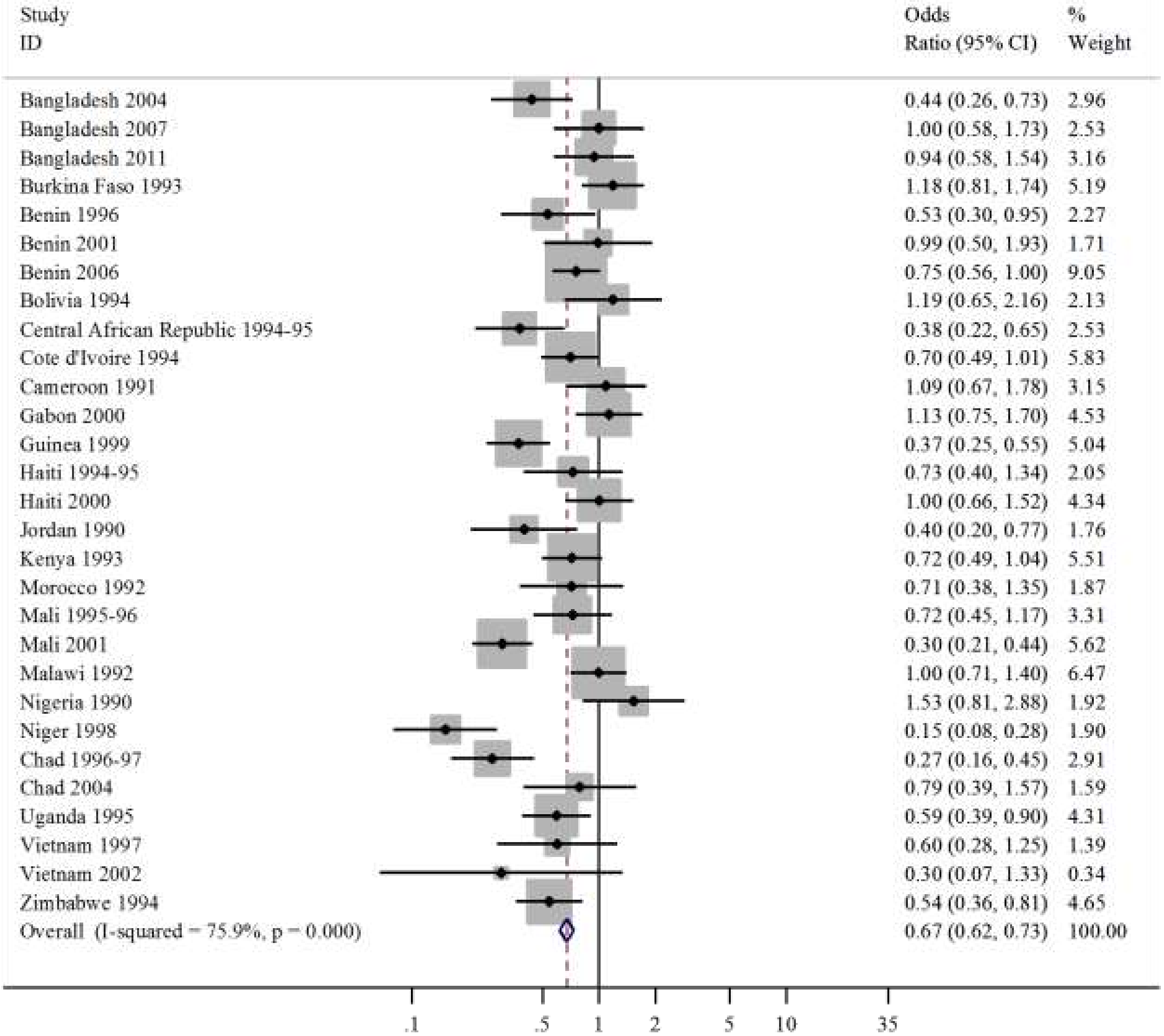


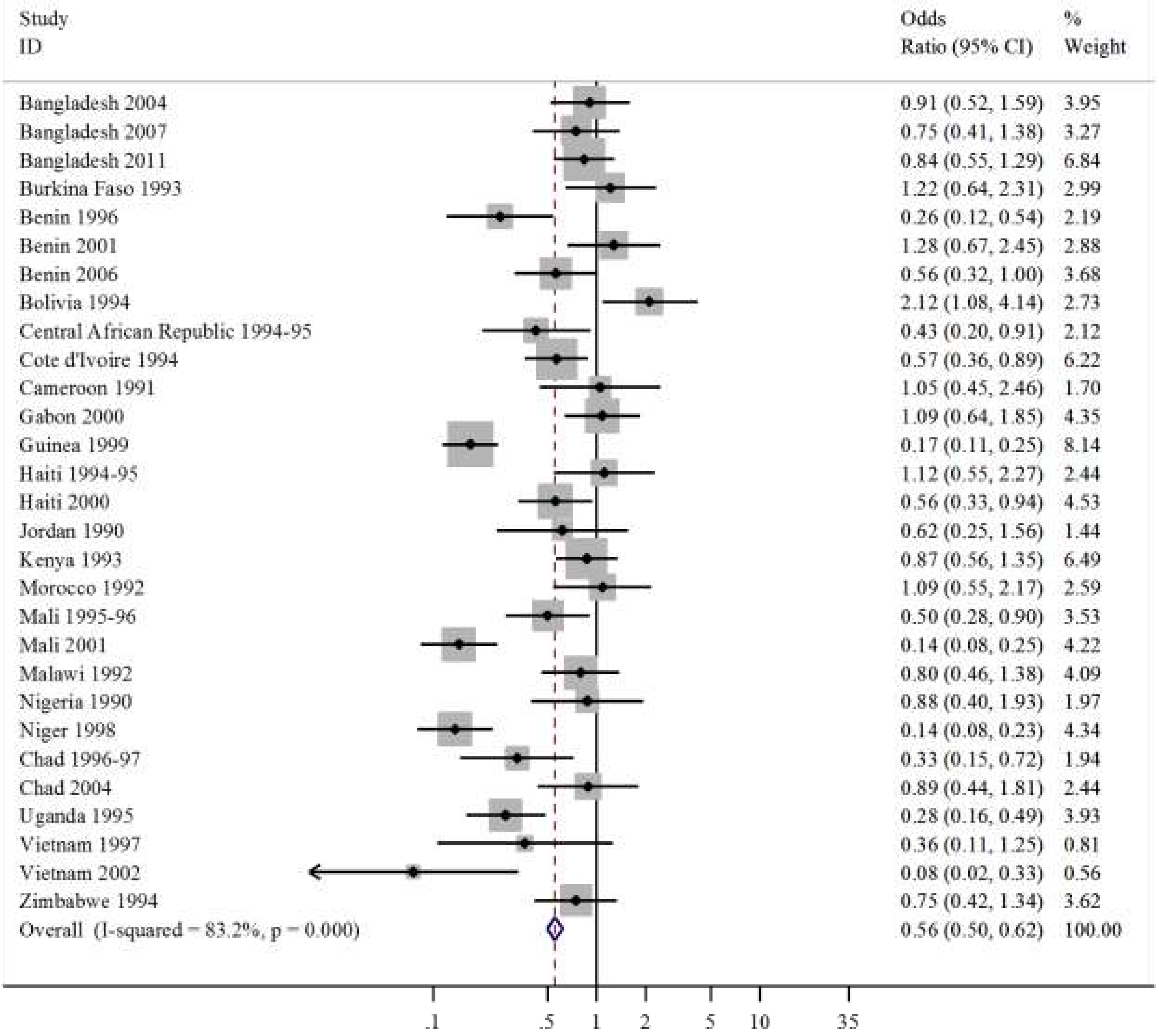
Figure A4: The effect of distance to health facility on receipt of antenatal care: survey-specific analysis



Study ID	Odds Ratio (95% CI)	% Weight
Bangladesh 2004	0.44 (0.26, 0.73)	2.96
Bangladesh 2007	1.00 (0.58, 1.73)	2.53
Bangladesh 2011	0.94 (0.58, 1.54)	3.16
Burkina Faso 1993	1.18 (0.81, 1.74)	5.19
Benin 1996	0.53 (0.30, 0.95)	2.27
Benin 2001	0.99 (0.50, 1.93)	1.71
Benin 2006	0.75 (0.56, 1.00)	9.05
Bolivia 1994	1.19 (0.65, 2.16)	2.13
Central African Republic 1994-95	0.38 (0.22, 0.65)	2.53
Cote d'Ivoire 1994	0.70 (0.49, 1.01)	5.83
Cameroon 1991	1.09 (0.67, 1.78)	3.15
Gabon 2000	1.13 (0.75, 1.70)	4.53
Guinea 1999	0.37 (0.25, 0.55)	5.04
Haiti 1994-95	0.73 (0.40, 1.34)	2.05
Haiti 2000	1.00 (0.66, 1.52)	4.34
Jordan 1990	0.40 (0.20, 0.77)	1.76
Kenya 1993	0.72 (0.49, 1.04)	5.51
Morocco 1992	0.71 (0.38, 1.35)	1.87
Mali 1995-96	0.72 (0.45, 1.17)	3.31
Mali 2001	0.30 (0.21, 0.44)	5.62
Malawi 1992	1.00 (0.71, 1.40)	6.47
Nigeria 1990	1.53 (0.81, 2.88)	1.92
Niger 1998	0.15 (0.08, 0.28)	1.90
Chad 1996-97	0.27 (0.16, 0.45)	2.91
Chad 2004	0.79 (0.39, 1.57)	1.59
Uganda 1995	0.59 (0.39, 0.90)	4.31
Vietnam 1997	0.60 (0.28, 1.25)	1.39
Vietnam 2002	0.30 (0.07, 1.33)	0.34
Zimbabwe 1994	0.54 (0.36, 0.81)	4.65
Overall (I-squared = 75.9%, p = 0.000)	0.67 (0.62, 0.73)	100.00

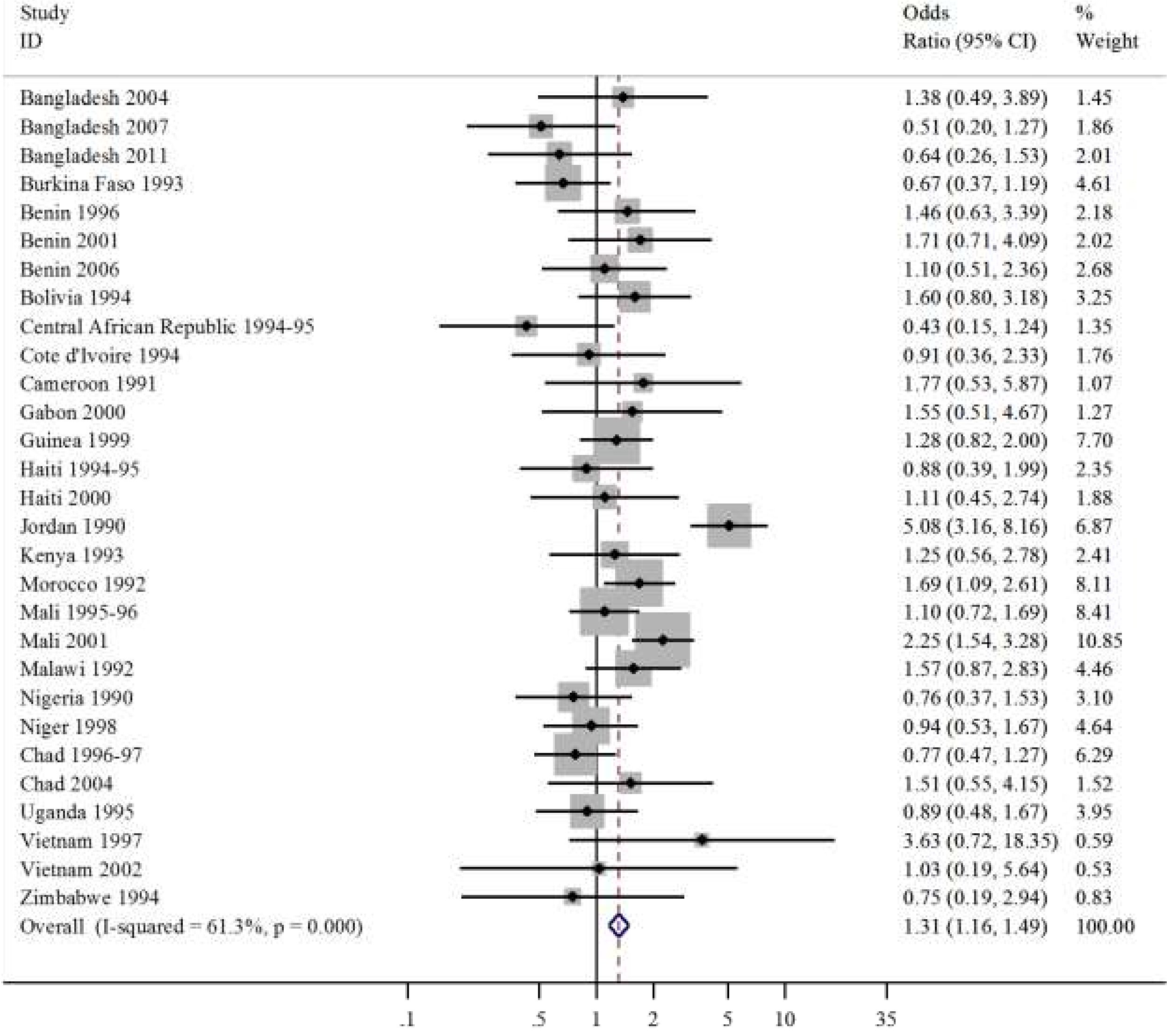
Notes: We report odds ratios for those who live farther than 10 km when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 10 km from the nearest facility, so the next maximum categorical distance from the facility was plotted instead. These surveys (with their maximum categorical distances in parentheses) are: Bangladesh 2004 (5 - 9.9 km); Burkina Faso 1993 (5 – 9.9 km); Cameroon 1991 (5- 9.9 km); Vietnam 1997 (3 – 4.9 km); and Vietnam 2002 (3 – 4.9 km). The results are based on survey-specific logistic regression with the same set of covariates as described in Table 1. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

Figure A5: The effect of distance to health facility on facility delivery: survey-specific analysis



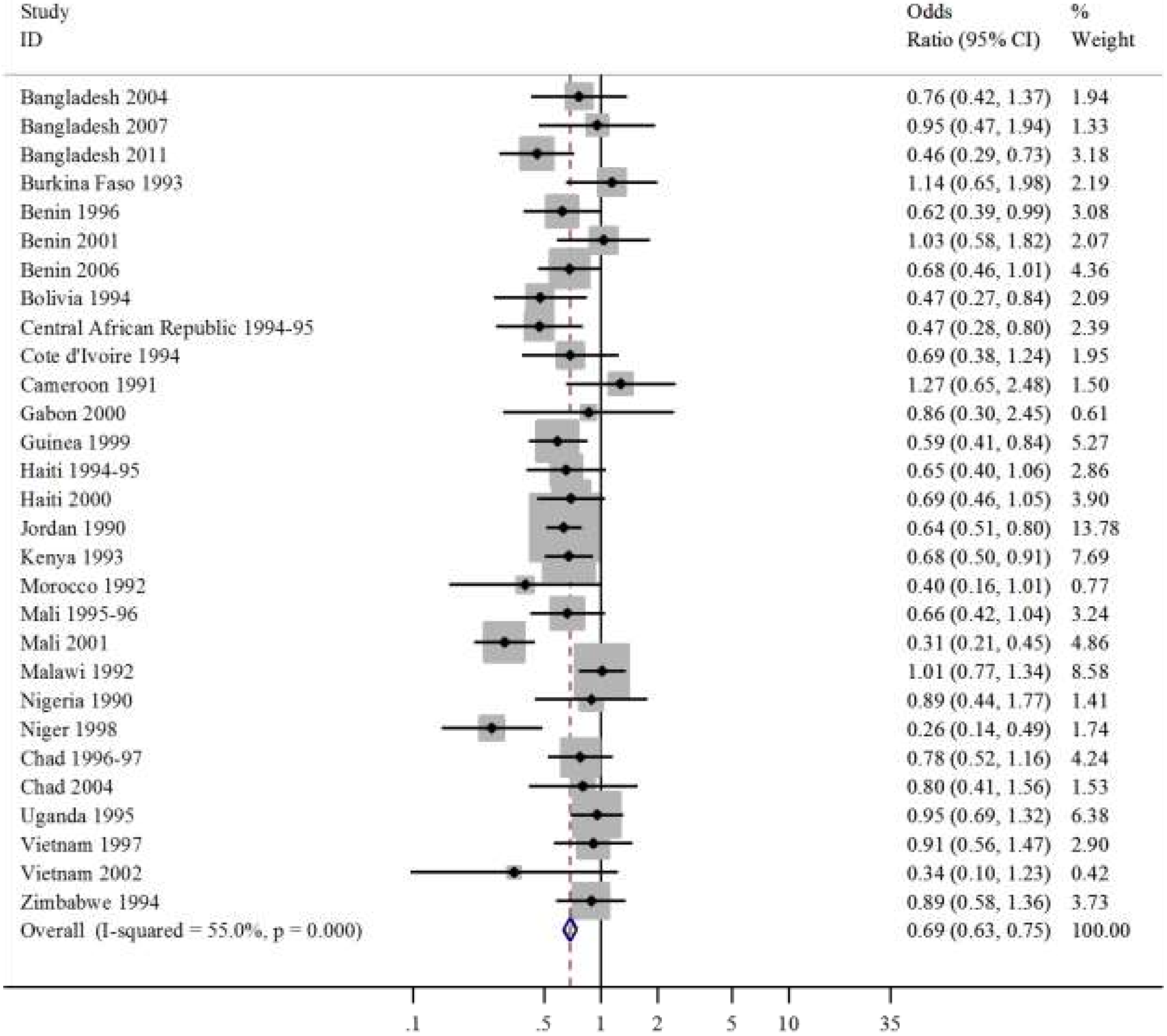
Notes: We report odds ratios for those who live farther than 10 km when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 10 km from the nearest facility, so the next maximum categorical distance from the facility was plotted instead. These surveys (with their maximum categorical distances in parentheses) are: Bangladesh 2004 (5 - 9.9 km); Burkina Faso 1993 (5 – 9.9 km); Cameroon 1991 (5- 9.9 km); Vietnam 1997 (3 – 4.9 km); and Vietnam 2002 (3 – 4.9 km). The results are based on survey-specific logistic regression with the same set of covariates as described in Table 1. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

Figure A6: The effect of time to health facility on neonatal death: survey-specific analysis



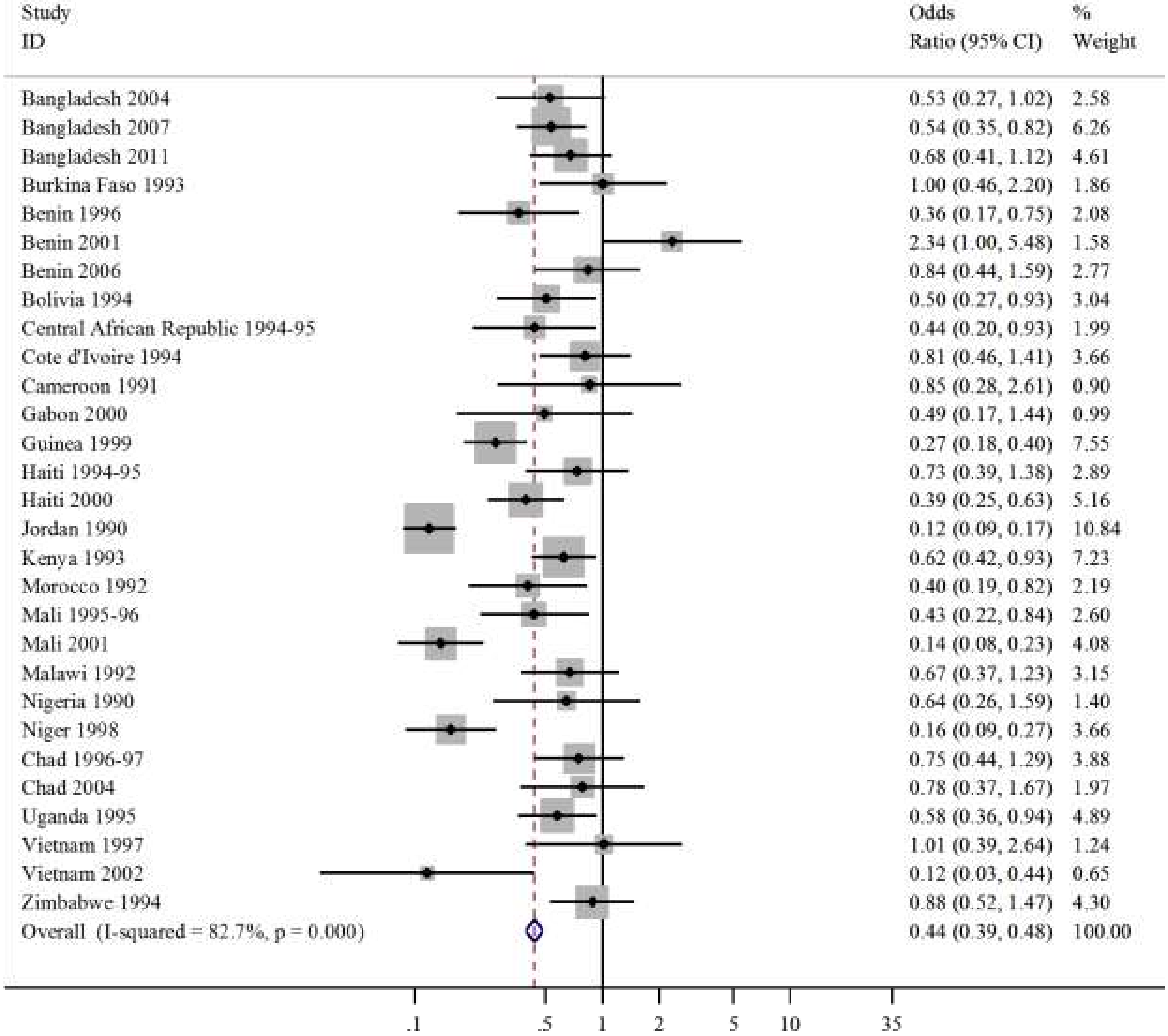
Notes: We report odds ratios for those who live farther than 60 minutes when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 60 minutes from the nearest facility, so the next maximum categorical time from the facility was plotted instead. These surveys (with their maximum categorical times in parentheses) are: Jordan 1990 (30 - 59.9 min); Vietnam 1997 (10 – 19.9 min); and Vietnam 2002 (30 – 59.9 min). The results are based on survey-specific logistic regression with the same set of covariates as described in Table A9. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

Figure A7: The effect of time to health facility on receipt of antenatal care: survey-specific analysis



Notes: We report odds ratios for those who live farther than 60 minutes when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 60 minutes from the nearest facility, so the next maximum categorical time from the facility was plotted instead. These surveys (with their maximum categorical times in parentheses) are: Jordan 1990 (30 - 59.9 min); Vietnam 1997 (10 – 19.9 min); and Vietnam 2002 (30 – 59.9 min). The results are based on survey-specific logistic regression with the same set of covariates as described in Table A9. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

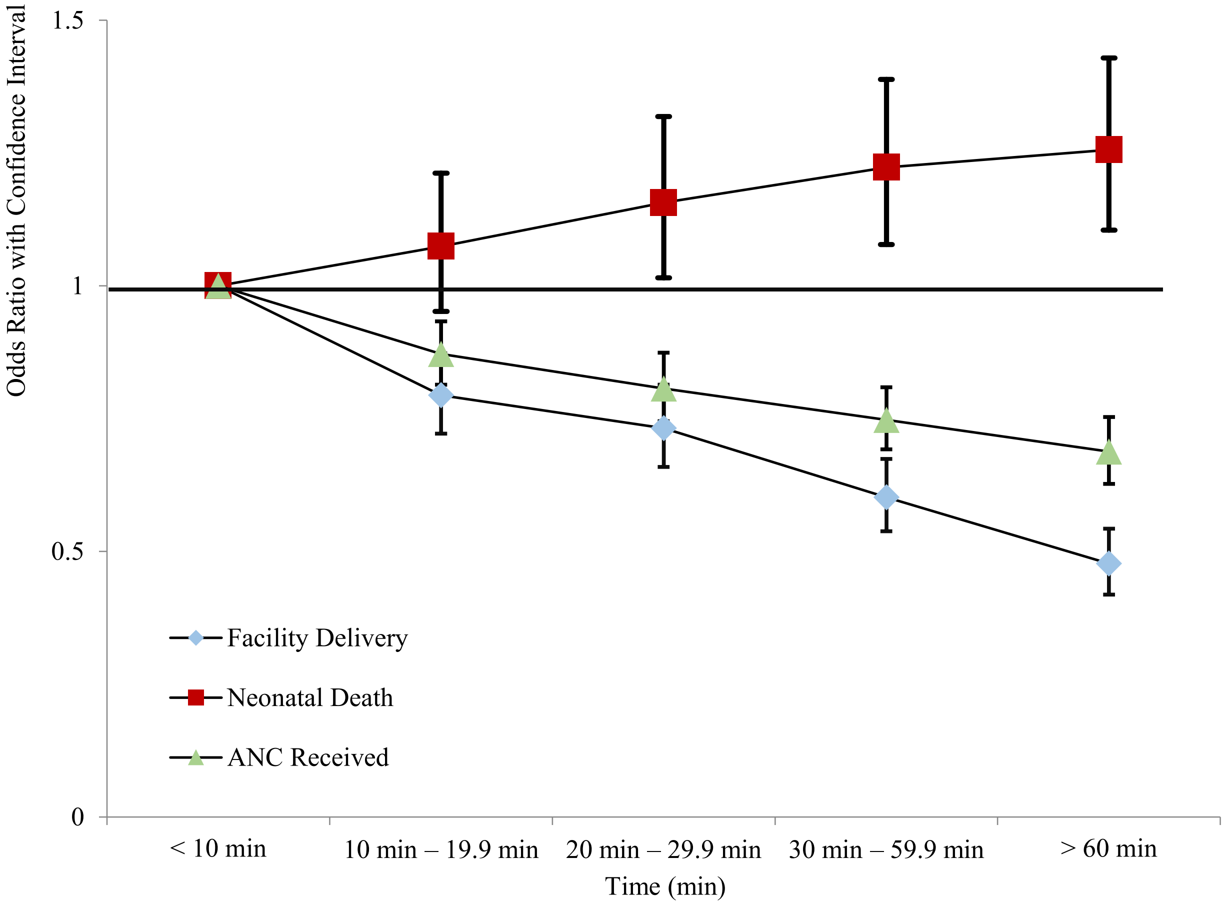
Figure A8: The effect of time to health facility on facility delivery: survey-specific analysis



Study ID	Odds Ratio (95% CI)	% Weight
Bangladesh 2004	0.53 (0.27, 1.02)	2.58
Bangladesh 2007	0.54 (0.35, 0.82)	6.26
Bangladesh 2011	0.68 (0.41, 1.12)	4.61
Burkina Faso 1993	1.00 (0.46, 2.20)	1.86
Benin 1996	0.36 (0.17, 0.75)	2.08
Benin 2001	2.34 (1.00, 5.48)	1.58
Benin 2006	0.84 (0.44, 1.59)	2.77
Bolivia 1994	0.50 (0.27, 0.93)	3.04
Central African Republic 1994-95	0.44 (0.20, 0.93)	1.99
Cote d'Ivoire 1994	0.81 (0.46, 1.41)	3.66
Cameroon 1991	0.85 (0.28, 2.61)	0.90
Gabon 2000	0.49 (0.17, 1.44)	0.99
Guinea 1999	0.27 (0.18, 0.40)	7.55
Haiti 1994-95	0.73 (0.39, 1.38)	2.89
Haiti 2000	0.39 (0.25, 0.63)	5.16
Jordan 1990	0.12 (0.09, 0.17)	10.84
Kenya 1993	0.62 (0.42, 0.93)	7.23
Morocco 1992	0.40 (0.19, 0.82)	2.19
Mali 1995-96	0.43 (0.22, 0.84)	2.60
Mali 2001	0.14 (0.08, 0.23)	4.08
Malawi 1992	0.67 (0.37, 1.23)	3.15
Nigeria 1990	0.64 (0.26, 1.59)	1.40
Niger 1998	0.16 (0.09, 0.27)	3.66
Chad 1996-97	0.75 (0.44, 1.29)	3.88
Chad 2004	0.78 (0.37, 1.67)	1.97
Uganda 1995	0.58 (0.36, 0.94)	4.89
Vietnam 1997	1.01 (0.39, 2.64)	1.24
Vietnam 2002	0.12 (0.03, 0.44)	0.65
Zimbabwe 1994	0.88 (0.52, 1.47)	4.30
Overall (I-squared = 82.7%, p = 0.000)	0.44 (0.39, 0.48)	100.00

Notes: We report odds ratios for those who live farther than 60 minutes when compared to the reference group who are within 1 km of a facility, In some surveys, there was no reported cluster that was farther than 60 minutes from the nearest facility, so the next maximum categorical time from the facility was plotted instead. These surveys (with their maximum categorical times in parentheses) are: Jordan 1990 (30 - 59.9 min); Vietnam 1997 (10 – 19.9 min); and Vietnam 2002 (30 – 59.9 min). The results are based on survey-specific logistic regression with the same set of covariates as described in Table A9. The square gives the estimated odds ratio and the error bars give the 95 percent confidence interval. The solid vertical line at 1 represents the odds ratio value under the null hypothesis.

Figure A9: The effect of time to health facility on antenatal care received, facility delivery, and neonatal death: pooled analysis



Notes: The results are based on the logistic regression results that are reported in Table A9. The odds ratios are for each time category, compared to the reference group of living within 10 minutes of a facility. The error bars indicate the 95 percent confidence interval. The horizontal line at 1 represents the odds ratio value under the null hypothesis.

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2. The Effect of Fertility Decline on Economic Growth in Africa: A Macrosimulation Model

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2.1. Abstract

We investigate the effects of a decline in fertility on economic growth and development outcomes using a macrosimulation model. We incorporate three fertility effects that have previously not been included in such models: the effect of fertility on child health and later worker productivity; the effect of fertility on savings; and a feedback mechanism from female education to fertility, in which changes in female education that are induced by declining fertility in turn alter subsequent fertility. We also improve the model of the economy by incorporating a more realistic three-sector framework and by allowing for labor market imperfections. Using data from Nigeria, we find that adding these channels roughly doubles the effect of an initial fertility decline on income per capita after 50 years when compared to previous simulation results.

2.2. Introduction

The demographic transition from high mortality and high fertility to low mortality and low fertility is well underway around the world and has started in Sub-Saharan Africa in recent decades. There is evidence that the decline in fertility, which accompanies the latter stages of the demographic transition, creates the potential for a demographic dividend and a window of opportunity for economic growth. In addition to the increase in income from the decline in youth dependency rates and the rise in working-age share of the population, the decline in fertility promotes changes in behavior that can lead to higher income. Lower fertility can induce higher labor force participation rates, particularly for women. Reduced youth dependency rates may also lead to increased investment in the health and education of each child, thereby increasing children's productivity when they enter the workforce. Changes in fertility and age structure may affect national savings rates and investment. Finally, there may also be a positive feedback effect between the demographic and economic transitions, whereby fertility decline induces improvements in health, education, female labor market participation, and economic growth, and these improvements in turn lead to further reductions in fertility and additional economic benefits.

While cross-country regression models suggest positive effects of fertility and age structure on economic growth (Barro 1991; Bloom and Canning 2008; Mankiw, Romer, and Weil 1992), these aggregate models do not usually identify the channels through which fertility works, and they often lack the ability to model country-specific factors in detail. An alternative approach, which we follow in this study, is to construct a macrosimulation model of economic growth and to parameterize the mechanisms in the model from microeconomic studies along the lines used by Moreland et al. (2014) and Ashraf, Weil, and Wilde (2013). Our approach is based on the work of Ashraf et al. (2013), who examine the economic effects of fertility decline through changes in age structure, female labor force participation, investment in children's education, and increases in the capital–labor ratio. In our modeling, we add three key mechanisms that have not been previously considered in this body of work. We then conduct a decomposition analysis in order to assess the relative impact of each of these added mechanisms, as well as other included channels, on key outcomes.

First, we add a channel that links fertility decline to improved health outcomes for children. Through this channel, smaller family sizes and longer intervals between births may allow for additional health investments in children, which, in turn, can contribute to physical and cognitive development and can lead to increases in human capital and improved worker productivity (Canning and Schultz 2012; Cleland et al. 2012).

Second, we incorporate a mechanism through which the change in the population age structure due to fertility decline may increase savings rates. In particular, savings rates at the household level vary with age, with a peak during people's working lives, so that aggregate savings at the national level will depend on the age structure of the population (Bloom, Canning, Mansfield et al. 2007; Higgins 1998; Lee, Mason, and Miller 2001; Leff 1969). There may also be an additional effect of lower fertility on expected transfers from children to their elderly parents, increasing the need for savings for retirement (Smith and Orcutt 1980; Weil 1994). Higher savings rates from reductions in fertility rates may, in turn, boost the capital–labor ratio over and above the effect of having smaller inflows of working-age people.

Third, we consider the effect of an initial decline in fertility brought about by an increase in contraceptive use through an expansion of family planning programs. We also add the possibility of subsequent further fertility reductions as fertility reacts endogenously to induced changes in social and economic conditions. In Africa, female education is an important driver of fertility decline, and a policy of expanding female education will have large fertility and economic growth effects (Canning, Raja, and Yazbeck 2015). Because such a policy will have both fertility and direct productivity effects on economic growth, it will be more difficult to analyze. We do, however, take account of induced changes in education and future fertility resulting from the initial fertility decline. In particular, if fertility decline leads to an increase in educational investments in children, these higher levels of education can reduce fertility in the next generation. This feedback channel implies that the effects of the initial decline in fertility are compounded by further reductions attributable to rising levels of female education (Drèze and Murthi 2001). This feedback mechanisms is slow in coming, as it occurs only when the child cohorts with increased educational attainment reach childbearing age (Cleland and Rodríguez 1988; Diamond, Newby, and Varle 1999; Osili and Long 2008).

In addition to adding these three mechanisms, we develop the economic structure of the model to make it more realistic. Previous simulation approaches, including the model by Ashraf, Weil, and Wilde (2013), assume a one-sector model of the economy and perfect markets so there is full employment. In such a model the supply-side effects of demographic change on labor and capital automatically result in increased output. However, evidence from cross-country studies shows that the demographic dividend is not automatic but rather depends on the appropriate economic policies to produce adequate demand for the resources produced by the supply side (Bloom et al. 2007). One way of allowing for market imperfections would be to allow for unemployment in the model so that increases in labor supply may potentially lead to mass unemployment rather than higher output.

While modeling mass unemployment in response to a rapidly increasing labor supply may be appropriate for developed countries, it does not appear to be appropriate for poor developing countries in Sub-Saharan Africa. In most of Sub-Saharan Africa, the lack of unemployment insurance implies that people are compelled to work even if the wage they earn is low (Bigsten and Horton 2009; Goldin 1994). In this setting, the effect of rapid population growth may be to drive more workers into low-wage, low-productivity jobs in labor-intensive traditional sectors, particularly in agriculture, rather than to create unemployment. To model this, we follow the Lewis (1954) model of developing economies and assume the economy is comprised of three sectors. The first of these sectors we take to be the modern part of the economy that encompasses industrial sectors such as manufacturing, sectors that demand skilled labor, and the formal service industries. In this sector, physical capital and labor augmented by human capital (in the form of education and health) are inputs for production, and workers are paid wages that are equal to their marginal product. The second sector, which we refer to as traditional, represents the labor-intensive part of the economy that uses labor and land as input factors of production. The traditional sector consists mainly of subsistence agriculture and low-skilled services such as roadside trading, though some agriculture and services are either physical or human capital intensive and should be thought of as being part of the modern sector. Like prior single-sector models, we also include a fixed factor, land, which can generate Malthusian crowding effects if population growth is rapid; however, this effect occurs only in the traditional sector in our model. In addition, we do not assume that wages equalize across sectors. Rather, wages are higher in the modern than in the traditional sector, and we impose a fixed wedge between the earnings in each sector, which reflects the cost of migration and other distortions such as taxes that are levied on the modern sector but not on the traditional sector. The equilibrium in the model is inefficient given that worker productivity and real wages are higher in the modern sector than in the traditional sector, which reflects a standard stylized fact that is observed in developing countries (Bloom, Canning, Hu et al. 2010). Finally, we allow for an exogenous contribution of a raw materials sector to output, which is often an important contribution to national income in many Sub-Saharan African countries. These additions, when taken together, allow our model to more realistically reflect Sub-Saharan African economies than a single-sector model with complete efficiency.

In our simulation analysis, we begin with a baseline scenario in which the time path of fertility follows the high-variant forecast of the 2010 Revision of the United Nations *World Population Projections* (United Nations 2010). We then compare the outcomes under the introduction of an intensive family planning program that lowers fertility. We assume that the intensity of the program is sufficient to reduce fertility to the UN low-variant forecast, in which the total fertility rate falls by 0.5 births per woman after 5 years, 0.8 births per woman after 10 years, and one birth after 15 years and thereafter from the start of the projection period. This reduction in fertility is consistent with estimates of the effect of family planning programs in Matlab, Bangladesh in the 1980s and in Navrongo, Ghana in the 1990s (Debpuur et al. 2002; Joshi and Schultz 2007; Miller and Babiarz 2016; Phillips et al. 2012), where changes in fertility in treatment areas were compared to changes in fertility in control areas that did not receive the family planning intervention, and where the effect on the total fertility rate appeared to have been a reduction of about one child per woman over a similar time horizon. We feed data from these two fertility scenarios into our model framework and run our simulation model to observe the differences in outcomes under each fertility scenario through each of the demographic and economic mechanisms outlined above, including feedbacks into further induced fertility decline.

2.3. The Model

We now outline the structure of the model. Additional details of the model, including our equations, are given in Appendix 1.[1] We consider a model of the demographic dividend in Sub-Saharan Africa, which gives rise to some issues that might not be present in developed countries. In particular, we allow for a three-sector model with a highly productive modern sector that uses physical capital, human capital, and labor, a traditional sector that uses land and labor, and a raw materials sector that requires no inputs.

2.3.1. Population and Effective Labor

The base of our model is similar to that of Ashraf, Weil, and Wilde (2013). We define each period in our model to be five years, and we divide the population into five-year age groups. We calibrate age-specific mortality rates to be consistent with the evolution of age groups from the 2010 Revision of the UN *World Population Prospects* (United Nations 2010). These age-group-specific mortality rates in each future five-year period decline over time in each country but are assumed to be the same across each scenario. For fertility, we begin with the high-variant scenario as our baseline. We then consider a family planning intervention that reduces fertility gradually over time as outlined above. When

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[1] Appendixes are available at the supporting information tab at wileyonlinelibrary.com/journal/pdr.

calculating the population distribution by sex under each of our scenarios, we adhere to the UN projections of the sex ratio at birth within each age group and over time.

Figure 1 illustrates the main demographic model and shows how we feed our fertility and mortality projections into a population model to obtain estimates of the population by five-year age group and sex in each period under each fertility scenario. We calculate the labor force by assuming that adults enter the labor force at age 20 and leave at age 65. The labor supply contribution by sex in each period is the size of the projected sex-specific population in that age group weighted by the sex- and age-group-specific labor force participation rates in that period. Labor force participation rates are obtained from the International Labour Office's ILOSTAT database (International Labour Office (ILO) 2013) for the year 2010. We assume that age-specific male participation rates are fixed at this level over time, but we modify the age-specific female labor force participation rate in each period to reflect the impact of fertility change and women's substitution between childcare and work on total female labor supply.

We then model the effects of fertility and demographic change on human capital accumulation, which we capture through effects on both child health and education. We assume that a given sex-specific cohort's educational attainment and health stock (quantified in average years of schooling per individual and adult height, respectively) are entirely amassed before age 20, after which the average level of schooling and average adult height for that cohort are held constant. We then parameterize the fertility-to-education and fertility-to-health relationships to capture the quality–quantity trade-off in which investment per child in education and health rises as the number of children falls (Becker and Lewis 1973; Becker 1981; Lam 2003).

In contrast to previous macrosimulation modeling, we endogenize the evolution of fertility over time through a feedback channel from female education to fertility. This feedback further reduces the fertility rate in the low-fertility scenario relative to the high-fertility scenario as increased female education feeds into lower fertility. We calculate average years of schooling and average height in each period separately by sex as weighted sums of the average years of schooling and average height of each cohort. We then combine the sex-specific estimates in a weighted average to estimate the level of human capital that is accumulated for the entire workforce for that period, and combine these human capital estimates with our projection of the size of the labor force to predict effective labor over time. Figure 2 outlines the process for deriving effective labor in our model and highlights the new channels (endogenous education feedback, health) with bold arrows.

2.3.2. Production

Figure 3 presents our full demographic–economic model of production. Estimates of education, health, and labor supply from our demographic simulations, which together comprise effective labor, are fed into our model along with capital and land. We consider a Lewis development economy with three sectors: a modern sector, a traditional sector, and a raw materials sector. Labor is shared between the modern and traditional sectors. Production in the modern sector is given by a standard Cobb–Douglas production function, with inputs of physical capital, labor allocated to the modern sector, and human capital in the form of average years of schooling in the workforce (as a proxy for education) and average height of the workforce (as a proxy for health). Aggregate production in the traditional sector is also modeled by a Cobb–Douglas production function, with agricultural land and labor allocated to the traditional sector as factor inputs. The stock of agricultural land is assumed to be fixed, but we acknowledge that there may be variable returns to land through advances in agriculture technologies, land reclamation and improvement, and more effective use of natural resources. In addition, the extensive margin of land cultivation may change as a result of population pressure;

however, it is difficult to estimate the variable returns to land and the substitutability between land and other factors of production, particularly across different countries and over time. We assume that the traditional sector does not use physical or human capital, and we model it to capture subsistence agricultural and low-skill production in the informal sector. This is in line with evidence that the capital intensity of agriculture is low in Sub-Saharan Africa (Schmidhuber, Bruinsma, and Boedeker 2009). The very limited evidence of the returns to schooling in agriculture in Sub-Saharan Africa suggests low or even zero returns (Glewwe 2002). Finally, we allow for a raw materials sector (e.g., oil or mineral production) that produces output exogenously of other inputs. While this sector requires both capital and labor inputs, it is not very labor intensive, and income from this sector comes almost entirely from a country's endowment of natural capital (Ross 2012). We therefore avoid modeling output as a function of inputs in this sector and include production from raw materials as a constant additive term in total output.

2.3.3. Capital Accumulation and Savings

We replicate a Solow framework for capital accumulation, assuming that net investment depends on aggregate output weighted by the savings rate and net of the depreciation of the level of capital stock. Following Bloom, Canning, Mansfield et al. (2007), we model the evolution of the savings rate as a function of the past savings rate, the level of income, and age structure in the form of the ratio of old-age dependents to the working-age population. By modeling savings in this manner, we capture the idea that savings behavior depends on age, where peak savings occur when people are prime-age workers and declines with age to the point where the old dis-save. The level of income has an important impact on savings: in very poor countries, there is little life-cycle saving, and retirement and saving for retirement are luxury goods and behaviors that emerge only once income levels are sufficiently high. Bloom, Canning, Mansfield et al. (2007) also emphasize that savings are dependent on incentives from social security systems; pay-as-you-go pension systems can generate income for retirement without the need to accumulate real savings. Such pension systems are not operational in our model. In Sub-Saharan Africa, however, it is likely that: 1) most savings come from a few well-off households, large firms, and governments; and 2) savings are low as a result of corruption and other institutional inefficiencies. Hence, a more detailed approach would be to model the savings behavior of households, firms, and governments separately. Finally, we make an additional simplifying assumption that investment is limited to domestic saving, and we ignore the role of international capital flows while recognizing that such flows might increase the size of the demographic dividend since a large workforce increases the return to capital and makes investment more attractive.

2.3.4. Labor Allocation across Sectors

Our model specification requires that modern- and traditional-sector wages, which endogenously adjust within their respective labor markets, will in turn determine equilibrium labor supply allocations across the two sectors that employ workers. The wage rate[2] in the modern sector in a given period is equal to the marginal product of labor in the modern sector for an additional worker with average levels of education and health. However, in following Lewis's dual-sector model of surplus labor, we assume that the traditional sector is not based on a market mechanisms but involves sharing of output among family members. Hence, the wage per worker in the traditional sector will be determined by the average product of that sector. This wage condition captures a common observation in low-income countries in which family members share incomes and communities pool and divide resources as a means of insuring against risk (Cypher and Dietz 2009; Lewis 1954).

We assume that labor moves between sectors so that net effective earnings are equalized across sectors. Since wages in the traditional sector are determined at the average and not at the margin, in

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[2] Throughout, we use the term wage to describe the wage rate per worker. This is distinct from the total wage bill, which can be calculated by multiplying the wage rate by the total number of workers.

equilibrium the marginal productivity in the traditional sector will be lower than in the modern sector. In addition, there may be costs, such as migration costs, labor and employer taxes, or bribes to corrupt officials, that are levied on workers or employers in the modern sector but not in the traditional sector and that, in turn, will discourage traditional-sector workers from entering the modern sector. These costs will also contribute to an inefficient allocation of labor across sectors. We assume workers will migrate between sectors to establish an equilibrium in which wages in the modern sector, net of all costs, are equal to wages in the traditional sector.

A key issue related to the demographic dividend is the ability of the economy to absorb the large numbers of young workers who enter the economy during the demographic transition. In Sub-Saharan Africa, this has mainly been an issue of workers being forced into low-productivity sectors rather than being driven into unemployment, and this assumption drives the rationale for our sectoral model (Filmer and Fox 2014). In some countries, however, rising youth unemployment is becoming an increasing concern, and in these cases a model of unemployment would be more appropriate.

2.4. Calibration

Table A1 describes the parameters used in the model, the parameter values used to calibrate the model, and the sources from which these values were obtained. Estimates of key parameters that illustrate the direct relationships between fertility and other factors are drawn from several sources. To identify the direct time cost and reduction in labor market participation due to an additional child, π, we follow the parameterization approach described in Ashraf, Weil, and Wilde (2013), who interpolated data for the Philippines from Tiefenthaler (1997) and found that lifetime female labor supply declines by an estimated 2 percent for each additional birth. This fairly small effect is consistent with the fact that female labor market participation in Sub-Saharan Africa is generally very high and has little scope for increase, particularly in low-income settings where women tend to be strongly attached to the labor market, working less during pregnancies but returning to the labor market right after giving birth. Because many women in Sub-Saharan Africa are either self-employed or work in the informal sector, mothers can often bring their young children to work with them. Therefore, an additional birth may not have a large impact on a woman's labor force participation in the traditional sector, where women most often work within the home and effectively combine work with childcare (Goldin 1994; Verick 2014; Westeneng and D'Exelle 2011), and it may be only in the modern sector that there is a sharp division between home and work and a tradeoff between working and looking after children. In the case of Nigeria, however, female labor force participation rates are more modest than in other Sub-Saharan African countries, with 47.1 percent of women reporting to be active in the labor force. This relatively low female labor force participation rate reflects the recent shifts in the labor market for women away from traditional sector employment and into formal sector employment where the opportunity costs of childcare and childrearing are higher. The potential effects of declining fertility on labor force participation, particularly within the formal sector, may therefore be stronger in this context.

Parameter estimates for the direct effect of fertility on educational attainment, θ_E, are obtained from Rosenzweig and Wolpin (1980) and Joshi and Schultz (2007), who drew on quasi-experimental evidence from a family planning intervention in Matlab and found that a 15 percent reduction in total fertility, which is equivalent to having one less birth, increases children's number of years of schooling by 20 percent. When considering the endogenous response of fertility to changes in education, we parameterize the coefficient ψ, the direct effect of education on fertility, using results from Osili and Long (2008), who examined the causal impact of a universal primary education program in Nigeria and found that each additional year of female schooling reduced fertility by 0.26 to 0.48 births, a reduction of 11–19 percent. We obtain our parameter value of 15 percent for ψ by averaging across the various estimates by Osili and Long.

We expect that a reduction in fertility will increase the health and nutrition resources available per child and lead to improved child health outcomes. Evidence from Matlab suggests that providing improved access to family planning and child health services reduced fertility and child mortality (Joshi and Schultz 2013); however, direct evidence on the effect of fertility on surviving children's health and subsequent worker productivity is limited. We therefore take an indirect approach to calibrate our estimate for θ_H, which captures the impact of fertility on child health and health human capital (as proxied by adult height), by first examining the effect of fertility on child height and stunting, then inferring this effect on adult height, and finally estimating the effect of adult height on worker productivity and wages.

Giroux (2008) and Kravdal and Kodzi (2011) examined the effect of fertility and the number of siblings on child stunting in Sub-Saharan Africa. While they found a strong association at the aggregate level, their estimates of the effect size are quite small at the household level. Kravdal and Kodzi used household-level data from 23 countries and found that an extra sibling increases the odds of stunting by about 2 percent, while Giroux estimated that the odds of stunting in six countries increased by about 3 percent with each additional child. We use the 2 percent estimate for our calibration; however, Kravdal and Kodzi found large effects of short birth intervals on the risk of stunting, so there is scope for larger effects of fertility on child height if reductions in fertility lead to both increases in birth intervals and a reduction in the number of siblings.

Victora et al. (2008) pooled results from longitudinal studies to estimate that each reduction of one standard deviation in a child's height-for-age score reduces adult height by 3.23 centimeters. Over the last 30 years, the distribution of child height-for-age has improved and the prevalence of stunting has declined. Stevens et al. (2012) examined trends in the distribution of height-for-age scores and found that in developing countries over the last 30 years, the average score has improved from –1.86 to –1.16 while the prevalence of child stunting (equivalent to a height-for-age score less than –2) has fallen from 47 percent to 30 percent. Combining these estimates suggests that a reduction in fertility and sibling numbers by one birth would increase the average height of adults by around 0.10 centimeters. If we assume an average adult height of 150 centimeters, this one-birth reduction would translate into an increase in adult height of about 0.067 percent.

Standard estimated values for production-factor shares are extracted from the economic growth literature, including the estimated capital share of output in the modern sector of $\alpha = \frac{1}{3} = 0.33$ (Hall and Jones 1999) and the estimated land share of output[3] in agriculture of $\beta = \frac{1}{6} = 0.167$ (Kawagoe, Hayami, and Ruttan 1985; Williamson 1998, 2002). For the productivity of human capital, we use estimates of the effect of schooling on height (measured in years and centimeters respectively) on log wages. We take the education parameter to be $\gamma = 0.1$, which is an average of the estimated returns to schooling (Banerjee and Duflo 2005; Oyelere 2010; Psacharopoulos 1994; Psacharopoulos and Patrinos 2004), and the health parameter to be $\lambda = 0.08$, which is based on the estimated wage returns to adult height (Schultz 2002, 2005). In modeling traditional-sector output as a function of land and labor, our production function for the traditional sector is a simplification of Kawagoe et

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[3] In our parameterization of the land factor share, β, we refer to Kawagoe et al.'s (1985) examination of the agricultural production function, in which the authors estimate an agricultural factor share between 0.1 and 0.2. Given that the parameter is small relative to the factor share in the modern sector, we set β to be 0.167, which yields a simple tractable solution for the allocation of modern-sector labor across sectors.LM_t.

al.'s model since we do not consider the significant contributions of other reproducible factors to output, including livestock, fertilizer, and machinery.

2.5. Data Sources

Our simulation is focused on interventions that alter the path of fertility from what would otherwise occur along a given baseline. We start with the current population age structure in the baseline scenario and assume that fertility and mortality will follow the UN's baseline high-variant forecast of fertility. We examine baseline and alternative scenarios constructed using demographic data from Nigeria. This approach allows us to better understand the timing by which different demographic–economic channels operate. Our baseline (high-variant) and alternative (low-variant) scenarios are constructed using vital rates from Nigeria and the 2010 Revision of the UN's *World Population Prospects*. Baseline data on age-specific fertility rates and projected populations are taken from the 2010 Revision (United Nations 2010).

For our economic model, we collect baseline data for modern-sector and traditional-sector outputs, modern-sector and traditional-sector labor inputs, and available land from *World Development Indicators* estimates (World Bank 2012), and we use capital stock estimates from the Penn World Tables (Feenstra, Inklaar, and Timmer 2015). Baseline data on average schooling and average height by sex and age group are obtained from the 2008 Nigeria Demographic and Health Survey (National Population Commission (NPC) [Nigeria] and ICF Macro 2009), while estimates of age-specific savings rates are taken from Bloom, Canning, Mansfield, et al (2007). Baseline labor force participation rates are obtained from the ILOSTAT repository (International Labour Office (ILO) 2013).

Table A2 describes each source of data that was used as baseline data for Nigeria.

2.6. Simulation Results for Nigeria

2.6.1. Demographic Scenario

Figure 4 shows the changing trajectories of fertility under the high- and low-variant fertility scenarios. Under the baseline high-variant scenario, total fertility declines from an initial 5.61 children per woman in 2005–2010 to 2.70 by 2095–2100. The decline in the total fertility rate under the low-variant scenario progresses on a faster trajectory than in the high variant such that the rates between these two scenarios differ by 0.5 births per woman in 2010–2015, by 0.80 births in 2015-2020, and by a fixed 1.0 birth per woman from 2020 onward.

When accounting for the endogenous responses of fertility from the education channel, the alternative low-variant projection diverges further from the projections that do not incorporate the feedback channel from education to fertility. This divergence is due to the fact that the endogenous feedback from education to fertility is calculated using the high-variant scenario as the reference; feedback effects of education under the low-variant scenario are therefore calculated as the additional effect of education on fertility due to deviations in scenario-specific fertility from the high variant. When we adjust for these effects, fertility under the endogenous low-variant scenario is projected to fall by an additional 0.55 births after 50 years and by 0.35 births by the end of the 90-year time horizon. This new pathway is indicated by the bottom line in Figure 4.

Figure 5 shows the trajectory of total population under each of the fertility scenarios. By these estimates, population under the endogenous low-variant scenario will be 25.6 percent lower than the population in the high-variant scenario in 2050 and 59.8 percent lower in 2100.

2.6.2. Three-Sector Economic Model Results

Figures 6–8 present the trajectory of income per capita, the share of workers in the modern sector, and changes in modern-sector capital per worker (the capital–labor ratio). Each of these trajectories is presented under the two fertility scenarios. We refer to the year 2010, which is the last year before total fertility rates in the two scenarios start to diverge, as the starting year for our simulation.

Figure 6 indicates that the reduction in fertility from the high-variant to the endogenous low-variant level results in a nearly twofold increase in per capita income (97.4 percent) over a 90-year time horizon. Figure 7 further illustrates the increase in the share of workers in the modern sector as a percent of the total labor supply. In both fertility scenarios, the share of workers starts out smaller in the modern sector than in the traditional sector at only 30 percent of the total labor force. However, beginning around 2025, the share of workers in the modern sector begins to exceed the share of workers in the traditional sector, reflecting the consequent shift in labor and increasing industrialization over time. While both fertility scenarios illustrate this transition from the traditional to the modern sector, the share of workers in the modern sector increases faster and remains higher in the alternative endogenous low-variant fertility scenario compared to the baseline high-variant fertility scenario over the time horizon.

Figure 8 shows that modern-sector capital per worker is fairly stable and approximately equal in the two fertility scenarios until around 2040, after which modern-sector capital per worker under the endogenous low-fertility scenario is projected to grow at a faster rate. Modern-sector capital per worker in the endogenous low-fertility scenario, at an estimated $61,239, is more than 2.7 times higher than in the high-fertility scenario, at an estimated $22,481, by 2100. However, capital per worker is not expected to increase substantially in either scenario for around 50 years. This is because our savings equation is largely driven by the income effect, in which economies with low income levels have low savings rates. Only when income levels rise substantially do domestic savings accelerate. This assumption highlights the potential role of foreign investment over the medium run in Sub-Saharan Africa as a source of funds for investment, given the weak initial rates of domestic savings.

2.6.3. Component Channels and their Long-Run Paths

Figures 9–12 illustrate the trajectories of four key channels through which changes in fertility affect income per capita and other indicators of economic growth. These channels are:

1. *The working-age population ratio*, defined as the ratio between the total number of workers in both the traditional and modern sectors and the total population. This measure reflects the potential for a demographic dividend by capturing the additional productivity that can be generated through shifts in the population age structure as a consequence of declining fertility.
2. *The average years of schooling attained*, which accounts for the education-as-human-capital channel through which declining fertility contributes to economic growth and productivity.
3. *Average adult height*, which proxies for health as the other human capital channel in the model.
4. *Female labor force participation*, which reflects the direct labor market opportunity cost of childbearing.

Figure 9 shows the long-run effects of declining fertility on the ratio of the working-age population (ages 20–64) to the total population. Reductions in the fertility rate over time contribute to a higher working-age population ratio as the base of the population pyramid shrinks relative to the productive working ages. Moreover, the working-age population ratio increases faster with larger declines in fertility. In particular, the difference in fertility between the high-variant fertility scenario and the endogenous low-variant scenario translates to a 6 percentage point difference in the working-age population ratio by 2060 and a 2.8 percentage point difference by the end of the projection period. A key difference is that lower fertility increases the working-age share of the population only until around 2070, after which sustained low fertility results in a rise in the old-age dependency rate and a falling working-age share. While the working-age share of the population is always higher under the low-fertility variant, the gap increases only until 2070. We therefore expect most of the income gains to have occurred by that time, with little additional benefit from age structure after 2070.

Figure 10 outlines the trajectories of education, as measured by average years of schooling attained by the workforce. This is calculated using the age- and sex-specific levels of schooling and labor force participation rates. While educational attainment is expected to increase in the workforce as a whole, it will increase at faster rates under lower fertility. In particular, average years of schooling under the endogenous low-fertility scenario are projected to be 2.47 years greater than under the baseline high-fertility scenario.

Despite declining infant mortality rates, adult heights have not increased in Sub-Saharan Africa and have even declined in many countries. This conflicting trend is likely due to the fact that infant mortality decline in the region has been achieved by health interventions that target child survival but do little to reduce morbidity or improve child physical development (Akachi and Canning 2010). Younger cohorts in Nigeria are shorter than those born earlier, and Figure 11 projects that average adult height in the workforce will decrease in the baseline high-variant fertility scenario until around 2040, after which adult height stabilizes and starts to increase by the end of the projection period. Similar to education, we predict that health human capital, as proxied by adult stature, will also be higher over time in the endogenous low-fertility scenario. In particular, adults under that scenario are predicted to gain 0.13 cm more than adults under the baseline high-fertility scenario over the projection period.

In assessing the response of female labor supply to declines in fertility, we observe a modest difference over time in female labor force participation rates associated with the two fertility scenarios, as depicted in Figure 12. We observe a 1.63 percentage point higher participation rate in the endogenous low-fertility scenario compared to the baseline high-fertility scenario.

2.6.4. Mechanism Analysis

A decline in fertility and any subsequent changes in population size and age structure are likely to affect economic outcomes through several mechanisms, each of which may operate at a different relative intensity and at a different time horizon (Ashraf, Weil, & Wilde, 2013). We decompose the overall effect of fertility reduction into the parts that run through these different mechanisms, and we acknowledge there are clearly interactions among the different effects in our model. We perform all of our comparative analyses of the effects of fertility under the assumption that all of the other mechanisms are operative; that is, we relate the results in our fully specified simulation model relative to results from a model in which one mechanism is suppressed.[4]

We begin by assessing the impact of our four new mechanisms (a three-sector economic framework with market frictions, an endogenous fertility mechanism, the inclusion of health as human capital, and an endogenous savings mechanism) individually on income per capita, which is our main economic outcome of interest. This analysis allows us to determine the sensitivity of our results to our assumptions about key parameters. We then fully decompose the effects of each of the mechanisms on income per capita to identify their relative importance at different time horizons.

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[4] An alternative would have been to conduct a comparative analysis using the model in which no other mechanisms are operative (which, in fact, would be equivalent to a re-simulation of the Ashraf et al. (2013) one-sector model).

Figure 13 projects the ratio of income per capita in the endogenous low-fertility scenario to income per capita in the high-fertility scenario in our full three-sector demographic–economic model, hereafter referred to as the CKW model, across the 90-year time horizon. The figure also compares the CKW results to projections of the income per capita ratio from: alternative models in which one of the four key mechanisms from the CKW model is suppressed; and a simulated base-case one-sector model in which all four key mechanisms from the CKW model are jointly suppressed. This base-case model presents a point of comparison for our results by replicating the conditions and results of the (Ashraf et al., 2013) model.[5]

Under the CKW model, the long-run effect of reducing fertility from the baseline high-variant fertility scenario to the endogenous low variant fertility scenario leads to an 95.2 percent increase in income per capita by 2060, which is roughly double the size of the 47.3 percent increase in income per capita predicted by the simulated base-case model over the same 50-year time horizon. The gains from low fertility occur over a 60-year period, with income per capita rising to about twice the level found in the high-fertility variant and then stabilizing at that higher ratio. The income effects in our model are larger and occur faster than those that are predicted by the base-case model. While the age structure effects of the demographic transition are transitory, the human capital effects of moving to low fertility are permanent.

The projected path of income per capita under the model where the use of the three-sector economic framework was suppressed (one-sector model) eventually converges to the projected path predicted by the full CKW model over the entire time horizon. Eventually, most workers are in the modern

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[5] The CKW model in which all four key mechanisms are suppressed differs from the original (Ashraf et al., 2013) model only in the differences in parameter values and functional forms between the two models.

sector, and the economy essentially collapses into a one-sector model with very small contributions from the traditional and natural resource sectors. However, economic growth under the three-sector model is much faster than in the one-sector model for a considerable period as slower population growth allows for more rapid industrialization and a higher share of the workforce is absorbed into the modern sector. The effect of endogenous savings is quite small and only really occurs after 2050 when income levels are high enough to make saving feasible. Health makes a contribution that is similar in magnitude to that of savings but at a slightly faster rate. However, the major reason for the difference between the predictions of our model and those from the one-sector model is the fertility feedback. If we switch this mechanism off, the gains from low fertility occur more quickly but converge to around the same level as the gains predicted by the one-sector model. The feedback acts as a multiplier effect, increasing the long-run gains from the initial level of fertility reduction. Finally, while the immediate effects of a rapid fertility decline is a mechanical increase in income per capita through a reduction in the number of child dependents, most of the economic gains are achieved through the other behavioral channels and are observed over a longer time horizon.

2.6.5. Decomposition of Mechanisms

Figure 14 presents a full decomposition of the fraction of the gain in income per capita over time that is attributable to the four mechanisms that are incorporated in the full CKW model. To assess the fraction of the gain that is due to each mechanism, we compare the level of income per capita in each year in the CKW model to the level that is predicted when the mechanism is suppressed. We then sum these individual mechanism effects to obtain an estimate the total effect that ignores interactions. Because the interactions among the mechanisms in the model, the effects from the individual mechanisms do not sum exactly to the total effect of a decline in fertility on income per capita. Finally, we divide the individual effects by the estimated total effect to produce a share of the total income gain attributable to each effect at each point in time and over the 90-year time horizon.

At the start of the projection period, the inclusion of three sectors accounts for more than 93 percent of the total income gain in the short run. However, the relative contribution of the three-sector mechanism falls quickly over time to about 30 percent after 50 years. Low fertility allows a larger percentage of workers to enter the high-productivity modern sector and promotes rapid economic growth. Eventually, when most workers are absorbed into the modern sector, this mechanism becomes unimportant, but sectoral shifts are an important driver of potential growth and accounted for a large part of the economic miracle in Asia (Nelson & Pack, 1999; Stiglitz & Yusuf, 2001). Here, we emphasize that we are estimating the effect of demographic change on economic growth through induced sectoral change.

We note that substantial economic impacts of fertility decline through the other demographic channels are not realized until much later (30 years or so after the start of the projection period). In particular, the endogenous fertility multiplier becomes increasingly important over time and is the largest contribution to the gains in the long run, accounting for more than two-thirds of the projected income gain over and above that of the simulated one-sector base-case model by 2060. The rest of the gains in the long run are due to the health and endogenous savings mechanisms. These model predictions are in line with the literature on the potential impact of demographic change and the role of population momentum on long-run growth (Blue & Espenshade, 2011). However, our decomposition analysis as it currently stands does not compare the relative contribution of these newly added mechanisms against some of the more traditional channels (e.g. the seven channels that were part of the Ashraf et al (2013) model) on which our model is built. Expanding the scope of our comparative analysis to include these mechanisms will allow us to make more general inferences about the factors that drive the relationship between population growth and economic growth.

2.7. Conclusions

We estimated the effect of a decline in fertility on economic growth in Nigeria using a demographic–economic macrosimulation model and improved on previous modeling approaches by incorporating four previously ignored channels: the effect of fertility on savings; a feedback from education to fertility; the effect of fertility on health; and the effect of a more realistic three-sector model with market imperfections, which are prevalent in the developing world.

Given our goal of providing a more comprehensive understanding of the relationship between fertility decline and income growth, a natural question to ask is how the additional channels that we add change the results previously found in the literature. Adding these new channels means that lowering the total fertility rate by one child per woman almost doubles income per capita by 2060, which is twice the size of the effect found by Ashraf, Weil, and Wilde (2013). Relative to previous approaches, our model predicts larger positive effects of fertility decline which, in turn, contribute to faster economic growth. Our contribution is to show the relative effects of these channels and to examine how much adding these channels adds to forecasting economic growth and how the timing of the effects differs across channels. Through this simulation exercise, we conclude that these previously ignored channels are perhaps even more important than the more traditional channels that have been considered to date. In the short to medium run, the main reason for the higher income effects in our model are due to the larger share of the workforce that moves into the modern sector of the economy when fertility is low. In the long run, lower fertility increases female education, which in turn lowers fertility in the next generation and produces a multiplier effect from any initial change in fertility.

Our results are tied to assumptions that govern the model's structure and dynamics. Our model is thus more useful for the insights it may provide into underlying processes and their interactions than for the predictions themselves. Including additional mechanisms in such a model adds realism but also increases complexity and risks decreasing the transparency of the findings. To make our model as transparent as possible, we include a full description of its structure and assumptions in Appendixes 1 and 2, and its parametrization in Tables A1 and A2.

When considering the basis for our counterfactual analysis, which rely on the fertility projections that are proposed in the U.N.'s "baseline" high-fertility and "alternative" low-fertility scenarios, we recognize that the plausibility of predicted fertility under the "baseline" scenario, in which fertility is predicted to decline slowly and even remain stagnant in the immediate future, has been the subject of recent debate around the speed of the fertility transition in Sub-Saharan Africa. In particular, evidence that was presented at the 2016 National Academy of Sciences workshop on "Recent Trends in Fertility in Sub-Saharan Africa" showed that: 1) the fertility decline may have slowed or even stagnated in several Sub-Saharan African countries in recent years; and 2) the rate of the decline in fertility in Sub-Saharan Africa might also be slower than what has been predicted. Taken together, this evidence provide some justification as to our choice of a baseline high-fertility trajectory, which predicts a slow fertility decline over the first 20 years. With this said, however, we are presently unable to elaborate on the extent to which this scenario is realistic, which can be better quantified by presenting confidence bounds around the projected economic and demographic estimates. We acknowledge that our inability to bound our estimates, both in the initial projections as well as in our final results, limits our inference on the predictive power of the model, and we are currently working to address this limitation in the next iteration of the model.

By the same token, we recognize that while our projections for the effects of fertility reduction are roughly double those that have previously been predicted, our estimated effects are generated by relatively large reductions in fertility (one birth) over a relatively short period of time (15 years). While such significant declines in fertility have been observed in settings where strong family planning programs have been implemented (e.g. Matlab, Navrongo), one may ask whether it is realistic to assume that similar programs and policies can replicate such results in Sub-Saharan Africa, where ideal family size and desired fertility are higher than in other parts of the world (Bongaarts 2011). Moreover, while access to family planning has improved in Sub-Saharan Africa over the last few decades, we observe that there is still considerable variation in the availability of family planning services across the continent, and access to family planning and reproductive health services in many countries in Sub-Saharan Africa remain low. We cite both the Matlab intervention as well as the family planning intervention study that was conducted in Navrongo, Ghana as our two main pieces of evidence for a one-birth decline from an intensive family planning intervention. Both the Matlab and Navrongo studies observed a one-birth decline in fertility in the intervention groups over similar (roughly 15-year) observation periods; however, both studies also observed that access to family planning and contraceptive prevalence rates were relatively low at baseline. Moreover, implementation of both the Matlab and Navrongo interventions was comprehensive, but also intensive and expensive. Clearly, family planning programs have costs and the programs cited here were expensive (Simmons, Balk, and Faiz 1991). Nevertheless, even the most expensive family planning programs have been shown to be cost-effective when compared to other interventions, even without considering their effects on economic growth (Simmons, Balk, and Faiz 1991; Schultz 1992; Cleland et al. 2006; Hughes and McGuire 1996). Taken together, we can infer that in contexts where access to family planning is higher, where a family planning intervention is less intensively rolled out, or where a family planning intervention is more expensive to roll out, we would assume to find smaller declines in fertility, and, hence, smaller downstream economic impacts. With this in mind, we might therefore think of the effects of a one-birth reduction in fertility to be an upper bound of the effect of an intensive family planning intervention on fertility decline.

Like Ashraf, Weil, and Wilde (2013) and others, we acknowledge that the economic growth brought about by fertility decline would not be sufficient to help a developing country "vault into the ranks of the developed" (National Research Council 1986). With that said, we argue that asking whether fertility decline alone could determine a country's path to economic growth and development was never an appropriate question to begin with. It is clear that there are many determinants of economic growth, and it is also clear that demographic change brought about by a reduction in fertility is one of these determinants. We would also highlight institutional factors, such as good governance, a market-based economy, openness to international trade, public investment in infrastructure and education, and improvements in total factor productivity as additional important mechanisms in a holistic view of economic development. Even if fertility were to decline and income per capita were to roughly double as we predict, it would still not be enough to close the estimated 30-fold gap in income per capita between rich and poor countries. To close such a gap would require several doublings in income per capita (United Nations Conference on Trade and Development 2002). However, while not the whole story, our model suggests that reducing fertility can make a substantial contribution to economic development in Africa.

2.8. Funding

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2.9. Notes

We thank Günther Fink, Jessica Cohen, and participants at the 2015 Population Association of America Annual Meeting, the Seventh African Population Conference, the 2015 Northeastern Universities Development Consortium Conference, and the NAS Workshop on Recent Trends in Fertility in Sub-Saharan Africa for their helpful comments and suggestions on the analysis.

2.10. Main Figures and Tables

Figure 1: Modeling Fertility, Population by Age, and Labor Supply

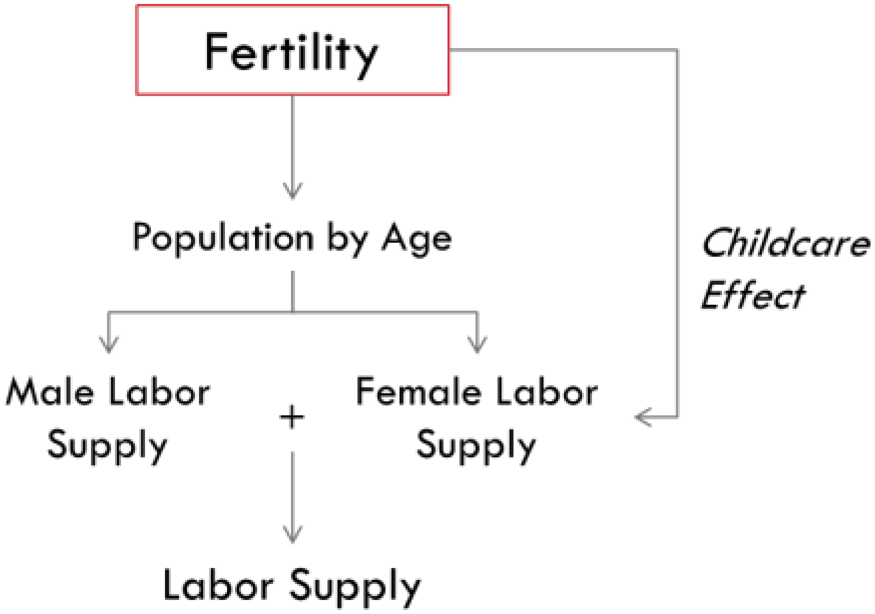


Figure 2: Effective Labor

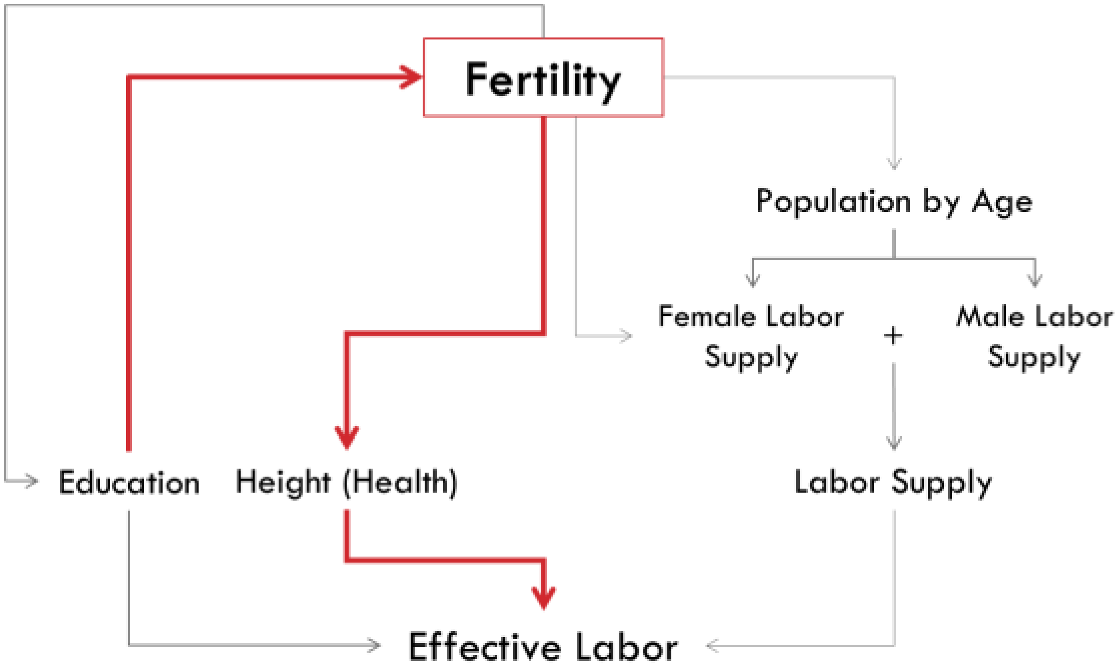


Figure 3: Full Demographic-Economic Model of Production

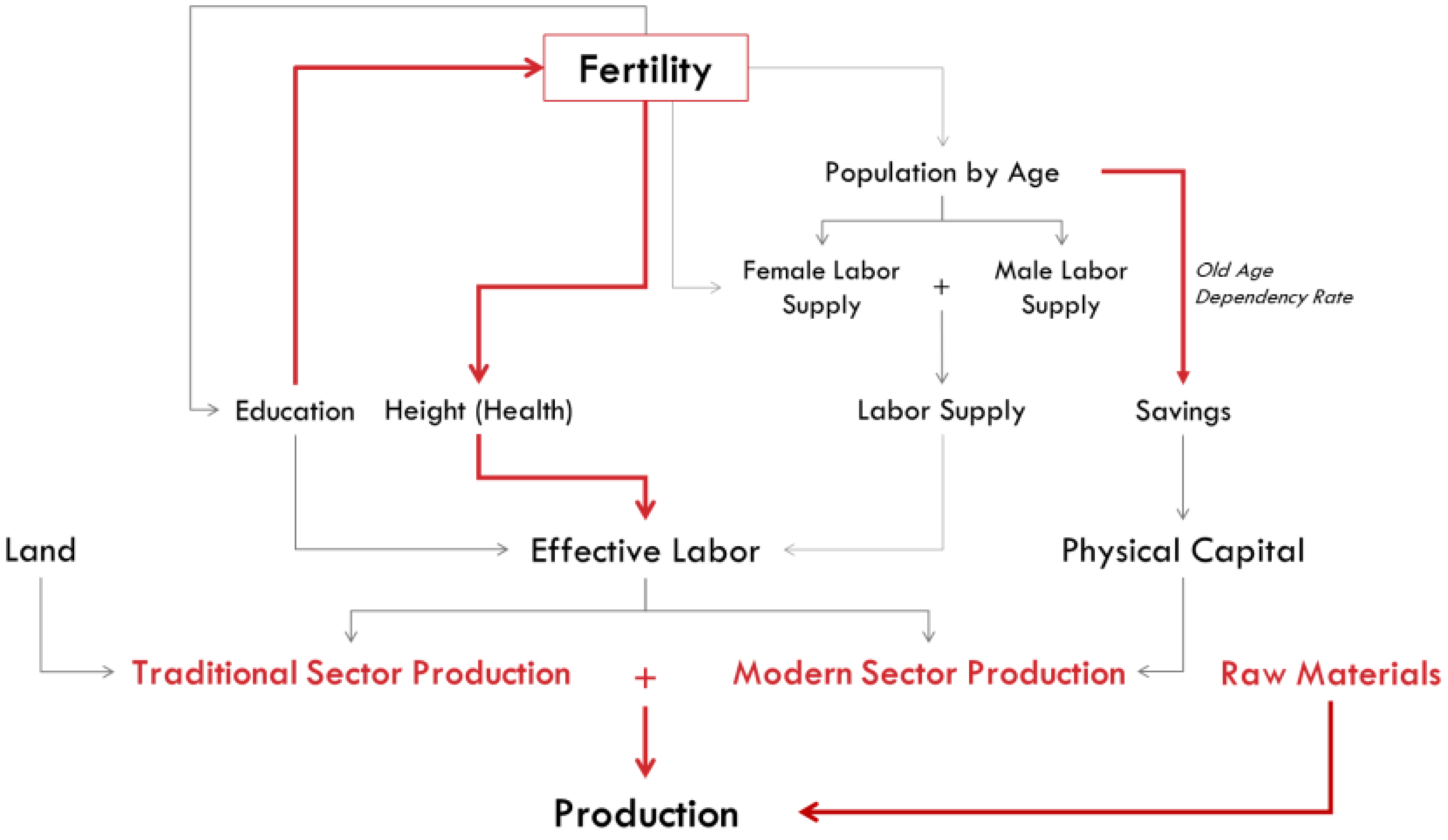


Figure 4: Total fertility rate (number of children per woman) under baseline high-fertility variant and alternative low-fertility variant scenarios, Nigeria

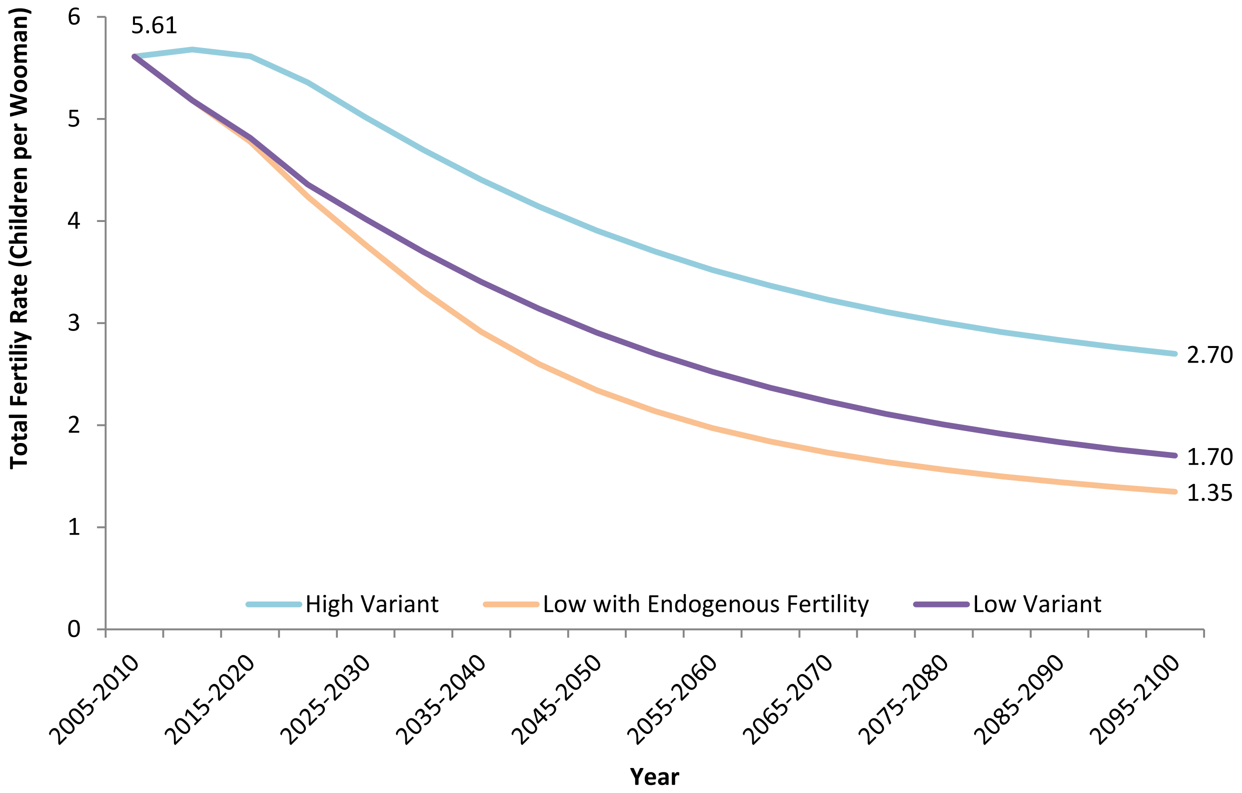


Figure 5: Population under high-fertility and endogenous low-fertility variant scenarios, Nigeria

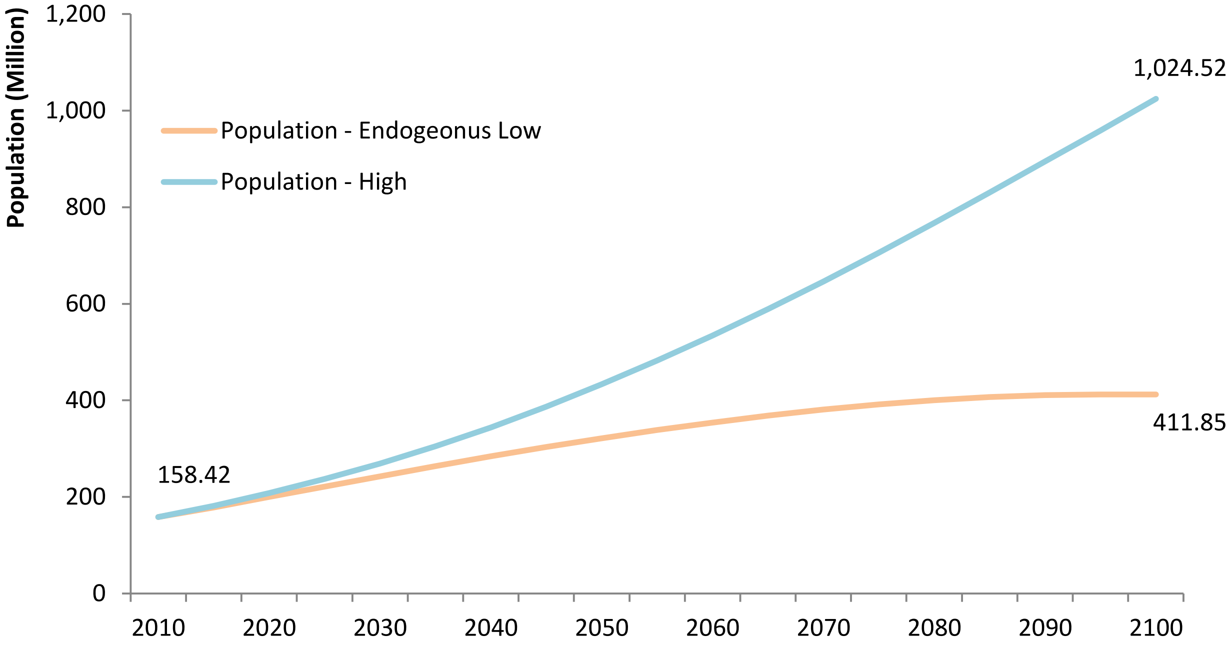


Figure 6: Per-capita income under high-fertility and endogenous low-fertility variant scenarios, Nigeria

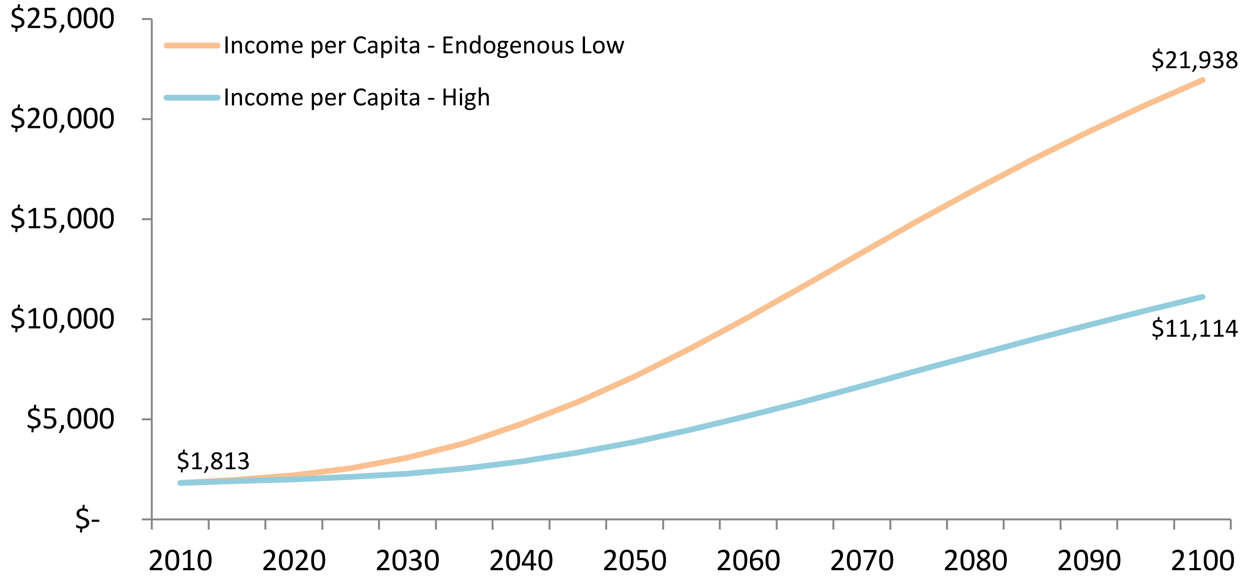


Figure 7: Percentage of workers in the modern sector under high-fertility and endogenous low-fertility variant scenarios, Nigeria

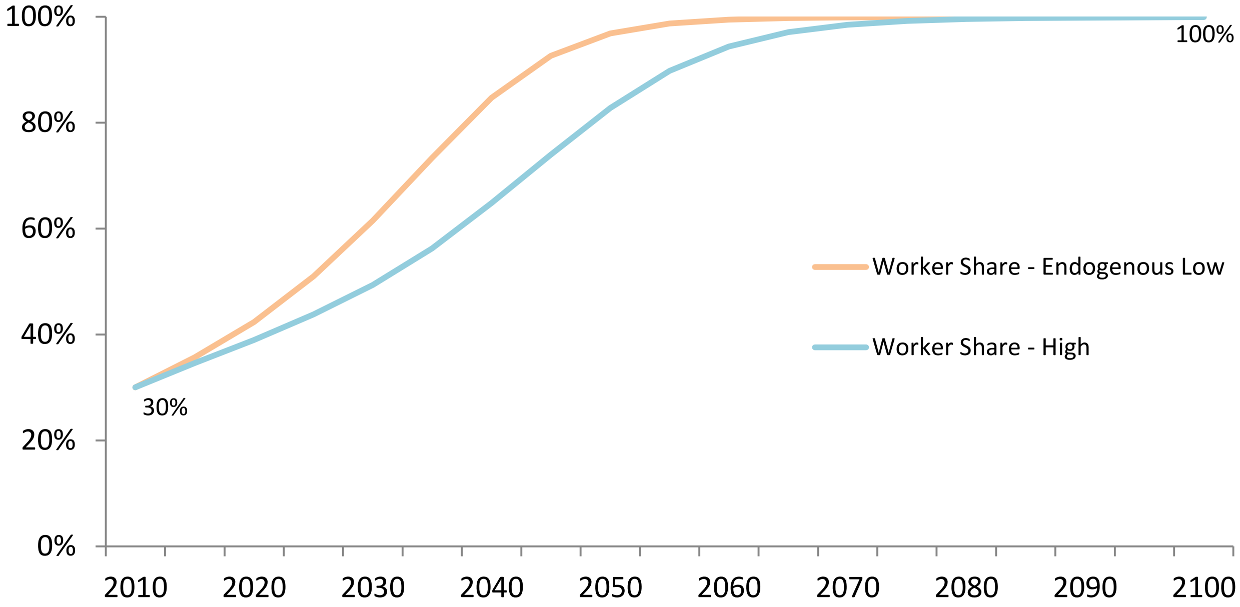


Figure 8: Modern sector capital per worker under high-fertility and endogenous low-fertility variant scenarios, Nigeria

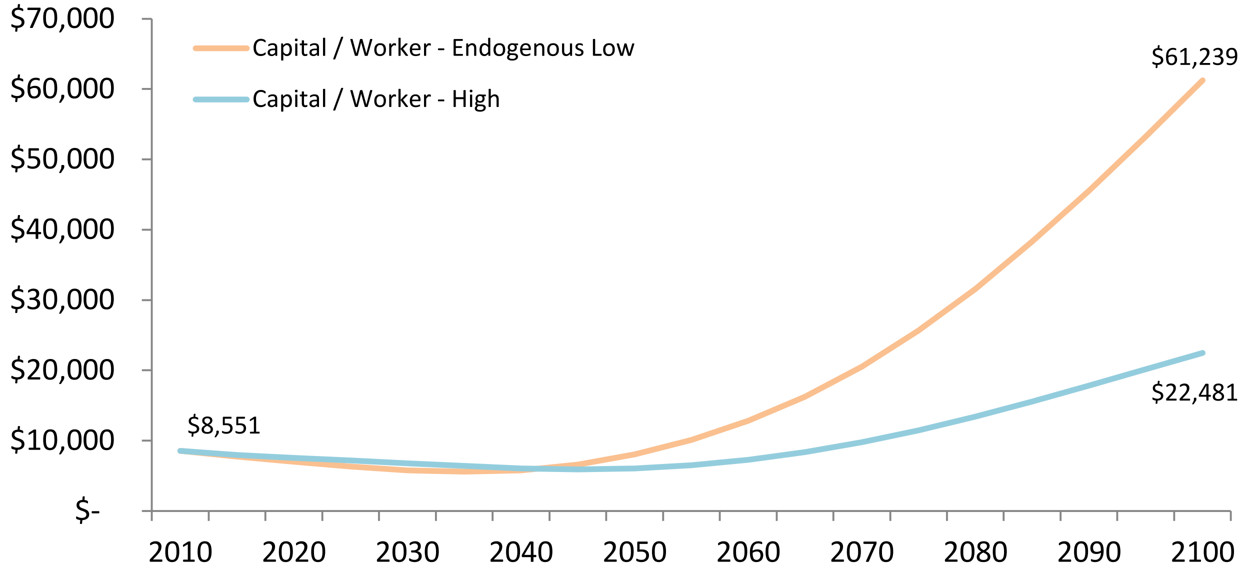


Figure 9: Proportion of Population of working age under high-fertility and endogenous low-fertility variant scenarios, Nigeria

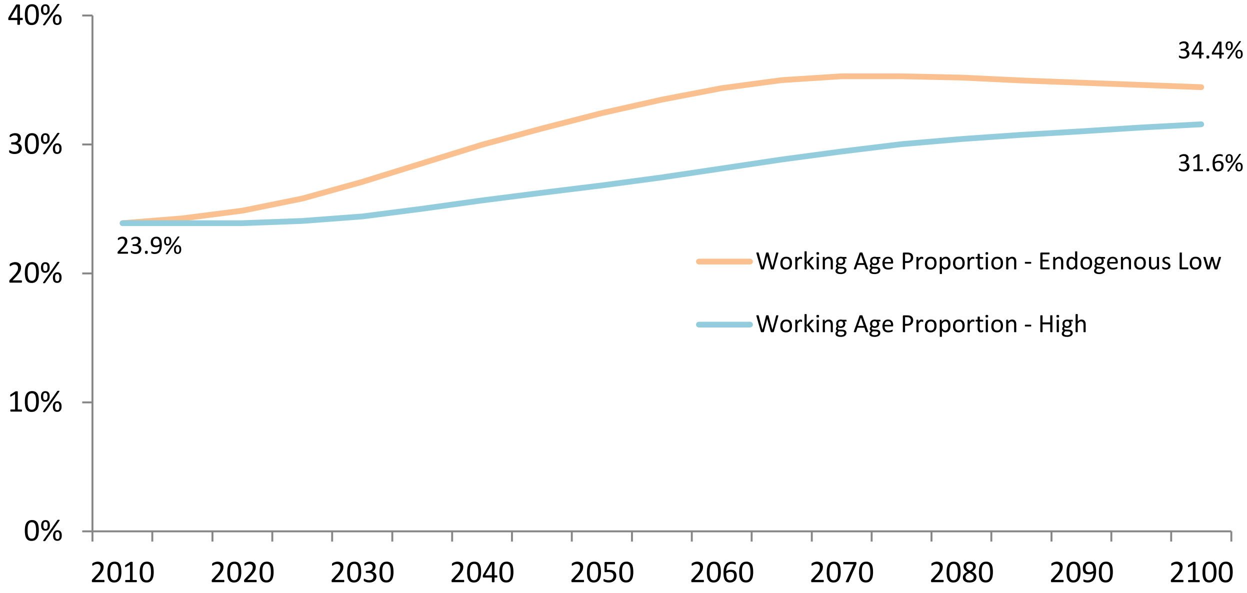


Figure 10: Average years of schooling of the workforce under the high-fertility and endogenous low-fertility variant scenarios, Nigeria

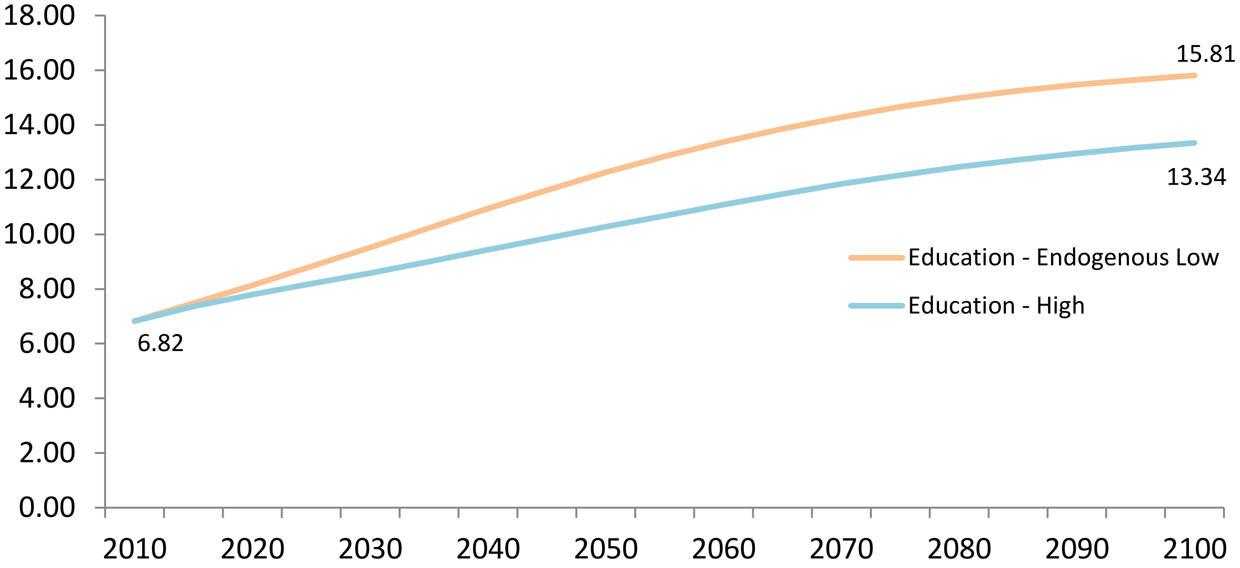


Figure 11: Average height of the workforce (in cm) under the high-fertility and endogenous low-fertility variant scenarios, Nigeria

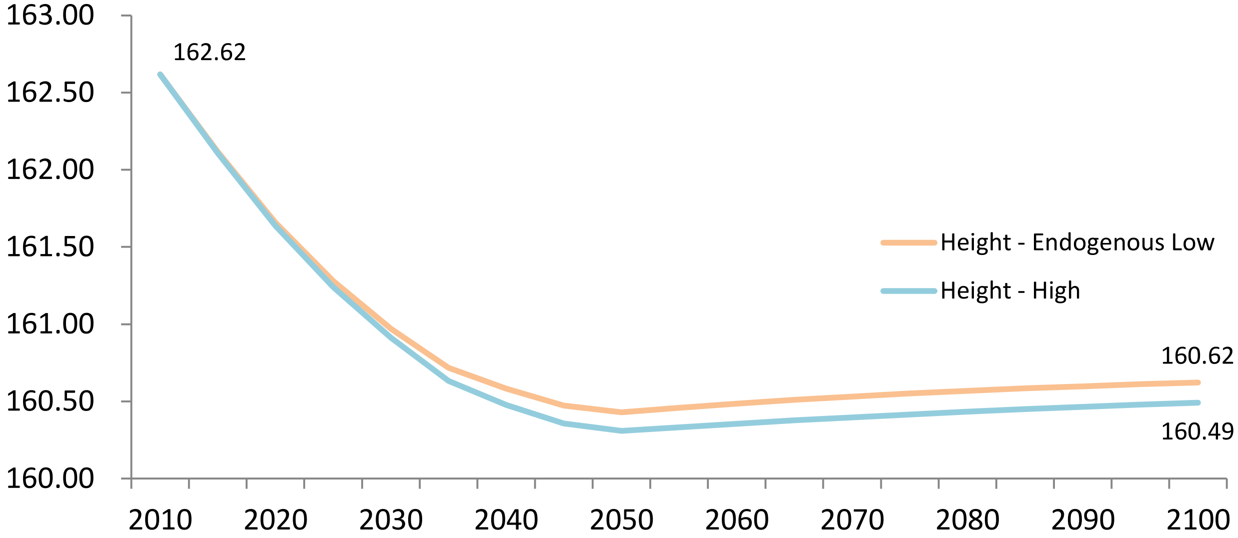


Figure 12: Female labor force participation rate under the high- and endogenous low-variant scenarios, Nigeria

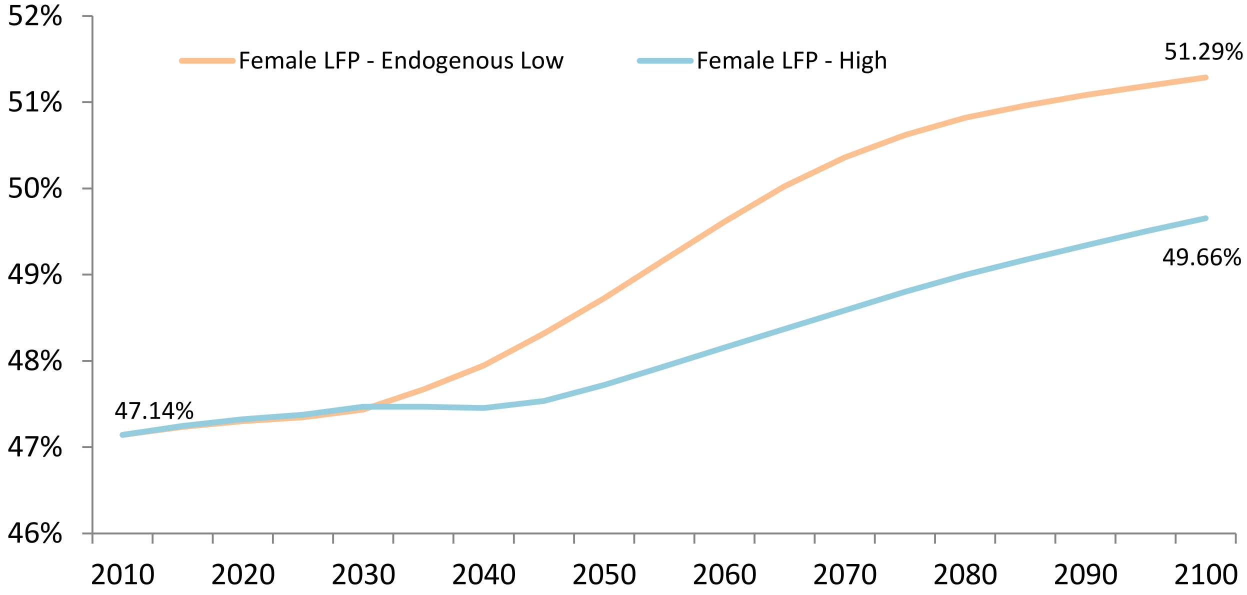


Figure 13: Comparison of income per capita scenarios across models, Nigeria

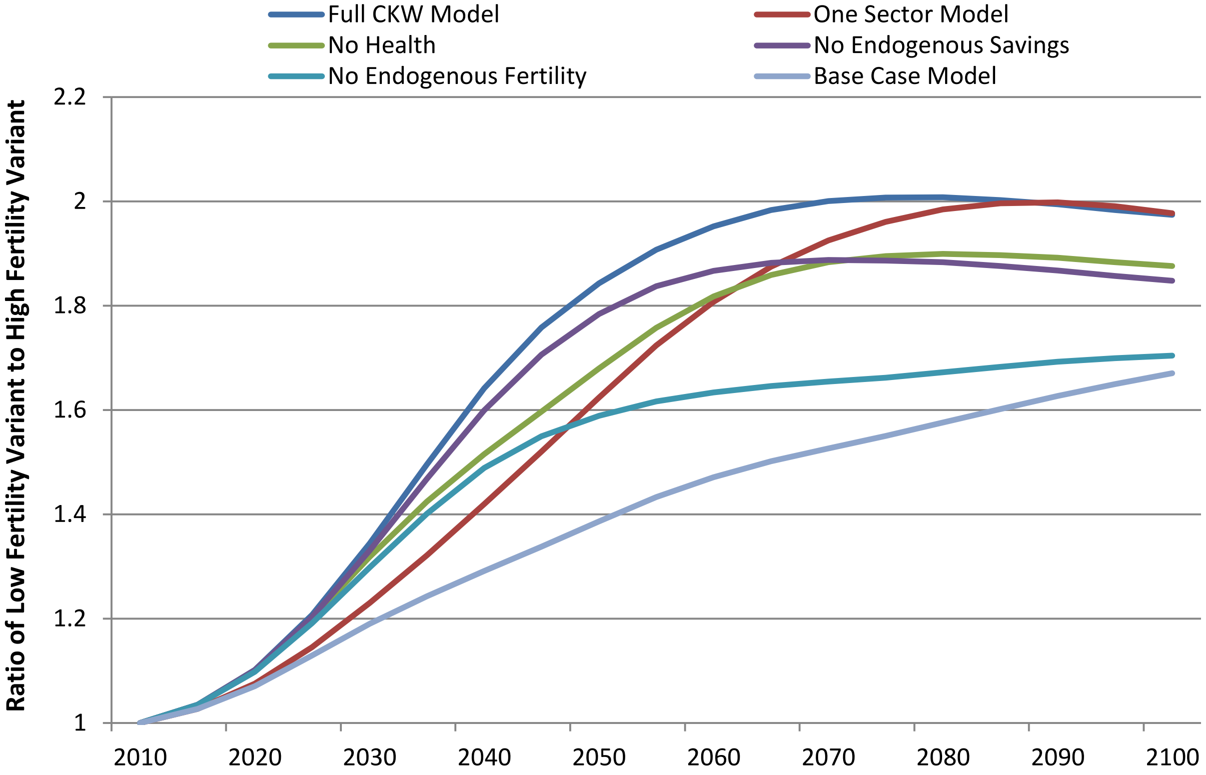
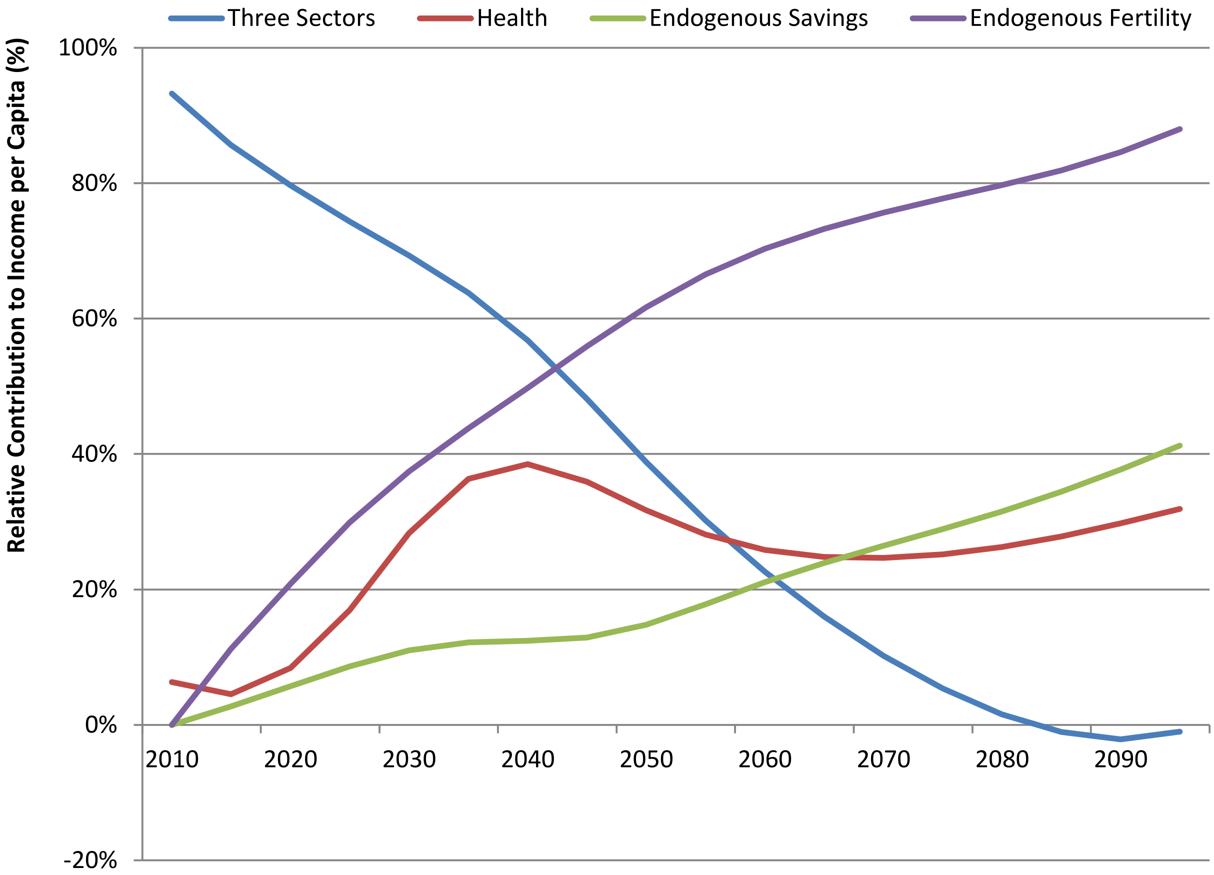


Figure 14: Decomposition of the gain in income per capita relative to the base case model by mechanism, Nigeria



2.11. Supplemental Material

2.11.1. Appendix 1: The Model

Population

We take a baseline age structure together with age-specific mortality and fertility rates to project the population over time. We divide population is divided into 21 age groups indexed from $i = 0,1, \ldots ,20$, with each group covering a 5-year age interval for populations aged 0-104 years of age and each time period t in our model corresponding to five years. The population at time t in age group i, $Pop_{i,t}$ for $i \geq 1$ is given by

$$Pop_{i,t} = (1 - d_{i,t})Pop_{i-1,t-1}$$

where $d_{i,t}$ refers to the mortality rate for age group i in period t and $(1 - d_{i,t})$ is the proportion of the cohort surviving into the next age group in in the next period. We assume that $d_{20,t} = 0$ so that no one survives to age 105. The population in age group 0, i.e. those who are between age 0 to 4 years of age, is given by the age group specific fertility rate in the period multiplied by the size of the that age group of female population, $Popf_{i,t}$, for women of reproductive age (ages 15 to 49). We also allow for infant and child mortality to be given by $d_{0,t}$, which is the proportion of births not surviving to be measured in the 0 to 4 year age cohort.

$$Pop_{0,t} = (1 - d_{0,t}) \sum_{i=3}^{9} f_{i,t}\, Popf_{i,t}$$

We follow the age structure of the female and male population separately from the initial year but assume that in future birth and death rates are the same for each sex.

We adopt the UNPP projections on mortality rates over time for each fertility scenario, which implies that age group specific mortality rates in each future five-year period are assumed to be fixed across each of the two fertility scenarios, but are not fixed over time, throughout our analysis. Each age group specific mortality rate is calculated as the implicit age group-by-year mortality rate from the medium fertility variant projection the United Nations World Population Prospects 2012. For example, the implicit death rate in age group 0 for both the baseline and alternative fertility scenarios is given by the population aged 0 to 4 divided by the number of births in the 5 year period under the medium variant fertility scenario.

On the other hand, we deviate from the UNPP methodology in our calculations of fertility across each scenario and over time. In contrast to previous simulation approaches, we endogenize the evolution of fertility over time by introducing a feedback mechanism from female education to fertility in a log-linear form as follows:

$$\log f_{i,t} = \log\left(f_{i,t}^{*} - \lambda_{i,t}\right) + \psi\left(EF_{i,t} - EF_{i,t}^{*}\right)$$

where $f_{i,t}^{*}$ is the fertility of age group i at time t forecasted by the United Nations Population Projection's high variant fertility scenario, $\lambda_{i,t}$ is the estimated age-specific fertility given the effect of the exogenous reduction in fertility (in our case, a family planning intervention) from the baseline high fertility scenario to the alternative low fertility scenario, $EF_{i,t}^{*}$ is the level of female education, measured by years of schooling, in the baseline high variant fertility scenario, and $EF_{i,t}$ is the level of female education that results given the deviation in fertility from the baseline high variant fertility scenario to fertility under the alternative low fertility variant scenario. The parameter ψ, which we expect to be negative, intends to capture the direct effect of increased female education on fertility. When considering how to measure educational attainment, we choose to use years of schooling as a proxy because it is tractable enough to be estimated using cross-country data and is widely accepted as a standard metric in academic and policy spheres, which in turn allows us to compare our estimates against existing evidence. Nevertheless, we recognize that our choice is limited to the extent that years of schooling may not reflect other key dimensions that determine educational attainment, including education quality, types of educational attainment (vocational training, apprenticeships, etc.), among others. Further refinements to our measure is planned for future work as additional data on these other factors are collected from low- and middle-income countries.

Labor Supply

We assume that children may enter the labor force at 20 and workers leave the labor force at 65. Our rationale for restricting our definition of the working age population to this age range is rooted in evidence from the national transfer accounts literature, which find that over 90 percent of lifetime earnings is accumulated in this age range in both developing and developed economies; moreover, labor income is low for children and young adults under 20, particularly in African economies due to poor employment opportunities, and the share of lifetime earnings at old ages is, at best, modest (Lee and Mason 2011). For each sex, we calculate the total labor supply contribution at time t as a function of the labor force participation rate at each age group i and time period t, $partm_{i,t}$ for males and $partf_{i,t}$ for females, and the size of the sex-specific population of age i at time t. Total male and female labor supply at time t, LSM_t and LSF_t, respectively, and total labor force LS_t are determined by

$$LSM_t = \sum_{i=4}^{12} partm_{i,t} Popm_{i,t} \qquad LSF_t = \sum_{i=4}^{12} partf_{i,t} Popf_{i,t} \qquad LS_t = LSM_t + LSF_t$$

where $Popm_{i,t}$ and $Popf_{i,t}$ are the projected male and female populations, respectively, in age group i at time t. We assume age specific male participation rates are constant over time and are fixed at their baseline level, $partm_{i,t} = partm_{i,0}$. We then modify the age-specific female labor force participation rate at t to reflect the effect of a decrease in total female labor supply due to increases in time devoted to childrearing, namely

$$partf_{i,t} = partf_{i,0} + \pi(f_{i,0} - f_{i,t})$$

where $partf_{i,0}$ is the baseline female labor force participation rate for age group i, π measures the effect of fertility on female labor supply, and $(f_{i,0} - f_{i,t})$ captures the difference between the age-specific fertility rate for cohort i at time t and the fertility rate of the group in the first five-year interval. Through this equation, we can predict the increase in female labor force participation rates as age-specific fertility rates decline (i.e. as the difference between baseline age-specific fertility rate $f_{i,0}$ and $f_{i,t}$ grows larger and becomes increasingly more positive). In our specification, we assume that there is no selection into labor force participation by either education or health – the human capital of each worker in age cohort is assumed to be equal to the average human capital of the cohort.

Our prediction is that while fertility inversely varies with female labor supply in most developed country settings, the same relationship is found to not be true in the Sub-Saharan African context, where household composition and the division of labor and childcare responsibilities among household members imply that the effect of fertility on female labor supply may be small or even positive (Westeneng and D'Exelle 2011). Moreover, women in Sub-Saharan Africa tend to be strongly attached to the labor market, working less during pregnancies but returning to the labor market right after giving birth. Because many women in Sub-Saharan Africa are either self-employed or work in the informal sector, mothers can and often do bring their young children to work with them. Hence, female labor force participation in these settings is already high, even during women's reproductive years, and women contribute to the labor force, though mostly through working in the informal sector and for low wages.

Education

We assume that a given sex specific cohort's educational attainment (quantified in average years of schooling per individual) is entirely amassed before age 20, after which the average level of schooling for that cohort is held constant for the remainder of that cohort's lifetime.[6] Letting $EM_{i,t}$ be the education of the male cohort and $EF_{i,t}$ be the education of the female cohort of age group i at time t, we have

$$EM_{i,t} = EM_{i-1,t-1} \text{ for } i \geq 5$$

$$EF_{i,t} = EF_{i-1,t-1} \text{ for } i \geq 5$$

We also expect that lower fertility will raise the average level of schooling. Models of the fertility transition stress the movement of households along a "quality-quantity" frontier in which investment per child in health and education rises as the number of children falls (Becker and Lewis 1973; Becker 1981; Lam 2003). We assume that the cohort's average years of schooling amassed by age 20, denoted $EM_{4,t}$ for male cohorts and $EF_{4,t}$ for female cohorts, is given by:

$$EM_{4,t} = EM^*_{4,t}[1 + \theta_E(TFR_{t-4} - TFR^*_{t-4})]$$

$$EF_{4,t} = EF^*_{4,t}[1 + \theta_E(TFR_{t-4} - TFR^*_{t-4})]$$

where $EM^*_{4,t}$ and $EF^*_{4,t}$ are exogenous measures of the average number of years of schooling acquired by each cohort in the baseline scenario, TFR_t is the total fertility rate at time t calculated from the age specific fertility rates of women of reproductive age in that time period, and TFR^*_t is the total fertility rate at t under the baseline scenario. The equations are specified using local linear approximations of the fertility-education relationship around each cohort's average number of years of schooling in the

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[6] In assuming that the stock of schooling remains constant after it is accumulated by age 20, we neglect to adjust for factors that reflect the depreciation of educational attainment over time. These factors, which are also likely to be associated with determinants of education quality, would certainly enrich the scope of analysis but are excluded because they, like educational quality, are difficult to estimate over time and across countries.

baseline scenario, $EM^*_{4,t}$ and $EF^*_{4,t}$. The parameter θ_E, which is assumed to be positive, captures the effect of fertility on children's education and is weighted by the cohort's baseline measure of schooling $EM^*_{4,t}$ and $EF^*_{4,t}$ such that a higher cohort baseline level of schooling lead to larger marginal gains to education from changes in fertility.

In our simulation model, we calculate average years of schooling at time t separately for each sex as a weighted sum of the average years of schooling of each cohort, using

$$EM_t = \sum_{i=4}^{12} \left[\frac{partm_{i,t} \cdot Popm_{i,t}}{\sum_{i=4}^{12} \left(partm_{i,0} \cdot Popm_{i,t} \right)} \right] EM_{i,t}$$

$$EF_t = \sum_{i=4}^{12} \left[\frac{partf_{i,t} \cdot Popf_{i,t}}{\sum_{i=4}^{12} \left(partf_{i,t} \cdot Popf_{i,t} \right)} \right] EF_{i,t}$$

and then combine the sex-specific estimates in a weighted average to estimate the average years of schooling for the entire workforce at time t

$$E_t = \frac{EM_t LSM_t + EF_t LSF_t}{LS_t}$$

Health

Our treatment of health parallels our model assumptions on educational attainment and schooling in the previous section. We proxy cohort health by cohort average adult height. Adult height has been found to be sensitive to childhood health and nutrition and is linked in turn to adult worker productivity (Schultz 2002). We assume that a given cohort's average height is attained by age 20, after which the average height for that cohort is held constant. We expect lower fertility to be reflected in additional investments that households with fewer children are able to make to improve child health and nutrition, which in turn reduce stunting and positively contribute to growth and development into adulthood.

To estimate the effects of fertility on a given cohort's height at time t, we assume that the cohort's average height amassed by age 20, denoted $HM_{4,t}$ for male cohorts and $HF_{4,t}$ for female cohorts, is given by:

$$HM_{4,t} = HM^*_{4,t}[1 + \theta_H(TFR_{t-4} - TFR^*_{t-4})]$$

$$HF_{4,t} = HF^*_{4,t}[1 + \theta_H(TFR_{t-4} - TFR^*_{t-4})]$$

where $HM^*_{4,t}$ and $HF^*_{4,t}$ are exogenous measures of the average height of each cohort in the baseline scenario, and θ_H is an exogenous constant that captures the direct effect of fertility on adult height. These equations mirror the equations that have been used to describe the relationship between fertility and education.

As was the case with our education estimates, we assume that the average height past age 20 for a given cohort i, $H_{i,t}$, remain constant. In particular:

$$HM_{i,t} = HM_{i-1,t-1} \text{ for } i \geq 5$$

$$HF_{i,t} = HF_{i-1,t-1} \text{ for } i \geq 5$$

Similarly, we calculate average height separately for each sex, namely

$$HM_t \;= \sum_{i=4}^{12} \left[\frac{partm_{i,t} \cdot Popm_{i,t}}{\sum_{i=4}^{12}\left(partm_{i,0} \cdot Popm_{i,t}\right)} \right] HM_{i,t}$$

$$HF_t \;= \sum_{i=4}^{12} \left[\frac{partf_{i,t} \cdot Popf_{i,t}}{\sum_{i=4}^{12}\left(partf_{i,t} \cdot Popf_{i,t}\right)} \right] HF_{i,t}$$

and then combine the sex-specific estimates in a weighted average to estimate the average height of the workforce at time t

$$H_t = \frac{HM_t LSM_t + HF_t LSF_t}{LS_t}$$

Production

We consider a Lewis development economy with three sectors, a modern sector, a traditional sector, which share the total labor supply across sectors to produce distinct commodities, and a raw materials sector. Aggregate production in the modern sector at time t is given by a standard Cobb-Douglas production function, with physical capital K_t, labor allocated to the modern sector LM_t, average years of schooling in the workforce (as a proxy for education) E_t, and average height of the workforce (as a proxy for health) H_t as factor inputs such that aggregate output in the modern sector at t, YM_t, is given by

$$YM_t = AM_t K_t^{\alpha} LM_t^{1-\alpha} e^{\gamma E_t + \lambda H_t}$$

where AM_t is the total factor productivity of the modern sector at t. Estimates for schooling E_t and health H_t are fed into the economic model from our demographic simulations as described in the previous section.

In a similar fashion, aggregate production in the traditional sector at t is also modeled by a Cobb-Douglas production function, with available land X and labor allocated to the traditional sector LA_t as factor inputs such that aggregate output from the traditional sector at t, YA_t, is given by

$$YA_t = AA_t X^{\beta} LA_t^{1-\beta}$$

where AA_t is the total factor productivity of the traditional sector at t.

Capital Accumulation and Savings

In our model, we extend the standard Solow framework for capital accumulation by assuming that capital stock in the period $t+1$, K_{t+1}, evolves over time according to the equation

$$K_{t+1} = s_t Y_t + (1-\delta) K_t$$

where s_t is the savings rate at time t and δ is the rate of depreciation of capital that is assigned a standard value of 7 percent (Schmitt-Grohe and Uribe 2006). We depart from the simplifying assumption of a constant savings rate and follow Bloom, Canning, Mansfield, et al. (2007), in which the evolution of the savings rate is defined by

$$s_t = \frac{S_t}{Y_t} = \phi_0 + \phi_1 s_{t-1} + \phi_2 w_t + \phi_3 w_t^2 + \phi_4 \frac{Old_t}{WA_t}$$

Here, $s_{t-1} = \frac{S_{t-1}}{Y_{t-1}}$ is the savings rate in the previous time period $t-1$, w_t is the annual aggregate wage at time t, which is defined as a fixed proportion of per-capita income in the same period (i.e. $w_t = (1-a)y_t$ for some fixed a), and $\frac{Old_t}{WA_t}$ captures the old-age dependency ratio, the ratio of old-age dependents to the working age population, at t. We assume that savings begins in a steady state equilibrium in 2010, that generates the observed capital stock, and we calibrate the constant term ϕ_0 to fit the baseline steady state savings, wage, and dependency ratio conditions. Further details on the derivation and interpretation of the savings equation can be found in Appendix 2.

Labor Allocation across Sectors

Our model specification requires that modern sector and traditional sector wages, which endogenously adjust within their respective labor markets, will in turn determine equilibrium labor supply allocations across the two sectors that employ workers. Total labor supply L_t is shared across the modern and traditional sectors such that

$$L_t = LM_t + LA_t$$

The wage per worker in the modern sector at time t, wM_t, is set to be equal to the marginal product of labor in the modern sector for an additional worker with average levels of education and health, or in log terms

$$\log wM_t = \log\left[(1-\alpha)\frac{YM_t}{LM_t}\right]$$

In contrast, we assume that the traditional sector is less developed and is more labor intensive with little to no capital endowment, thereby resulting in the wage per worker in the traditional sector at time t, wA_t, being determined by the average product, or in log terms:

$$\log wA_t = \log \frac{YA_t}{LA_t}$$

Since the wage in the traditional sector is determined at the average and not on the margin, in equilibrium there will be too many workers in the traditional sector. In addition, there may be migration costs or other barriers to entry into modern sector jobs, which are parametrized by the term b, that will contribute to an inefficient allocation of labor across sectors. In equilibrium, workers will migrate between sectors and wages will adjust such that

$$\log wM_t - \log b = \log wA_t$$

Here, b is a constant that is set so as to explain any baseline differential in sector wages and is then held constant over time. If we replace modern sector and traditional sector wages with their respective wage-output equilibrium conditions and substitute modern sector and traditional sector output with their respective production functions, we obtain:

$$Z_t LM_t^{-\alpha} = (L_t - LM_t)^{-\beta}$$

where

$$Z_t = \frac{(1-\alpha) \cdot AM_t K_t^{\alpha} e^{\gamma E_t + \lambda\, H_t}}{b \cdot AA_t X^{\beta}}$$

For $\alpha = \frac{1}{3}$ and $\beta = \frac{1}{6}$, we can explicitly solve for LM_t as

$$LM_t = \frac{1}{2}\left(Z_t^3 \sqrt{Z_t^6 + 4L_t} - Z_t^6 \right)$$

We can verify that $0 \leq LM_t \leq L_t$, and we calibrate the value of b so that initial labor stock in the modern sector, LM_t, matches the data. We then fix b to that value in all subsequent simulations.

2.11.2. Appendix 2: The Savings Equation

In modeling the evolution of savings, we follow the example of Bloom, Canning, Mansfield, et al. (2007) in which we consider cohort-specific savings decisions over time and aggregate across cohorts to find national savings. In the Bloom et al. (2007) savings model, the authors allow for both retirement decisions and savings decisions to depend on life expectancy, in which they argue that longer life spans lead to longer periods of retirement and increased pre-retirement savings. To derive the savings relationship, the authors first jointly solve for individuals' optimal lifetime labor supply, consumption, and savings, which are functions of life expectancy, using a lifetime utility maximization problem and derive the aggregate savings relationship (Equation 30) as follows:

$$s_t = \frac{S_t}{Y_t} = h(z, \sigma, w_t, R^*) + \frac{\sigma}{BR} - \frac{Old_t}{WA_t} + \eta \frac{Young_t}{WA_t} + \log\left(\frac{LF_t}{WA_t}\right) + \log(1-\alpha)$$

where z is life expectancy, σ is the growth rate of wages, w_t is the wage rate at time t, R^* is a mandatory retirement age constraint (usually 65), BR is the birth rate, $\frac{Old_t}{WA_t}$ captures the old-age dependency rate at t, $\frac{LF_t}{WA_t}$ captures the labor force participation rate at t, and α is the capital share of output.

To estimate the equation above, the authors test for potential non-linear effects of life expectancy, wages, and wage growth rate on savings behavior by performing a second-order Taylor series expansion on the h function around these three variables and including first-level interaction terms in h. They also include a lagged savings rate term to adjust for dynamic dependency in the time path of savings. The parameters of this saturated equation are then estimated in a dynamic fixed effects panel model using data for a panel of countries from 1960 to 2000 and a specification that is robust to country fixed effects and that allows for a dynamic evolution of aggregate savings as it adjusts towards its steady state (Table 4, Column 3). After removing insignificant variables sequentially, the authors arrive at the final regression specification below (Table 4, Column 4), which we use as our main savings equation:

$$s_t = \phi_0 + \phi_1 s_{t-1} + \phi_2 w_t + \phi_3 w_t^2 + \phi_4 \frac{Old_t}{WA_t}$$

To parameterize the coefficients ϕ_1 to ϕ_4 in this specification, we use estimates from the full model in Table 4, Column 3, and we then calibrate the estimate for ϕ_0 to be the value that achieves a steady state rate of savings under the baseline conditions for savings, wages, and the age dependency ratio, i.e. ϕ_0 is fit under $s_t = s_{t-1} = s^*$, the steady state savings rate, for the given s_0, w_0, and $\frac{Old_0}{WA_0}$.

Table A1: Parameter Calibration

Parameter Symbol	Value	Description	Source(s)
π	0.02	Effect of fertility on female labor supply	Ashraf et al. (2013)
θ_E	0.2	Effect of fertility on childhood education	Joshi and Schultz (2007); Rosenzweig and Wolpin (1980)
ψ	-0.15	Effect of women's education on fertility	Osili and Long (2008)
θ_H	-0.00067	Effect of fertility on adult height	Giroux (2008); Joshi and Schultz (2013); Kravdal and Kodzi (2011); Stevens et al. (2012); Victora et al. (2008)
α	0.33	Capital share of output in modern sector	Hall and Jones (1999)
β	0.167	Land share of output in traditional sector	Kawagoe et al. (1985); Williamson (1998, 2002)
γ	0.1	Economic returns to schooling	Banerjee and Duflo (2005); Oyelere (2010); Psacharopoulos (1994); Psacharopoulos and Patrinos (2004)
λ	0.08	Effect of health on output	Schultz (2002, 2005)
δ	0.07	Depreciation rate of capital	Schmitt-Grohe and Uribe (2006)
ϕ_1	0.758	Effect of lagged savings on current savings	Bloom et al. (2007)
ϕ_2	0.133	Effect of wage rate on savings rate	Bloom et al. (2007)
ϕ_3	-0.006	Effect of squared wage rate on savings rate	Bloom et al. (2007)
ϕ_4	-0.209	Effect of ratio of old to working age population on savings rate	Bloom et al. (2007)

Table A2: Data Sources

Data Type	Source(s)
Baseline population by age and sex, 2010	UN World Population Prospects (United Nations 2010)
Baseline age-specific fertility rates, 2010-2100	UN World Population Prospects (United Nations 2010)
Years of education by 5 year age-sex groups, 2010	2008 Nigeria DHS (National Population Commission (NPC) [Nigeria] and ICF Macro 2009)
Adult height by 5 year age-sex groups, 2010	2008 Nigeria DHS (National Population Commission (NPC) [Nigeria] and ICF Macro 2009)
Labor force participation by 5 year age-sex groups, 2010	ILO (International Labour Office (ILO) 2013)
Output, 2005	Penn World Tables (Feenstra et al. 2015)
Output, 2010	Penn World Tables (Feenstra et al. 2015)
Oil Output, 2010	Penn World Tables (Feenstra et al. 2015)
Capital stock, 2010	Penn World Tables (Feenstra et al. 2015)
Agricultural land, 2010	WDI (World Bank 2012)
Proportion of GDP between modern and traditional sectors, 2010	WDI (World Bank 2012)
Proportion of labor between modern and traditional sectors, 2010	WDI (World Bank 2012)

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3. Height among Healthy Children in Low- and Middle-Income Countries: An Assessment

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3.1. Abstract

Background

In spite of rapid economic development and reductions in child mortality worldwide, continued high rates of early childhood stunting have put the global applicability of international child height standards into question.

Objective

We use population-based survey data to identify children growing up in healthy environments in low- and middle-income countries (LMICs) and compare the height distribution of these children to the height distribution of the reference sample established by the World Health Organization (WHO).

Design

Height data was extracted from 169 Demographic and Health Surveys (DHS) collected across 63 countries between 1990 and 2014. Children were classified as having grown up in ideal environments if they: 1) had access to safe water and sanitation (WASH); 2) lived in households with finished floors, a TV, and a car; 3) were born to highly educated mothers; 4) were a single birth; and 5) were delivered in hospitals. We compared the heights of children in ideal environments to the WHO reference sample, and we estimated the relative contributions of our five selected "ideal environment" criteria to current height-for-age z-score (HAZ) differentials observed in the pooled DHS sample.

Results

A total of 878,249 height records were extracted, and 1,006 children (0.1%) were classified as having been raised in an ideal home environment. The mean HAZ in this sample was not statistically different from zero (95% CI [-0.039, 0.125]), the HAZ standard deviation for this sample was estimated to be 1.3, and 5.3 percent of children in this sample were classified as stunted (HAZ < -2). Similar means, standard deviations, and stunting rates were found when less restrictive definitions of ideal environments were used. Low maternal education and household poverty were the largest contributors to the HAZ deficits observed in pooled and country-specific analyses.

Conclusions

The large current gaps in children's heights relative to the reference sample are likely not due to innate or genetic differences between children, but rather reflect children's continued exposure to poverty, lack of maternal education, and lack of access to WASH across populations.

3.2. Keywords

Child stunting; height-for-age; height distributions; World Health Organization; international growth standards; low- and middle-income countries; Demographic and Health Surveys

3.3. Introduction

In 2010, more than 167 million children (25.6 percent) aged 5 and under in low- and middle-income countries (LMICs) were estimated to be stunted (de Onis, Blössner, & Borghi, 2012). While substantial progress has been made towards reducing child mortality worldwide (Wang et al., 2014), progress on child height and stunting has been slow, particularly in South Asia and parts of sub-Saharan Africa. The continued high rates of stunting despite rapid improvements in child survival and economic development in many regions has led to a resurgence of concerns regarding the suitability of applying international child growth standards across all populations globally.

While the Multicentre Growth Reference Study (MGRS), which was conducted by the World Health Organization (WHO) to establish international child growth standards, made a significant effort to include children from all regions of the world, the extent to which the final MGRS sample may be representative of the global child population remains somewhat unclear. In particular, the final MGRS sample did not include any populations from East Asia (Cole, 2007), and even within those participating countries (Brazil, Norway, Oman, India, Ghana, and the United States), the representativeness of the children who were eventually selected is a continued source of debate. In order to assess growth trajectories among children who were not exposed to any major risk factors, the MGRS intentionally restricted sampling to women living in high-income areas with easy access to health services. In practice, this sampling strategy generally resulted in the selection of relatively homogeneous groups of mothers who lived in a small number of privileged urban neighborhoods of each country (de Onis et al., 2004); these mothers may not capture the full social, behavioral, and genetic diversity of their respective countries and may be even less likely to fully reflect global genetic and environmental variation (Cole, 2007; Goldstein & Tanner, 1980; Van Loon, Saverys, Vuylsteke, Vlietinck, & Eeckels, 1986).

Empirical evidence on the adequacy of global growth standards for different populations of children under 5 has been mixed (Cole, 2007). Studies from Hong Kong (Hui et al., 2008) and Saudi Arabia (Al-Shehri et al., 2006) have argued that local height patterns are not consistent with international standards. A recent systematic review of child growth concluded that global height and weight reference curves for children under 5 may not be justified for all subpopulations and that using WHO standards for head circumference would put many children at risk for misdiagnosis of macrocephaly or microcephaly (Natale & Rajagopalan, 2014). These findings are contrasted by a large body of evidence, including historical work and, more recently, comparative studies from Togo, Haiti, and Egypt (Graitcer & Gentry, 1981), which suggests that the WHO MGRS growth standards are indeed appropriate as a reference for healthy child development and that height and weight distributions can be inferred from well-to-do children (Habicht, Yarbrough, Martorell, Malina, & Klein, 1974).

In this study, we combine all available height data for children under the age of 5 in LMICs collected through the Demographic and Health Survey (DHS) program, and we compare the empirical height distribution of children living in ideal home environments in developing countries to the reference sample established by the MGRS.

3.4. Subjects and Methods

3.4.1. Study Design

This study used cross-sectional data from the DHS program to compare the height distribution of children growing up in safe environments in developing countries to the age- and gender-specific height distributions observed in the MGRS.

3.4.2. Data and Setting

The DHS are nationally-representative household surveys that provide information on a wide range of indicators in the areas of population, maternal and child health, and nutrition. More than 300 DHS surveys have been collected in over 90 countries since 1984. For the purposes of this study, we restricted the analysis to surveys with anthropometric data as well as complete data on key health intervention coverage indicators. A total of 1,115,198 anthropometric records for children under age 5 were available from the DHS program. We excluded child observations with missing information in the following covariates: the child's place of delivery; whether the child received a BCG or DPT-1 vaccination; the level of education of the child's mother; information on the quality of water and sanitation in the child's household; whether the child's household had access to a TV; whether the child's household had access to a car; and the type of flooring in the child's household. Table A1 and Figure A1 in the Supplemental Material section provide further details on sample selection as well as final sample composition.

3.4.3. Statistical Methods

We pooled all available anthropometric data on children aged 5 and younger from the DHS, and we used existing covariate data to identify children growing up in ideal home environments. Given that only limited biomedical information is available on children in the DHS, we primarily focused on social determinants of health outcomes when generating our classification of "ideal environments." Specifically, we defined a child to have grown up in an ideal home environment it the child was: 1) a single birth; 2) born to a mother with higher education; 3) living in a household with finished floors, a TV, and a car; 4) living in a household with access to safe water and sanitation; and 5) was delivered in a hospital and received both BCG and DPT-1 vaccinations.

As a first step, we compared children meeting these conditions to the general (pooled DHS) sample and then plotted the distribution of height-for-age z-score (HAZ score) among children living in ideal home environments against the standard normal distribution of the MGRS reference sample.

We then computed the HAZ score deficit that can be attributed to each of the five key factors used for defining an ideal home environment by first estimating a multiple linear regression of child HAZ scores on these factors together and then taking the product of the estimated factor coefficients, each of which captured the association between that particular factor and the child HAZ score, and the proportion of the pooled DHS sample that did not exhibit that factor.

3.4.4. Sensitivity Analysis

In order to illustrate the sensitivity of our results, we explored alternative definitions of ideal home environments, and compared means and standard deviations of the resulting HAZ distributions to the standard normal distribution observed in the MGRS. We also showed separate results for children below and above age 2 in order to address concerns surrounding the imprecise measurement of children's length at very young ages.

As an additional robustness check, we assessed whether differences in height distributions between children in the ideal group and children in the remaining non-ideal sample might be driven by underlying differences in maternal height across these two subsamples. To do so, we first overlaid the height distributions for mothers of children in the ideal home environment group and mothers of children in the non-ideal sample, and we then calculated the difference in means between these two groups by running a multiple linear regression of maternal height on a binary variable indicating whether or not the mother belonged to the ideal group. In this regression, the coefficient estimate on the binary variable described the adjusted mean difference between mothers of children belonging to the ideal group sample and mothers of children in the non-ideal sample with respect to maternal height. To examine the relationship between maternal height and child height in ideal home environments, we non-parametrically estimated the relationship between maternal height and child height for the ideal group subsample using a local polynomial smoothed regression. In estimating this regression, we adopted the Epanechnikov kernel density function for the weights and used the rule-of-thumb (ROT) method to determine the bandwidth.

For our analysis, all significance tests of means and linear estimations were conducted using multiple linear regressions that controlled for survey (country-year) fixed effects, and coefficient standard errors were clustered at the primary sampling unit (DHS cluster) level. All analyses were performed using Stata software, version 13 (StataCorp, College Station, TX).

3.5. Ethical Considerations

This study obtained a human subjects exemption from the institutional review board at Harvard University (protocol number IRB16-0515). Only de-identified data were obtained from DHS.

3.6. Results

A total of 878,249 child anthropometric records with complete covariate data were extracted from 169 DHS surveys conducted between 1990 and 2014 in 63 countries. A total of 1,006 children (0.1%) born to 824 mothers (mothers report on all children under 5 years of age) from 23 countries met all of the target criteria for having grown up in an ideal home environment. The list of countries that comprise the full DHS sample and the sample of children living in ideal environments are presented in Tables A2 and A3, respectively. Table 1 compares mother and household characteristics between children in ideal home environments and children not living in ideal home environments. No major differences were found with respect to age and sex when comparing children from non-ideal home environments in the pooled DHS sample to children in our ideal group. By construction, the children in our ideal group had better educated mothers and lived in substantially wealthier households. Children in our ideal group were also much more likely to live in urban areas and were much less likely to be born to a teenage mother. In Table A4, we compared average sample characteristics of children in our ideal group sample to the reference sample that was used to generate the WHO child growth standards. On average, mothers of children in our ideal group sample were slightly older and more educated, but were also slightly shorter, than mothers of children from the WHO reference sample. In general, children from our ideal group sample came from very similar households with similar socioeconomic characteristics when compared with children from the WHO reference sample.

Figure 1 shows the empirical distribution of HAZ scores of children living in ideal home environment relative to the distribution of HAZ scores in the WHO reference sample, which is, by construction, normally distributed with mean 0 and standard deviation 1. The overall distributions were relatively closely aligned, with a mean HAZ of 0.043 (95% CI [-0.039, 0.125]) in the ideal home environment group. Compared to the WHO reference sample, the empirical distribution of HAZ among children with ideal home environments appeared to be slightly more dispersed with a standard deviation of 1.33.

Figure 2 further highlights the differences in dispersion between the ideal group sample and the WHO reference sample by comparing the average HAZ in each percentile. While the average HAZ among children in the ideal group sample was very close to zero (0.03) at the 50th percentile, larger HAZ differentials for this sample were observed the bottom and top percentiles. In the ideal group sample, the average HAZ at the 3rd percentile was -2.6, and 5.3% of children in this sample had a HAZ score of less than -2 and would thus be classified as stunted. Similarly, the average HAZ at the 97th percentile of the ideal group sample was 2.5, with 5.3% of children having a HAZ score of greater than 2.

Figure 3 shows the results of our sensitivity analysis, in which we relaxed each of the specific target criteria that were used to select children from ideal home environments. When we removed the restriction on coverage of health services (namely receipt of skilled delivery at birth and receipt of vaccinations), the sample size increased to N = 1,296, with very little change in the mean (-0.009) and standard deviation (1.34) of the HAZ in the subsample. When we removed the restriction on water and sanitation (WASH), the sample size increased to N = 6,638, with a lower mean HAZ of -0.25 and a standard deviation of 1.44. Finally, removal of the asset and education restrictions resulted in sample sizes of N = 2,572 and N = 2,132, with means of -0.07 and -0.10 and standard deviations of 1.24 and 1.33, respectively.

In Figure A2, we present estimated densities stratified by children's age. The mean HAZ score was 0.088, with a standard deviation of 1.44, for children under age 2; for children between 24 and 59 months of age, the mean HAZ score was 0.017, with a standard deviation of 1.26.

Figure 4A compares the height distribution of mothers of children in the ideal group with the height distribution of mothers of children from non-ideal settings. On average, mothers of children in the ideal group were 3.28 cm ($\beta = 3.28;\ 95\%\ CI\ [2.68, 3.88]$) taller than mothers of children who were not from ideal home environments. Moreover, 6.1 percent of mothers in the ideal home environment sample were shorter than 150 cm, while the same was true for 17.7 percent of mothers in the non-ideal home environment sample. Figure 4B presents the empirical association between maternal height and child HAZ scores among mothers and children from the ideal group subsample. We found that the overall relationship was linear in the 145 cm to 180 cm range, with larger declines for very short (less than 145 cm) mothers. Moreover, the average child HAZ score increased from a level of about one standard deviation below the mean for children born to mothers who were around 145 cm to an average child HAZ score of one standard deviation above the mean for children born to mothers who were around 175 cm. These findings suggest a child HAZ score differential of approximately 0.067 standard deviations per cm of maternal height.

Table A5 presents results from our multivariable regression model as well as calculations of the contribution to the overall HAZ score deficit for each of our target criteria. The average HAZ among children not exposed to any of the five target criteria was -2.2 [-2.19, -2.13]. Large and highly statistically significant associations with HAZ were found for all five target criteria, and the largest associations were found for being a single birth ($\beta = 0.597, 95\%\ CI\ [0.568, 0.625]$), followed by being born to a mother with higher education ($\beta = 0.537, 95\%\ CI\ [0.521, 0.554]$). When assessing the overall contribution of each criterion to the total HAZ score deficit, we estimated that high maternal education accounted for about one quarter of the pooled HAZ score deficit, while hospital delivery, which served as our proxy for health service coverage, accounted for about 13 percent of the deficit. Household wealth and socioeconomic status accounted for about 19 percent of the total HAZ deficit, and access to water and sanitation accounted of about 14 percent of the deficit. The contribution of being a multiple birth to the deficit was small due to the low prevalence of the risk factor.

In Table A6, we present the relative contribution of each target criterion by country and found similar results to those presented in the pooled analysis. In particular, we found that for most countries, a lack of maternal education and exposure to household poverty were the principal factors that contributed to the large HAZ deficits that were observed.

3.7. Discussion

The results presented in this study indicate that the global reference curves that are currently used to track and assess children's height effectively describe the empirical distribution of height once sampling is restricted to children who live in presumably well-off environments. Our results suggest that the average HAZ score among children who grow up in well-off home environments in developing countries today is very close to zero, with a mean and median height very close to the reference values that were developed in the MGRS study. Compared to the WHO reference sample, the distribution of heights appears slightly more dispersed in the ideal home environment sample, with an estimated standard deviation of 1.3, and slightly more than 5 percent of children in our ideal environment sample either have a HAZ score of less than -2 or a HAZ score of greater than 2. The slightly thicker tails of the distribution could, in theory, be created by the more diverse genetic and environmental mix in our ideal environment sample; however, it is also possible that the observed height measures vary more due to the likely larger variation in survey and measurement quality in the DHS compared to the original MGRS (Assaf, Kothari, & Pullam, 2015).

The main advantage of our analytic approach is that the large DHS sample allows us to directly work with a representative sample of children rather than focusing on specific, locally identified privileged subpopulations. While the resulting sub-sample of interest, the "ideal group" sample, is very small compared to the larger DHS sample (about 0.1% of the entire DHS sample), it can easily be compared to more general populations and enables us to make direct inferences on key risk factors that we believe are driving the large observed gaps in current HAZ outcomes.

The presented study has several limitations. First, and most importantly, one might argue that the identified "ideal group" sample may not be an ideal normative or clinical benchmark for the wider population. The most obvious theoretical concern surrounding such non-representative sampling is the existence of underlying genetic variations in height, where it may be possible that privileged mothers globally are taller on average, although it is not obvious why this should be the case. All of the evidence that is presented in this study suggests that there is a height gap between our reference sample and the more general population; however, this height gap is almost certainly not just reflecting differences in genetic composition but is also, to an arguably large degree, attributable to differential exposure to poverty and malnutrition in childhood and adolescence. Even if one would take the 3.28 cm average difference in maternal height between mothers in our ideal group and mothers from non-ideal home environments as an estimate of the true underlying genetic difference, this observed difference would only be able to explain less than a quarter of a standard deviation of the global HAZ score deficit.

A second limitation of the study is that all of the empirical estimates presented are based on cross-sectional data, and although we include survey (country-year) fixed effects in our regressions, we cannot completely account for potential global and country-level trends in child height over time. In choosing a limited number of risk factors for our analysis, we may also have missed other key risk factors that could significantly explain the global child height deficit. The associations that we estimate between risk factors and average HAZ presented may therefore be confounded by these other factors that are not included in our model, and the attributed HAZ deficits thus overstate the true causal effects of the factors analyzed. Finally, we acknowledge that although our choice of child height as a proxy for accumulated health stock and early-life environment has been commonly used in the literature (Fogel, 1986; Martorell & Habicht, 1986; Steckel, 1995), there are other metrics that may also be appropriate for assessing child growth and development, including weight-for-age, head circumference, and upper arm circumference, among others.

Proponents of global growth standards have long emphasized that differences in children's heights during the first five years of life are primarily influenced by nutrition, feeding practices, environment, and receipt of healthcare rather than by genetic or ethnic factors and have cited that children under 5 who are given the optimum start in life tend to grow and develop similarly (Das, Bhattacharyya, & Bhattacharyya, 2009; Habicht et al., 1974; Who Multicentre Growth Reference Study Group, 2006). Setting such a standard would be achieved by restricting children in a reference sample to those who are growing optimally under conditions that facilitate achievement of their full genetic growth potential and who can therefore be viewed as a model for other children to follow (de Onis, Garza, Onyango,

& Martorell, 2006). All of the data analyzed in this study suggests that the large differences in average HAZ, including the high stunting rates that are observed in South Asia and in parts of Sub-Saharan Africa, are not due to genetic or other non-modifiable traits, but simply reflect the continued presence of large disparities in maternal education, health service coverage, as well as general living conditions. Policies and programs that aim to improve early-life environments for children are therefore likely to not only yield substantial increases in the coverage rates of critical health and development interventions but also may contribute to further improving child growth and well-being.

3.8. Acknowledgements

3.8.1. Competing Interests

All authors declare that no competing interests exist.

3.8.2. Author Contributions

All authors participated in the conception, analysis, design, and writing of the article. All authors have read and approved the final manuscript and are aware that the manuscript is being submitted to the journal.

3.8.3. Data Availability

All data that are used for this study are available for free download after registering with the DHS Program at http://dhsprogram.com/data/.

3.9. Main Figures and Tables

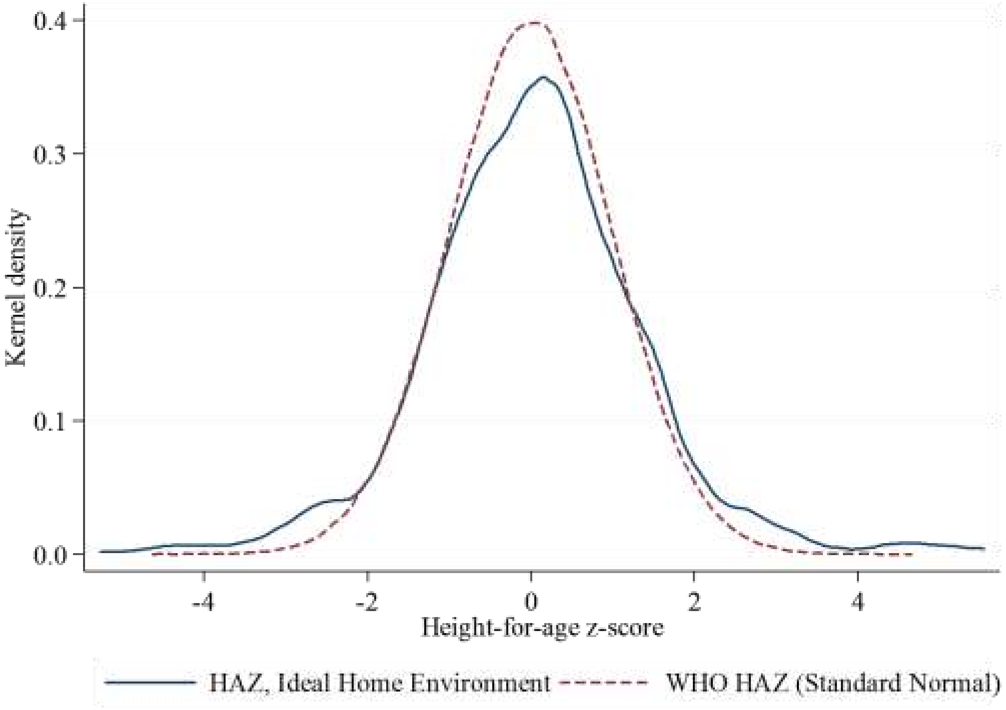
Table 1: Socioeconomic Characteristics of Children and Mothers, Descriptive Statistics

	Non-ideal home environments		**Ideal home environments**	
	N = 877,243		***N = 1,006***	
	N	*(%)*	*N*	*(%)*
Covariates				
Child is female	433,524	49.4	482	47.9
Child age 0	189,376	21.6	171	17.0
Child age 1	187,775	21.4	198	19.7
Child age 2	178,659	20.4	215	21.4
Child age 3	165,273	18.8	231	23.0
Child age 4	156,160	17.8	191	19.0
Multiple birth	20,941	2.4	0	0.0
Mother age < 20	119,275	13.6	29	2.9
Mother age 20-34	628,688	71.7	825	82.0
Mother age 35+	129,280	14.7	152	15.1
Mother: no education	322,715	36.8	0	0.0
Mother: primary education	299,685	34.2	0	0.0
Mother: secondary education	210,638	24.0	0	0.0
Mother: tertiary education	44,155	5.0	1,006	100.0
Mother is married	651,107	74.2	644	64.0
Urban residence	299,619	34.2	880	87.5
Household has TV	320,397	36.5	1,006	100.0
Household has car	47,451	5.4	1,006	100.0
Household has finished floor	374,103	42.6	1,006	100.0
Household has flush toilet	114,651	13.1	1,006	100.0
Household purchases drinking water	20,392	2.3	1,006	100.0
Delivery at hospital	255,971	29.2	1,006	100.0
Child received BCG vaccine	734,170	83.7	1,006	100.0
Child received DPT1 vaccine	705,425	80.4	1,006	100.0

	Non-ideal home environments			**Ideal home environments**		
	N	*Mean*	*SD*	*N*	*Mean*	*SD*
Outcomes						
Child HAZ score	877,243	-1.416	1.659	1006	0.043	1.332
Height of mother, cm	798,861	156.41	7.133	526	159.67	6.116

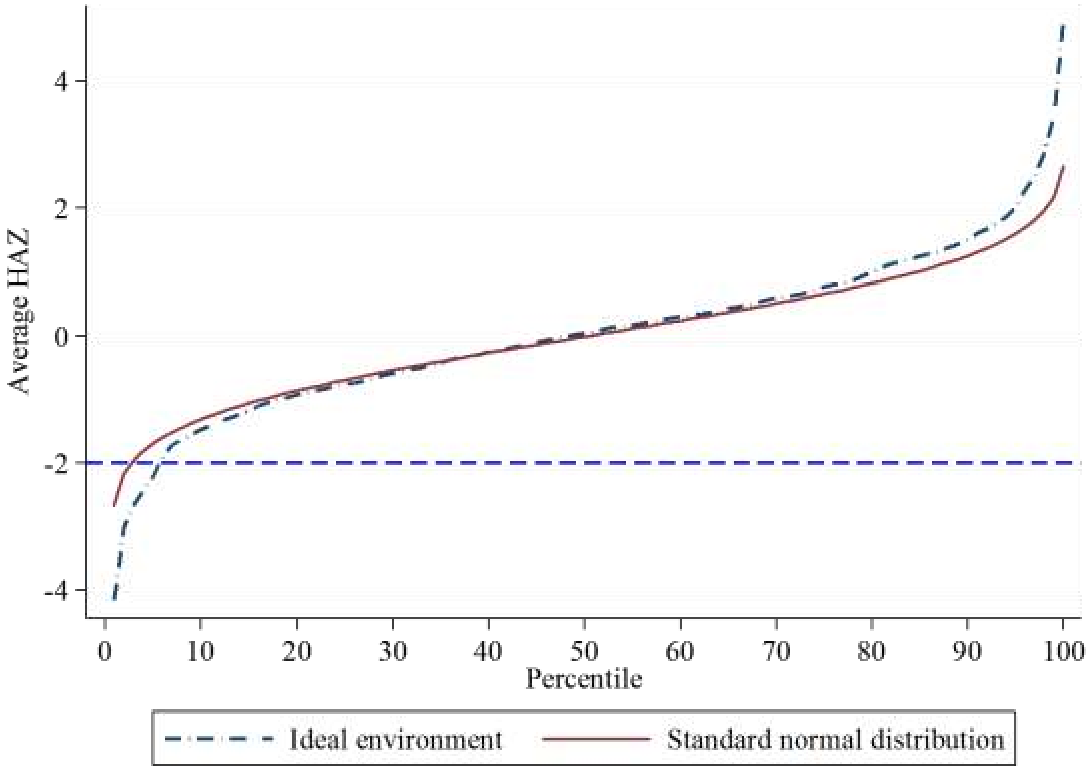
Note: The table presents descriptive statistics for each of the key variables in the analysis. Each variable in the "Covariates" sub-section is defined as a binary indicator (yes/no), while the outcome variables are continuous. Statistics include: the number of observations, *N*; the percentage of respondents who responded "yes" or in the affirmative for that variable; and the variable mean (for outcome height and HAZ variables only).

Figure 1: Kernel Density Plot of Empirical HAZ Distribution in Ideal Home Environment Sample vs. WHO HAZ (Standard Normal) Distribution



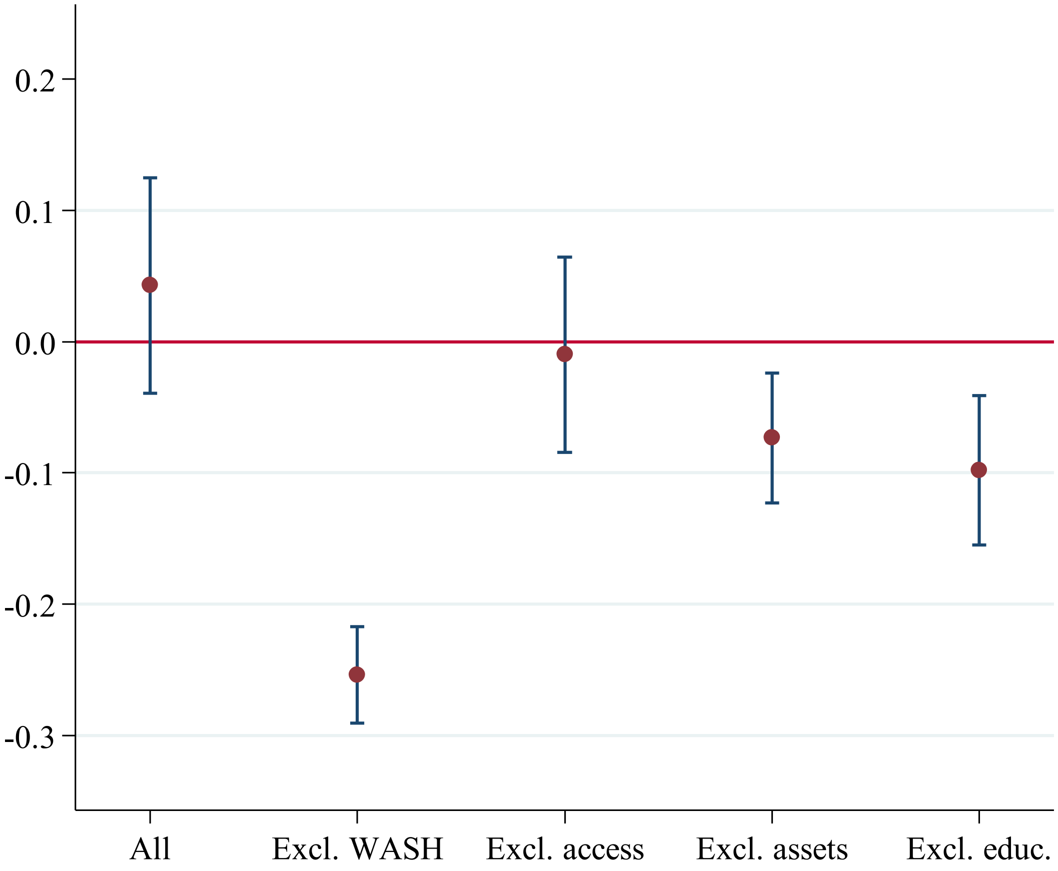
Notes: The solid line presents the distribution of HAZ scores for children from ideal home environments (N = 1,006). This sample is distributed with a mean of 0.043 and standard deviation of 1.33, which are estimated using a linear regression that controlled for survey (country-year) fixed effects and coefficient standard errors that were clustered at the primary sampling unit (DHS cluster) level. The dashed line presents the distribution of HAZ scores from the WHO reference sample, which, by construction, is normally distributed with mean 0 and standard deviation 1.

Figure 2: Percentile-Specific HAZ Distribution in Ideal Home Environment Sample vs. WHO Reference Sample



Notes: The dash-dotted curve presents the distribution of HAZ scores for children from ideal home environments by percentile (N = 1,006), while the solid curve presents the distribution of HAZ scores for the WHO reference sample by percentile. The dashed horizontal line at a HAZ score of -2 represents the WHO-established child stunting cutoff score.

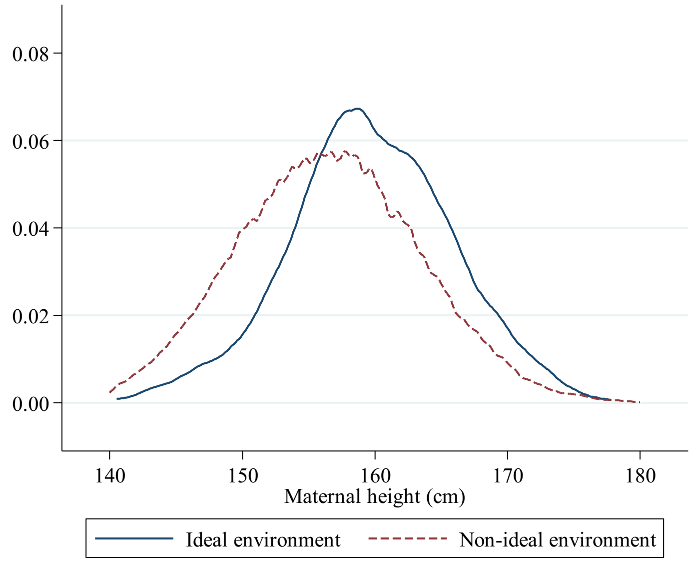
Figure 3: Sensitivity Analysis: Estimated Mean HAZ under Alternative Ideal Home Environment Definitions



Notes: The figure presents mean HAZ scores (dots) and their associated 95 percent confidence intervals (bars) that are estimated by selecting children from alternative ideal home environments, whereby each of the target criteria used to select the ideal child sample is individually removed. The first specification presents the mean HAZ score and 95 percent confidence interval for children under ideal home environments in which all target criteria used for selection are imposed (N = 1,006). The second, third, and fourth, and fifth specifications present the mean HAZ scores and 95 percent confidence intervals for children under an alternative ideal home environment in which the restrictions on access to safe water and sanitation (WASH) (N = 6,638), health service access and coverage namely (receipt of skilled delivery at birth and receipt of vaccinations) (N = 1,296), household possession of assets (TV, car, finished flooring) (N = 2,572), and maternal education (N = 2,132) are removed, respectively. Means and confidence intervals under each home environment specification are estimated using linear regressions that controlled for survey (country-year) fixed effects and coefficient standard errors that were clustered at the primary sampling unit (DHS cluster) level.

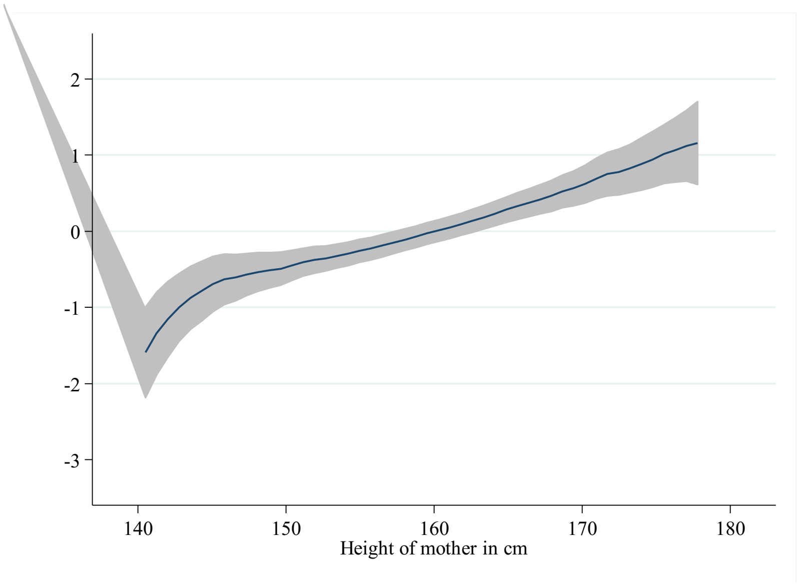
Figure 4: Histogram Plot of HAZ Distribution in Ideal Home Environment Sample, Stratified by Maternal Height

Figure 4A: A Comparison of Maternal Height Distributions among Mothers from Ideal Home Environments and Mothers from Non-Ideal Home Environments



Notes: The solid line presents the distribution of HAZ scores for mothers of children from ideal home environments (N = 824). The dashed line presents the distribution of HAZ scores for mothers of children from the remaining pooled DHS sample (N = 556,255).

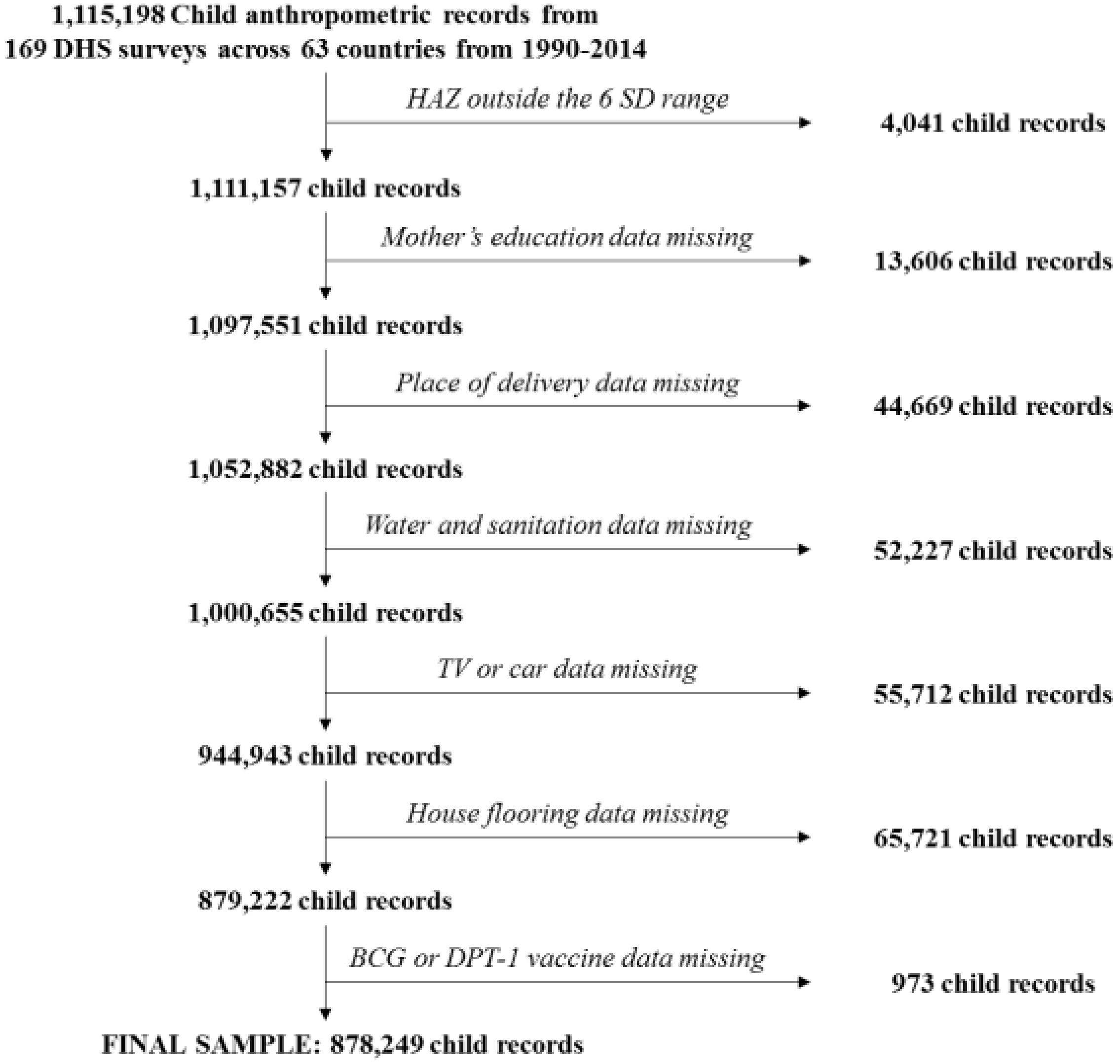
Figure 4B: The Relationship between Maternal Height and Child HAZ Scores in Ideal Environments



Notes: The figure presents the nonparametric relationship between maternal height and the child HAZ score among the sample of mothers and children from ideal home environments. A local polynomial smoothed regression is calculated using the Epanechnikov kernel density function for the weights and the rule-of-thumb (ROT) estimation method to determine the bandwidth. The grey areas depict the 95 percent confidence bands around the estimated regression plot.

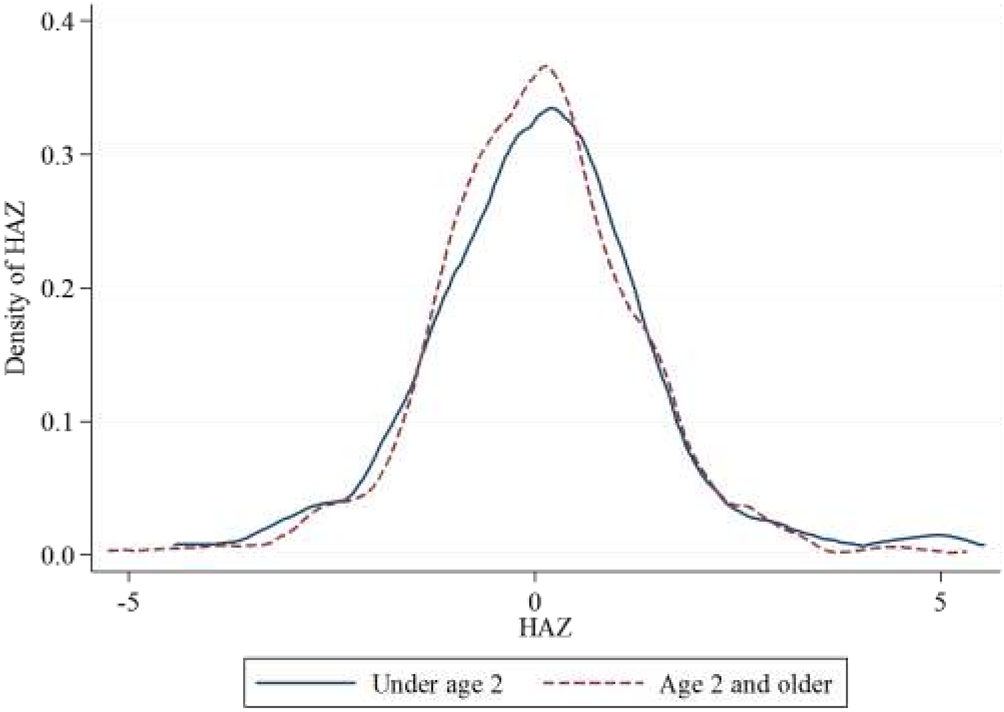
3.10. Supplemental Material

Figure A1: Participant Flowchart



Notes: The flowchart presents the process by which the final pooled DHS sample was selected. The number of child records that were excluded at each stage are presented along with their reasons for exclusion.

Figure A2: HAZ Distribution in Ideal Environment Sample, Stratified by Child Age



Notes: The solid line presents the distribution of HAZ scores of children under the age of 2 from ideal home environments (N = 369). The dashed line presents the distribution of HAZ scores for children aged 2 and older from ideal home environments (N = 637).

Table A1: Observations dropped from analysis

Starting Sample	**1,115,198**	
	No. Obs. Dropped	Pct. of Starting Sample
HAZ was outside 6 SD range	4,041	0.36
Mother's education data missing	13,606	1.22
Place of delivery data missing	44,669	4.01
Water and sanitation data missing	52,227	4.68
TV or car data missing	55,712	5.00
House flooring data missing	65,721	5.89
BCG or DPT-1 vaccination data missing	973	0.09
Final Sample	**878,249**	**78.75%**

Notes: The unit of observation is the child.

Table A2: Country List and Child Sample Size by Country

Country	Year of first DHS survey	Year of last DHS survey	Total sample size
Albania	2008	2008	1,275
Armenia	2000	2010	3,936
Azerbaijan	2006	2006	1,803
Bangladesh	1996	2011	27,543
Benin	1996	2011	25,202
Bolivia	2003	2003	8,857
Burkina Faso	1992	2010	21,755
Burundi	2010	2010	3,314
Cambodia	2000	2000	3,242
Cameroon	1991	2011	11,661
Central African Republic	1994	1994	2,253
Chad	1996	2004	9,663
Colombia	1995	2009	17,397
Comoros	1996	2012	3,127
Congo, Dem. Rep.	2007	2013	10,993
Congo, Rep.	2005	2011	7,537
Cote d'Ivoire	1994	2011	7,754
Dominican Republic	1991	2013	27,284
Egypt, Arab Rep.	1992	2014	59,748
Ethiopia	2000	2011	21,396
Gabon	2000	2012	6,372
Ghana	1993	2014	12,463
Guatemala	1995	1995	8,360
Guinea	1999	2012	8,340
Guyana	2009	2009	1,525
Haiti	1994	2012	14,462
Honduras	2005	2011	18,172
India	2005	2005	38,290
Jordan	1997	1997	5,569
Kazakhstan	1995	1999	1,255
Kenya	1993	2014	34,712
Kyrgyz Republic	1997	2012	4,737
Lesotho	2004	2009	2,836
Liberia	2006	2013	7,263
Madagascar	1992	2008	15,858
Malawi	2000	2010	21,176
Maldives	2009	2009	2,204
Mali	1995	2012	28,376
Moldova	2005	2005	1,240
Morocco	1992	2003	9,444
Mozambique	1997	2011	19,740

Namibia	1992	2013	10,147
Nepal	1996	2011	16,559
Nicaragua	1997	2001	12,371
Niger	1992	2012	16,103
Nigeria	1990	2013	51,453
Pakistan	2012	2012	2,867
Paraguay	1990	1990	3,578
Peru	1991	2012	68,354
Rwanda	2000	2010	13,312
Sao Tome and Principe	2008	2008	1,416
Senegal	1992	2014	32,311
Sierra Leone	2008	2013	6,006
Swaziland	2006	2006	1,964
Tanzania	1991	2009	26,448
Timor Leste	2009	2009	6,825
Togo	1998	2013	6,423
Turkey	2003	2003	3,805
Uganda	1995	2011	13,526
Uzbekistan	1996	1996	947
Yemen, Rep.	1991	1991	2,051
Zambia	1992	2013	31,147
Zimbabwe	1994	2010	12,502
Total			**878,249**

Notes: The unit of observation is the child.

Table A3: List of Countries with Children from Ideal Households

Country	Year of first DHS survey	Year of last DHS survey	Total sample size	Percent
Albania	2008	2008	10	0.99
Azerbaijan	2006	2006	1	0.1
Colombia	2009	2009	41	4.08
Dominican Republic	2002	2013	639	63.52
Egypt, Arab Rep.	2000	2014	26	2.58
Ghana	2014	2014	9	0.89
Guyana	2009	2009	2	0.2
Haiti	2005	2005	2	0.2
Honduras	2005	2011	84	8.35
India	2005	2005	10	0.99
Kenya	2003	2014	10	0.99
Maldives	2009	2009	4	0.4
Moldova	2005	2005	6	0.6
Morocco	2003	2003	5	0.5
Namibia	2006	2013	3	0.3
Nigeria	2003	2013	63	6.26
Pakistan	2012	2012	10	0.99
Paraguay	1990	1990	1	0.1
Peru	2003	2012	43	4.27
Timor Leste	2009	2009	4	0.4
Turkey	2003	2003	28	2.78
Uganda	2011	2011	3	0.3
Zambia	2013	2013	2	0.2
Total			**1,006**	

Notes: The unit of observation is the child.

Table A4: DHS Ideal Environment Sample vs. WHO Reference Sample

	WHO n = 1743	DHS n = 1006
Reproductive History of Mother		
Children born alive, median (range)	2 (1 – 12)	2 (1 - 9)
With < 3 children (%)	78.1	74.7
Primiparous (%)	45.7	44.1
Parental Characteristics		
Years of education completed		
Mother (mean ± SD)	14.5 ± 3.6	15.3 ± 3.1
< 10 y	10.9	0
10 – 14 y	30.3	31.9
15 – 19 y	54.5	67.5
≥ 20 y	4.3	0.6
Father (mean ± SD)	15.0 ± 4.1	
< 10 y	11.2	
10 – 14 y	24.9	
15 – 19 y	54.1	
≥ 20 y	9.8	
Maternal Age (mean ± SD)	29.4 ± 4.9	30.8 ± 5.4
< 20 y	2.6	0.5
20 – 24 y	12.1	13.5
25 – 29 y	35.9	29
30 – 34 y	33.8	31.1
> 35 y	15.6	19.8
Mother's height, cm (mean ± SD)	161.6 ± 7.2	159.7 ± 6.1
Father's height, cm (mean ± SD)	175.1 ± 7.9	
Socioeconomic Factors		
Piped water (%)	100	0
Flush toilet (%)	99.8	100
Refrigerator (%)	99.7	98.3
Gas / electric cooker (%)	99.7	
Telephone (%)	93.4	
Car (%)	86.2	100

Table A5: Estimated HAZ Deficit and Attributable Deficit by Target Criteria, Global Analysis

	(1)	(2)	(3)	(4)
	HAZ Estimate	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment (z-score)	% of total deficit
Higher education	0.537***	0.949	0.509	24%
	[0.521, 0.554]		[0.494, 0.526]	
Hospital delivery	0.383***	0.707	0.271	13%
	[0.373, 0.393]		[0.264, 0.278]	
Housing and assets	0.434***	0.959	0.416	19%
	[0.415, 0.453]		[0.398, 0.434]	
Water and sanitation	0.304***	0.988	0.300	14%
	[0.271, 0.336]		[0.268, 0.332]	
Single birth	0.597***	0.024	0.014	1%
	[0.568, 0.625]		[0.007, 0.008]	
Constant	-2.158***			
	[-2.187, -2.130]			
Observations	878,249	Total attributable HAZ deficit	-1.511	
R-squared	0.081			

*** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Notes: The table presents results from a multivariable regression using the full analytic sample of 878,249 child anthropometric records with complete covariate data across 169 surveys conducted between 1990 and 2014 in 63 countries. Coefficient estimates are presented in Column 1 with 95% confidence intervals in the brackets below. The regression includes survey (country-year) fixed effects, and coefficient standard errors are clustered at the primary sampling unit (DHS cluster) level. Column 2 presents the proportion of the full analytic sample that does not have the particular factor for which the coefficient estimate is calculated; for example, 94.9 percent of children in the analytic sample are born to mothers without higher education. Column 3 presents the attributable HAZ deficit after having adjusted for the particular factor. The attributable HAZ deficit for a given factor, along with its corresponding confidence interval, is calculated by taking the product of the factor's coefficient estimate obtained from column 1 and the proportion of the analytic sample without that factor from column 2. The total attributable HAZ deficit is calculated by summing up the attributable HAZ deficits from each of the five factors, and Column 4 presents the proportion of the total attributable HAZ deficit that can be attributed to that particular factor, which is calculated by taking the ratio of the attributable HAZ deficit from that factor as a percentage of the total attributable HAZ deficit.

Table A6: Estimated HAZ Deficit and Attributable Deficit by Target Criteria, Country-Specific Analysis

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Albania			
Higher education	0.892	0.479 [0.465 - 0.494]	22.2
Hospital delivery	0.236	0.09 [0.088 - 0.093]	4.2
Housing and assets	0.654	0.284 [0.271 - 0.296]	13.2
Water and sanitation	0.914	0.278 [0.248 - 0.307]	12.9
Single birth	0.023	0.014 [0.013 - 0.014]	0.6
Armenia			
Higher education	0.695	0.373 [0.362 - 0.385]	17.3
Hospital delivery	0.723	0.277 [0.27 - 0.284]	12.8
Housing and assets	0.805	0.349 [0.334 - 0.365]	16.2
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.017	0.01 [0.01 - 0.011]	0.5
Azerbaijan			
Higher education	0.9	0.483 [0.469 - 0.499]	22.4
Hospital delivery	0.33	0.126 [0.123 - 0.13]	5.9
Housing and assets	0.966	0.419 [0.401 - 0.438]	19.4
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.013	0.008 [0.007 - 0.008]	0.4
Bangladesh			
Higher education	0.942	0.506 [0.491 - 0.522]	23.4
Hospital delivery	0.902	0.345 [0.336 - 0.354]	16
Housing and assets	0.999	0.434 [0.415 - 0.453]	20.1
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.012	0.007 [0.007 - 0.008]	0.3
Benin			
Higher education	0.995	0.534 [0.518 - 0.551]	24.8
Hospital delivery	0.727	0.278 [0.271 - 0.286]	12.9
Housing and assets	0.974	0.423 [0.404 - 0.441]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.046	0.027 [0.026 - 0.029]	1.3

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Bolivia			
Higher education	0.925	0.497 [0.482 - 0.512]	23
Hospital delivery	0.519	0.199 [0.194 - 0.204]	9.2
Housing and assets	0.917	0.398 [0.381 - 0.415]	18.4
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.011	0.007 [0.006 - 0.007]	0.3
Burkina Faso			
Higher education	0.997	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.945	0.362 [0.352 - 0.371]	16.8
Housing and assets	0.983	0.427 [0.408 - 0.445]	19.8
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.026	0.016 [0.015 - 0.016]	0.7
Burundi			
Higher education	0.986	0.529 [0.514 - 0.546]	24.5
Hospital delivery	0.709	0.272 [0.264 - 0.279]	12.6
Housing and assets	0.986	0.428 [0.409 - 0.447]	19.8
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.022	0.013 [0.012 - 0.014]	0.6
Cambodia			
Higher education	1	0.537 [0.521 - 0.554]	24.9
Hospital delivery	0.973	0.373 [0.363 - 0.382]	17.3
Housing and assets	0.993	0.431 [0.412 - 0.45]	20
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.014	0.008 [0.008 - 0.009]	0.4
Cameroon			
Higher education	0.981	0.527 [0.511 - 0.543]	24.4
Hospital delivery	0.7	0.268 [0.261 - 0.275]	12.4
Housing and assets	0.949	0.412 [0.394 - 0.43]	19.1
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.04	0.024 [0.023 - 0.025]	1.1

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Central African Republic			
Higher education	0.998	0.536 [0.52 - 0.553]	24.8
Hospital delivery	0.818	0.313 [0.305 - 0.321]	14.5
Housing and assets	0.988	0.429 [0.41 - 0.448]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.015	0.009 [0.009 - 0.009]	0.4
Chad			
Higher education	0.997	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.836	0.32 [0.312 - 0.329]	14.8
Housing and assets	0.982	0.426 [0.408 - 0.445]	19.7
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.022	0.013 [0.012 - 0.014]	0.6
Colombia			
Higher education	0.86	0.462 [0.448 - 0.476]	21.4
Hospital delivery	0.202	0.077 [0.075 - 0.079]	3.6
Housing and assets	0.944	0.41 [0.392 - 0.428]	19
Water and sanitation	0.963	0.293 [0.261 - 0.324]	13.6
Single birth	0.009	0.005 [0.005 - 0.006]	0.2
Comoros			
Higher education	0.947	0.509 [0.493 - 0.525]	23.6
Hospital delivery	0.587	0.225 [0.219 - 0.231]	10.4
Housing and assets	0.939	0.408 [0.39 - 0.425]	18.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.036	0.021 [0.02 - 0.023]	1
Congo, Dem. Republic			
Higher education	0.991	0.532 [0.516 - 0.549]	24.7
Hospital delivery	0.757	0.29 [0.282 - 0.298]	13.4
Housing and assets	0.99	0.43 [0.411 - 0.448]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.029	0.017 [0.016 - 0.018]	0.8

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Congo, Republic			
Higher education	0.982	0.527 [0.512 - 0.544]	24.4
Hospital delivery	0.357	0.137 [0.133 - 0.14]	6.3
Housing and assets	0.984	0.427 [0.408 - 0.446]	19.8
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.033	0.02 [0.019 - 0.021]	0.9
Cote d'Ivoire			
Higher education	0.995	0.534 [0.518 - 0.551]	24.8
Hospital delivery	0.867	0.332 [0.323 - 0.341]	15.4
Housing and assets	0.967	0.42 [0.401 - 0.438]	19.4
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.034	0.02 [0.019 - 0.021]	0.9
Dominican Republic			
Higher education	0.868	0.466 [0.452 - 0.481]	21.6
Hospital delivery	0.071	0.027 [0.026 - 0.028]	1.3
Housing and assets	0.904	0.392 [0.375 - 0.41]	18.2
Water and sanitation	0.785	0.239 [0.213 - 0.264]	11.1
Single birth	0.022	0.013 [0.012 - 0.014]	0.6
Egypt, Arab Republic			
Higher education	0.906	0.487 [0.472 - 0.502]	22.5
Hospital delivery	0.68	0.26 [0.254 - 0.267]	12.1
Housing and assets	0.947	0.411 [0.393 - 0.429]	19
Water and sanitation	0.997	0.303 [0.27 - 0.335]	14
Single birth	0.031	0.019 [0.018 - 0.019]	0.9
Ethiopia			
Higher education	0.99	0.532 [0.516 - 0.548]	24.6
Hospital delivery	0.934	0.358 [0.348 - 0.367]	16.6
Housing and assets	0.995	0.432 [0.413 - 0.451]	20
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.017	0.01 [0.01 - 0.011]	0.5

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Gabon			
Higher education	0.982	0.527 [0.512 - 0.544]	24.4
Hospital delivery	0.36	0.138 [0.134 - 0.141]	6.4
Housing and assets	0.913	0.396 [0.379 - 0.414]	18.4
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.038	0.023 [0.022 - 0.024]	1.1
Ghana			
Higher education	0.983	0.528 [0.512 - 0.545]	24.5
Hospital delivery	0.662	0.254 [0.247 - 0.26]	11.7
Housing and assets	0.964	0.418 [0.4 - 0.437]	19.4
Water and sanitation	0.996	0.303 [0.27 - 0.335]	14
Single birth	0.039	0.023 [0.022 - 0.024]	1.1
Guatemala			
Higher education	0.991	0.532 [0.516 - 0.549]	24.7
Hospital delivery	0.802	0.307 [0.299 - 0.315]	14.2
Housing and assets	0.978	0.424 [0.406 - 0.443]	19.7
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.009	0.005 [0.005 - 0.006]	0.2
Guinea			
Higher education	0.99	0.532 [0.516 - 0.548]	24.6
Hospital delivery	0.882	0.338 [0.329 - 0.347]	15.7
Housing and assets	0.962	0.418 [0.399 - 0.436]	19.3
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.038	0.023 [0.022 - 0.024]	1.1
Guyana			
Higher education	0.943	0.506 [0.491 - 0.522]	23.5
Hospital delivery	0.271	0.104 [0.101 - 0.107]	4.8
Housing and assets	0.915	0.397 [0.38 - 0.414]	18.4
Water and sanitation	0.984	0.299 [0.267 - 0.331]	13.9
Single birth	0.02	0.012 [0.011 - 0.013]	0.6

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Haiti			
Higher education	0.987	0.53 [0.514 - 0.547]	24.6
Hospital delivery	0.855	0.327 [0.319 - 0.336]	15.2
Housing and assets	0.983	0.427 [0.408 - 0.445]	19.8
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.023	0.014 [0.013 - 0.014]	0.6
Honduras			
Higher education	0.97	0.521 [0.505 - 0.537]	24.1
Hospital delivery	0.458	0.175 [0.171 - 0.18]	8.1
Housing and assets	0.932	0.404 [0.387 - 0.422]	18.7
Water and sanitation	0.892	0.271 [0.242 - 0.3]	12.6
Single birth	0.013	0.008 [0.007 - 0.008]	0.4
India			
Higher education	0.924	0.496 [0.481 - 0.512]	23
Hospital delivery	0.609	0.233 [0.227 - 0.239]	10.8
Housing and assets	0.968	0.42 [0.402 - 0.439]	19.5
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.012	0.007 [0.007 - 0.008]	0.3
Jordan			
Higher education	0.769	0.413 [0.401 - 0.426]	19.1
Hospital delivery	0.232	0.089 [0.087 - 0.091]	4.1
Housing and assets	0.812	0.352 [0.337 - 0.368]	16.3
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.021	0.013 [0.012 - 0.013]	0.6
Kazakhstan			
Higher education	0.837	0.449 [0.436 - 0.464]	20.8
Hospital delivery	0.414	0.159 [0.154 - 0.163]	7.3
Housing and assets	0.935	0.406 [0.388 - 0.424]	18.8
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.014	0.008 [0.008 - 0.009]	0.4

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Kenya			
Higher education	0.954	0.512 [0.497 - 0.529]	23.7
Hospital delivery	0.723	0.277 [0.27 - 0.284]	12.8
Housing and assets	0.979	0.425 [0.406 - 0.443]	19.7
Water and sanitation	0.998	0.303 [0.27 - 0.335]	14.1
Single birth	0.025	0.015 [0.014 - 0.016]	0.7
Kyrgyz Republic			
Higher education	0.629	0.338 [0.328 - 0.348]	15.7
Hospital delivery	0.798	0.306 [0.298 - 0.314]	14.2
Housing and assets	0.704	0.306 [0.292 - 0.319]	14.2
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.016	0.01 [0.009 - 0.01]	0.4
Lesotho			
Higher education	0.982	0.527 [0.512 - 0.544]	24.4
Hospital delivery	0.618	0.237 [0.231 - 0.243]	11
Housing and assets	0.975	0.423 [0.405 - 0.442]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.023	0.014 [0.013 - 0.014]	0.6
Liberia			
Higher education	0.992	0.533 [0.517 - 0.55]	24.7
Hospital delivery	0.755	0.289 [0.282 - 0.297]	13.4
Housing and assets	0.992	0.431 [0.412 - 0.449]	20
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.033	0.02 [0.019 - 0.021]	0.9
Madagascar			
Higher education	0.983	0.528 [0.512 - 0.545]	24.5
Hospital delivery	0.778	0.298 [0.29 - 0.306]	13.8
Housing and assets	0.987	0.428 [0.41 - 0.447]	19.8
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.017	0.01 [0.01 - 0.011]	0.5

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Malawi			
Higher education	0.998	0.536 [0.52 - 0.553]	24.8
Hospital delivery	0.786	0.301 [0.293 - 0.309]	13.9
Housing and assets	0.994	0.431 [0.413 - 0.45]	20
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.029	0.017 [0.016 - 0.018]	0.8
Maldives			
Higher education	0.971	0.521 [0.506 - 0.538]	24.2
Hospital delivery	0.602	0.231 [0.225 - 0.237]	10.7
Housing and assets	0.958	0.416 [0.398 - 0.434]	19.3
Water and sanitation	0.945	0.287 [0.256 - 0.318]	13.3
Single birth	0.014	0.008 [0.008 - 0.009]	0.4
Mali			
Higher education	0.997	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.965	0.37 [0.36 - 0.379]	17.1
Housing and assets	0.976	0.424 [0.405 - 0.442]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.025	0.015 [0.014 - 0.016]	0.7
Moldova			
Higher education	0.801	0.43 [0.417 - 0.444]	19.9
Hospital delivery	0.033	0.013 [0.012 - 0.013]	0.6
Housing and assets	0.773	0.335 [0.321 - 0.35]	15.5
Water and sanitation	0.975	0.296 [0.264 - 0.328]	13.7
Single birth	0.015	0.009 [0.009 - 0.009]	0.4
Morocco			
Higher education	0.978	0.525 [0.51 - 0.542]	24.3
Hospital delivery	0.669	0.256 [0.25 - 0.263]	11.9
Housing and assets	0.901	0.391 [0.374 - 0.408]	18.1
Water and sanitation	0.993	0.302 [0.269 - 0.334]	14
Single birth	0.021	0.013 [0.012 - 0.013]	0.6

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Mozambique			
Higher education	0.996	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.869	0.333 [0.324 - 0.342]	15.4
Housing and assets	0.975	0.423 [0.405 - 0.442]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.031	0.019 [0.018 - 0.019]	0.9
Namibia			
Higher education	0.969	0.52 [0.505 - 0.537]	24.1
Hospital delivery	0.296	0.113 [0.11 - 0.116]	5.3
Housing and assets	0.902	0.391 [0.374 - 0.409]	18.1
Water and sanitation	0.999	0.304 [0.271 - 0.336]	14.1
Single birth	0.026	0.016 [0.015 - 0.016]	0.7
Nepal			
Higher education	0.98	0.526 [0.511 - 0.543]	24.4
Hospital delivery	0.884	0.339 [0.33 - 0.347]	15.7
Housing and assets	0.998	0.433 [0.414 - 0.452]	20.1
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.009	0.005 [0.005 - 0.006]	0.2
Nicaragua			
Higher education	0.961	0.516 [0.501 - 0.532]	23.9
Hospital delivery	0.478	0.183 [0.178 - 0.188]	8.5
Housing and assets	0.958	0.416 [0.398 - 0.434]	19.3
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.015	0.009 [0.009 - 0.009]	0.4
Niger			
Higher education	0.996	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.988	0.378 [0.369 - 0.388]	17.5
Housing and assets	0.971	0.421 [0.403 - 0.44]	19.5
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.029	0.017 [0.016 - 0.018]	0.8

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Nigeria			
Higher education	0.946	0.508 [0.493 - 0.524]	23.5
Hospital delivery	0.726	0.278 [0.271 - 0.285]	12.9
Housing and assets	0.929	0.403 [0.386 - 0.421]	18.7
Water and sanitation	0.996	0.303 [0.27 - 0.335]	14
Single birth	0.029	0.017 [0.016 - 0.018]	0.8
Pakistan			
Higher education	0.89	0.478 [0.464 - 0.493]	22.1
Hospital delivery	0.477	0.183 [0.178 - 0.187]	8.5
Housing and assets	0.933	0.405 [0.387 - 0.423]	18.8
Water and sanitation	0.987	0.3 [0.267 - 0.332]	13.9
Single birth	0.019	0.011 [0.011 - 0.012]	0.5
Paraguay			
Higher education	0.965	0.518 [0.503 - 0.535]	24
Hospital delivery	0.672	0.257 [0.251 - 0.264]	11.9
Housing and assets	0.92	0.399 [0.382 - 0.417]	18.5
Water and sanitation	0.992	0.302 [0.269 - 0.333]	14
Single birth	0.022	0.013 [0.012 - 0.014]	0.6
Peru			
Higher education	0.828	0.445 [0.431 - 0.459]	20.6
Hospital delivery	0.607	0.232 [0.226 - 0.239]	10.8
Housing and assets	0.948	0.411 [0.393 - 0.429]	19.1
Water and sanitation	0.989	0.301 [0.268 - 0.332]	13.9
Single birth	0.012	0.007 [0.007 - 0.008]	0.3
Rwanda			
Higher education	0.993	0.533 [0.517 - 0.55]	24.7
Hospital delivery	0.878	0.336 [0.327 - 0.345]	15.6
Housing and assets	0.991	0.43 [0.411 - 0.449]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.023	0.014 [0.013 - 0.014]	0.6

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Sao Tome and Principe			
Higher education	0.997	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.394	0.151 [0.147 - 0.155]	7
Housing and assets	0.99	0.43 [0.411 - 0.448]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.035	0.021 [0.02 - 0.022]	1
Senegal			
Higher education	0.995	0.534 [0.518 - 0.551]	24.8
Hospital delivery	0.88	0.337 [0.328 - 0.346]	15.6
Housing and assets	0.959	0.416 [0.398 - 0.434]	19.3
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.031	0.019 [0.018 - 0.019]	0.9
Sierra Leone			
Higher education	0.989	0.531 [0.515 - 0.548]	24.6
Hospital delivery	0.873	0.334 [0.326 - 0.343]	15.5
Housing and assets	0.99	0.43 [0.411 - 0.448]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.034	0.02 [0.019 - 0.021]	0.9
Swaziland			
Higher education	0.937	0.503 [0.488 - 0.519]	23.3
Hospital delivery	0.618	0.237 [0.231 - 0.243]	11
Housing and assets	0.873	0.379 [0.362 - 0.395]	17.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.023	0.014 [0.013 - 0.014]	0.6
Tanzania			
Higher education	0.996	0.535 [0.519 - 0.552]	24.8
Hospital delivery	0.84	0.322 [0.313 - 0.33]	14.9
Housing and assets	0.993	0.431 [0.412 - 0.45]	20
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.029	0.017 [0.016 - 0.018]	0.8

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Timor Leste			
Higher education	0.983	0.528 [0.512 - 0.545]	24.5
Hospital delivery	0.93	0.356 [0.347 - 0.365]	16.5
Housing and assets	0.981	0.426 [0.407 - 0.444]	19.7
Water and sanitation	0.998	0.303 [0.27 - 0.335]	14.1
Single birth	0.017	0.01 [0.01 - 0.011]	0.5
Togo			
Higher education	0.994	0.534 [0.518 - 0.551]	24.7
Hospital delivery	0.797	0.305 [0.297 - 0.313]	14.1
Housing and assets	0.976	0.424 [0.405 - 0.442]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.038	0.023 [0.022 - 0.024]	1.1
Turkey			
Higher education	0.96	0.516 [0.5 - 0.532]	23.9
Hospital delivery	0.572	0.219 [0.213 - 0.225]	10.2
Housing and assets	0.839	0.364 [0.348 - 0.38]	16.9
Water and sanitation	0.911	0.277 [0.247 - 0.306]	12.8
Single birth	0.016	0.01 [0.009 - 0.01]	0.4
Uganda			
Higher education	0.98	0.526 [0.511 - 0.543]	24.4
Hospital delivery	0.686	0.263 [0.256 - 0.27]	12.2
Housing and assets	0.989	0.429 [0.41 - 0.448]	19.9
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.024	0.014 [0.014 - 0.015]	0.7
Uzbekistan			
Higher education	0.885	0.475 [0.461 - 0.49]	22
Hospital delivery	0.046	0.018 [0.017 - 0.018]	0.8
Housing and assets	0.981	0.426 [0.407 - 0.444]	19.7
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.013	0.008 [0.007 - 0.008]	0.4

	Proportion of sample without factor	Attributable HAZ deficit from factor adjustment, z-score [95% CI]	%
Yemen, Republic			
Higher education	0.979	0.526 [0.51 - 0.542]	24.4
Hospital delivery	1	0.383 [0.373 - 0.393]	17.7
Housing and assets	0.83	0.36 [0.344 - 0.376]	16.7
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.009	0.005 [0.005 - 0.006]	0.2
Zambia			
Higher education	0.977	0.525 [0.509 - 0.541]	24.3
Hospital delivery	0.777	0.298 [0.29 - 0.305]	13.8
Housing and assets	0.975	0.423 [0.405 - 0.442]	19.6
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.028	0.017 [0.016 - 0.018]	0.8
Zimbabwe			
Higher education	0.981	0.527 [0.511 - 0.543]	24.4
Hospital delivery	0.897	0.344 [0.335 - 0.353]	15.9
Housing and assets	0.964	0.418 [0.4 - 0.437]	19.4
Water and sanitation	1	0.304 [0.271 - 0.336]	14.1
Single birth	0.025	0.015 [0.014 - 0.016]	0.7

Notes: The table presents results from a multivariable regression using the global analytic sample of 878,249 child anthropometric records with complete covariate data across 169 surveys conducted between 1990 and 2014 in 63 countries. The global regression, whose results are presented in Column 1 of Table A5, includes survey (country-year) fixed effects, and coefficient standard errors are clustered at the primary sampling unit (DHS cluster) level. Column 1 presents the proportion of the country-specific sample that does not have the particular factor for which the factor estimate is calculated; for example, 98.1 percent of children in the analytic sample for Zimbabwe are born to mothers without higher education. Column 2 presents the attributable HAZ deficit after having adjusted for the particular factor. The attributable HAZ deficit for a given factor in the country, along with its corresponding confidence interval, is calculated by taking the product of the factor's coefficient estimate obtained from the global regression (column 1 in Table A5) and the proportion of the country-specific analytic sample without that factor from column 2. Column 3 presents the proportion of the country's total attributable HAZ deficit that can be attributed to that particular factor, which is calculated by taking the ratio of the attributable HAZ deficit from that factor as a percentage of the total attributable HAZ deficit.

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4. Conclusions and Next Steps

4.1. Conclusions

In this dissertation, I present three studies that, together, explore key determinants of maternal and child health and survival, the processes through which these factors lead to improved health among women and their children, and the implications of improved maternal and child health on downstream health and well-being. To this end, my dissertation research has led me to conclude the following:

1. (Paper 1): Physical access to health services is improving in most countries, and almost 60 percent of households live within 3 km of a health facility. However, distance to facilities does not only matter when facilities are far, but also when facilities are close, and even minor variations in physical access to services are likely to have substantial impacts on health behaviors and outcomes. For example, children who live in households that are 3 km from a health facility have a 25 percent higher odds of dying in the neonatal period compared to children who live within 1 km from a facility.
2. (Paper 2): There is increasing evidence to show that a decline in fertility, which comprises the latter stages of the demographic transition, creates the potential for a demographic dividend and a window of opportunity for improved health and economic growth. Moreover, the magnitude of this economic growth factor may be substantially larger than what has been previously thought.
3. (Paper 3): There is reason to believe that observed differences in child height are likely not due to innate or genetic differences, but rather reflect children's continued exposure to resource-poor environments, poor maternal education, and lack of access to health and sanitation.

4.2. Challenges and Next Steps

When reflecting upon the findings of my dissertation research, I have also identified several methodological, conceptual, and empirical limitations to my studies, many of which have motivated me to pursue future research to determine if and how they may be overcome. I present examples of challenges from and next steps for each of these studies below:

4.2.1. Paper 1: The Problem of Correcting for Geospatial Displacement

In the absence of direct measures of facility distance, most of the existing literature has relied on imputed straight-line distances to facilities, which are subject to a substantial amount of measurement error. Possibly the largest concern, however, stems from the geoscrambling of location coordinates by the surveyors to protect respondent confidentiality. Even when the displacement algorithm is known, any direct matching of displaced households to facilities will induce bias into the estimates of distance that are calculated, and adjusting for this bias has been shown to be difficult. Currently, I am helping to develop a numerical integration and multiple imputation method that may allow for consistent and unbiased estimation when a spatial variable is known to be mismeasured. I intend to pursue this line of research further to determine: 1) the conditions under which it may be possible to numerically correct for induced spatial mismeasurement; 2) the extent to which such numerical adjustment methods may be generalizable to other settings.

4.2.2. Paper 2: Expanding the Model for Policy

My research on the links between population and economic development, both at the micro and macro level, has played a significant role in shaping my academic interests, and I hope to continue to investigate topics related to the demographic dividend in developing countries as part of my future work. I look forward to further developing the macrosimulation model by: 1) incorporating additional economic channels that may impact key outcomes (e.g. unemployment effects, the role of institutions and governance); 2) expanding the predictive power of the model to include additional outcome predictions (e.g. distributional implications of fertility transition, measuring the gender dividend, etc.); and 3) configuring the design and outputs of the model for policy audiences.

4.2.3. Paper 3: Inference Using Panel Data and Other Measures of Child Growth

While our study serves as a first step to validating the use of international growth standards in children, many questions still remain. A limitation of our study is that all of the empirical estimates presented are based on cross-sectional data, which prevents us from sufficiently accounting for potential global and country-level trends in child height over time. In choosing a small number of risk factors for our analysis, we may also have missed other key risk factors that could significantly explain the global child height deficit. Finally, we acknowledge that although our choice of child height as a proxy for accumulated health stock and early-life environment has been commonly used in the literature, there are other metrics that may also be appropriate for assessing child growth and development, including weight-for-age, head circumference, and upper arm circumference, among others. I propose to address these limitations in future work by incorporating findings from longitudinal data, expanding the range of risk factors in the analysis, and validating the use of international reference populations for other commonly used measures of child growth.