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

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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 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 mechanism 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 incorporating 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 that 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 the traditional sector, 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 Prospects* (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 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.

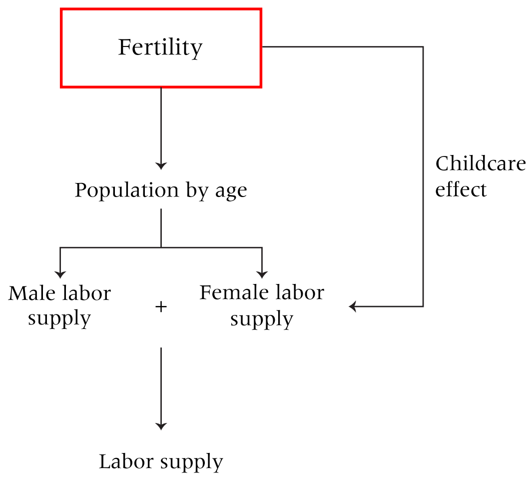
The model

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.

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

FIGURE 1 Modeling fertility, population by age, and labor supply

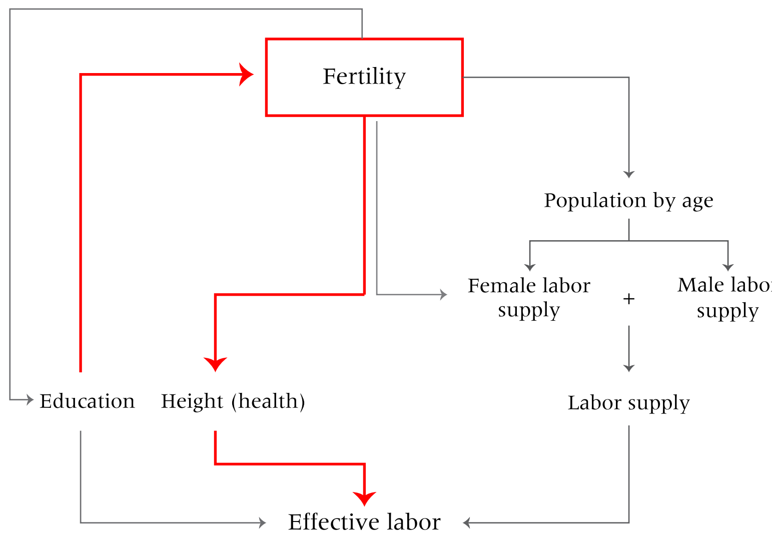


the UN *World Population Prospects* (United Nations 2010). These age-group-specific mortality rates in each future five-year period decline over time in each country but are assumed to be the same across each scenario. For fertility, we begin with the high-variant scenario as our baseline. We then consider a family planning intervention that reduces fertility gradually over time as outlined above. When 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

FIGURE 2 Modeling effective labor



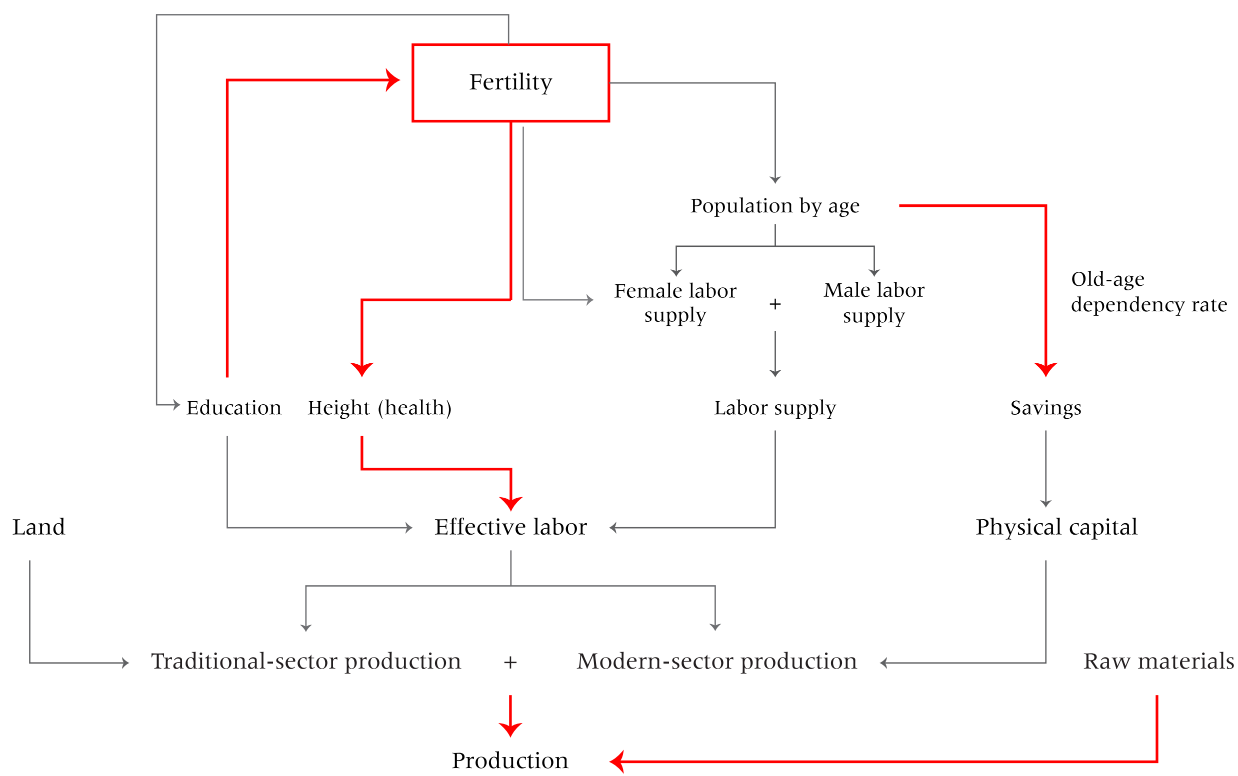
educational attainment and health stock (quantified in average years of schooling per individual and adult height, respectively) are entirely amassed before age 20, after which the average level of schooling and average adult height for that cohort are held constant. We then parameterize the fertility-to-education 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.

Production

Figure 3 presents our full demographic–economic model of production. Estimates of education, health, and labor supply from our demographic

FIGURE 3 Full demographic–economic model of production



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.

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.

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 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 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.

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 Africa is very high and has little scope for increase. In the traditional sector, work is often in the home and can be combined 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.

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 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 one-third ($\alpha = 0.33$) (Hall and Jones 1999) and the estimated land share of output[3] in agriculture of one-sixth ($\beta = 0.167$) (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 economic returns to schooling (Banerjee and Duflo 2005; Oyelere 2010; Psacharopoulos 1994; Psacharopoulos and Patrinos 2004), and the health parameter (the effect of health on ouput) 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 al.'s model since we do not consider the significant contributions of other reproducible factors to output, including livestock, fertilizer, and machinery.

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).

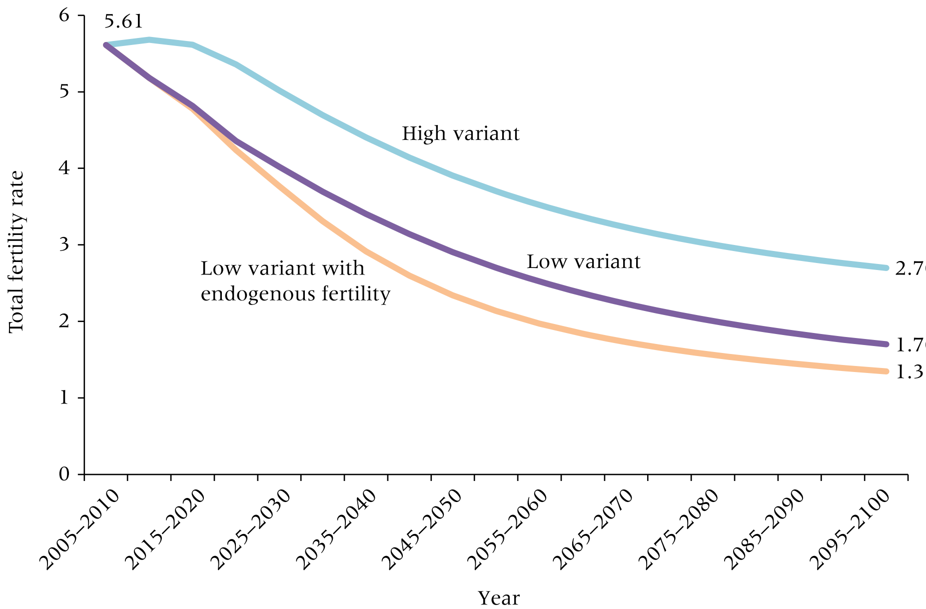
Table A2 describes each source of data that was used as baseline data for Nigeria.

Simulation results for Nigeria

Demographic scenario

Figure 4 shows the changing trajectories of fertility under the high- and low-variant fertility scenarios. Under the baseline high-variant scenario,

FIGURE 4 Total fertility rate under baseline high-variant and alternative low-variant fertility scenarios, Nigeria



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.

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

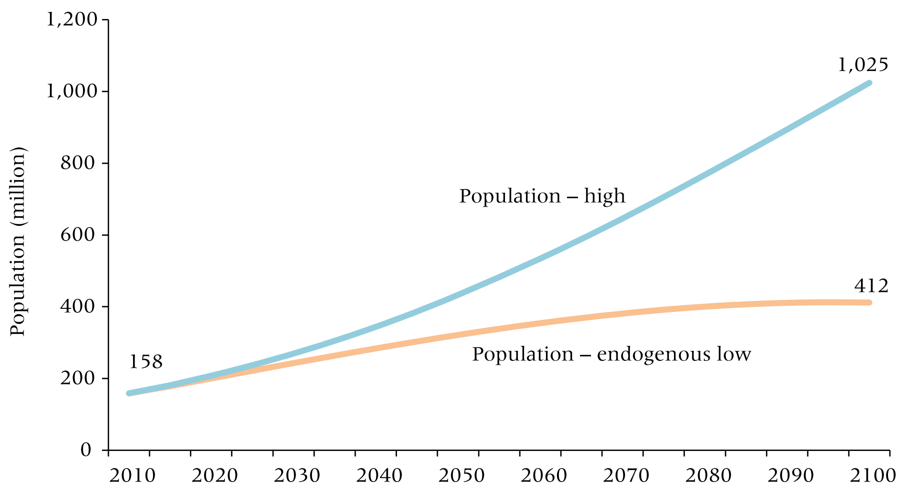
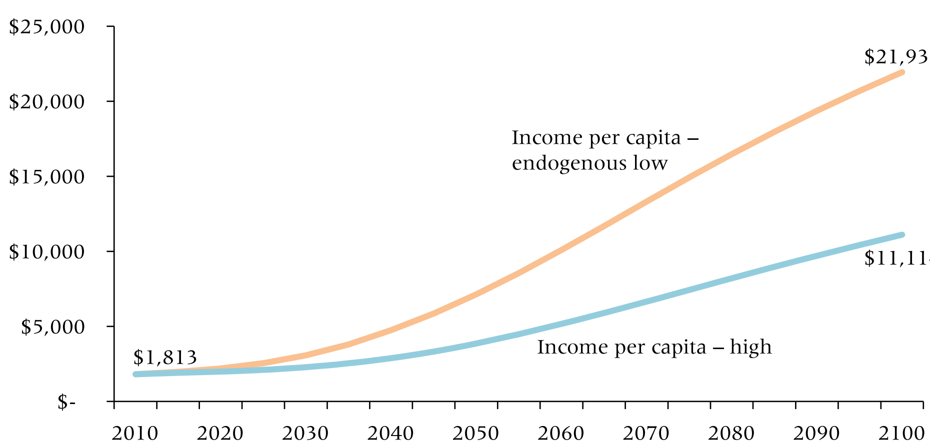


FIGURE 6 Per capita income under high-variant and endogenous low-variant fertility scenarios, Nigeria



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

FIGURE 7 Percent of workers in the modern sector under high-variant and endogenous low-variant fertility scenarios, Nigeria

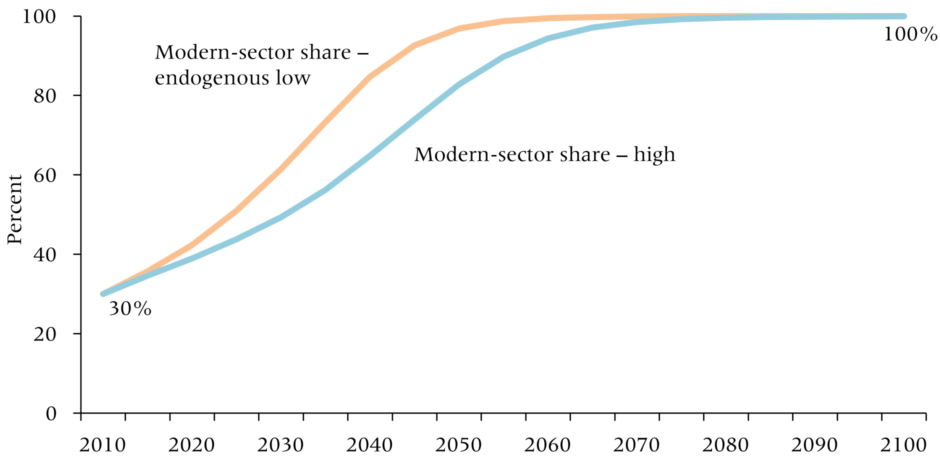
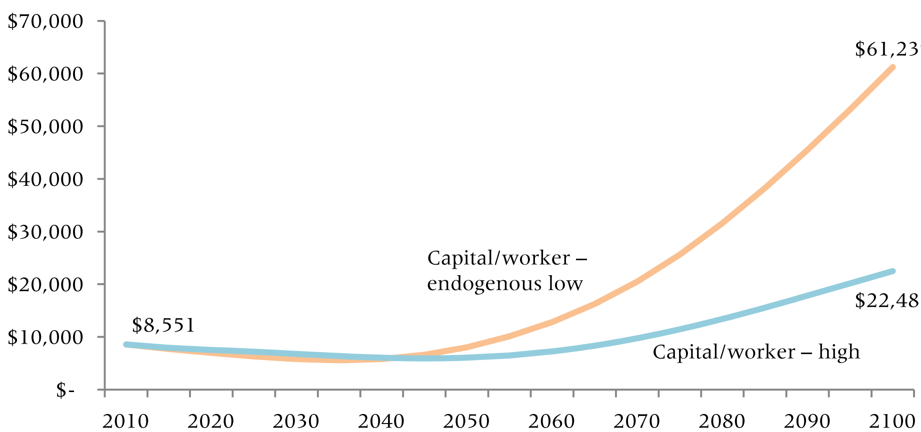


FIGURE 8 Modern-sector capital per worker under high-variant and endogenous low-variant fertility scenarios, Nigeria



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.

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

FIGURE 9 Percent of population of working age under high-variant and endogenous low-variant fertility scenarios, Nigeria

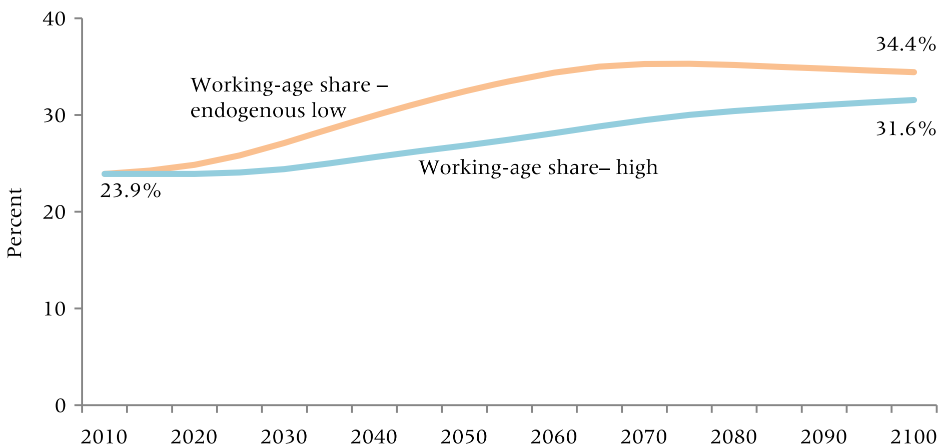
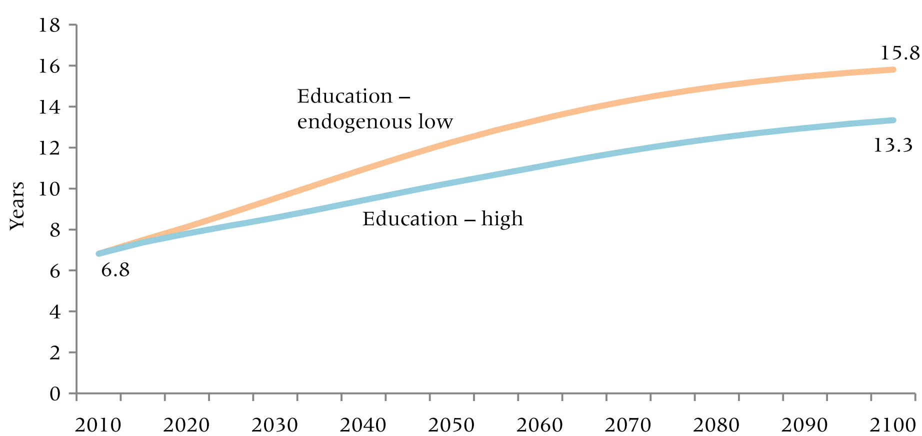


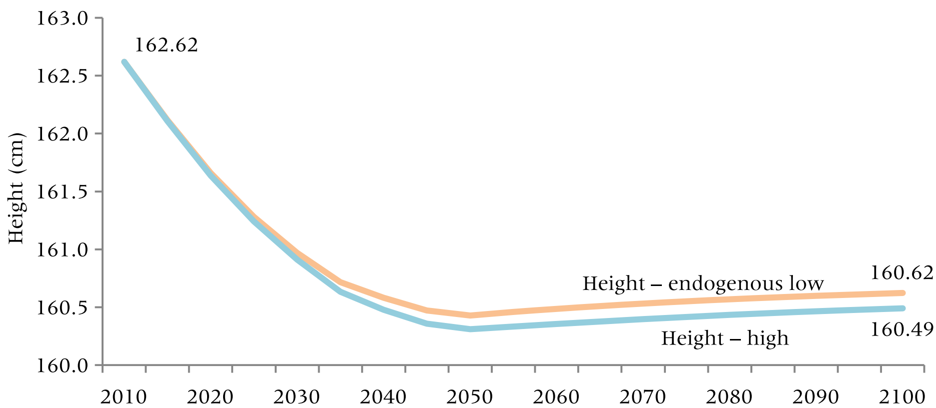
FIGURE 10 Average years of schooling of the workforce under high-variant and endogenous low-variant fertility scenarios, Nigeria



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

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

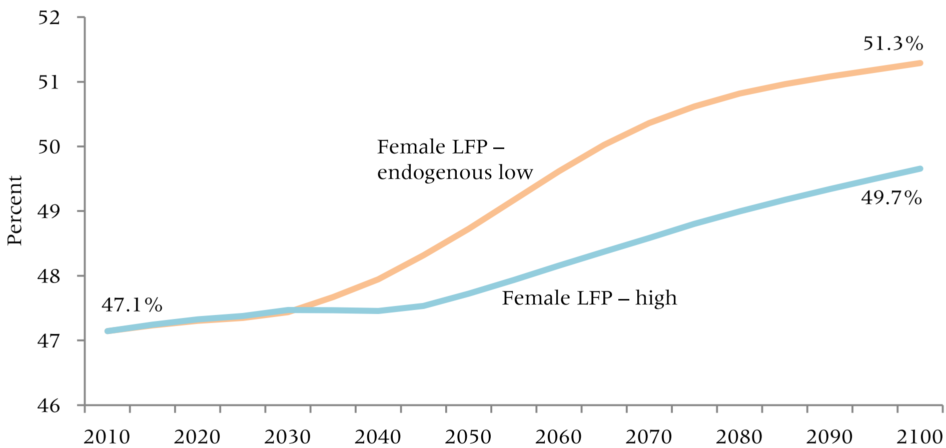


age- and sex-specific levels of schooling and labor force participation rates. While educational attainment is expected to increase in the workforce as a whole, it will increase at faster rates under lower fertility. In particular, average years of schooling under the endogenous low-fertility scenario 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.

FIGURE 12 Female labor force participation rate (in percent) under high-variant and endogenous low-variant fertility scenarios, Nigeria



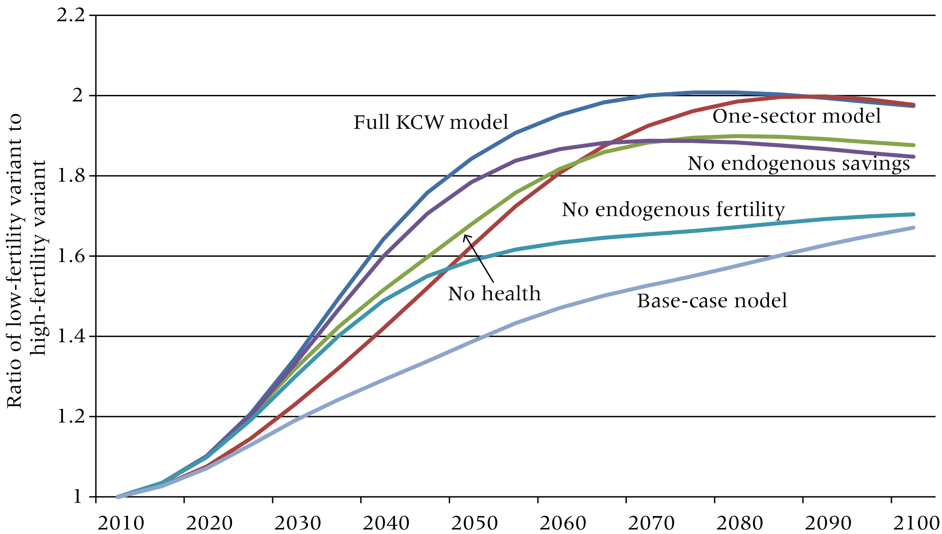
Mechanism analysis

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 et al. 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 assess 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.

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 KCW model, across the 90-year time horizon. The figure also compares the KCW results to projections of the income per capita ratio from: alternative models in which one of the four key mechanisms from the KCW model

FIGURE 13 Comparison of income per capita scenarios across models, Nigeria

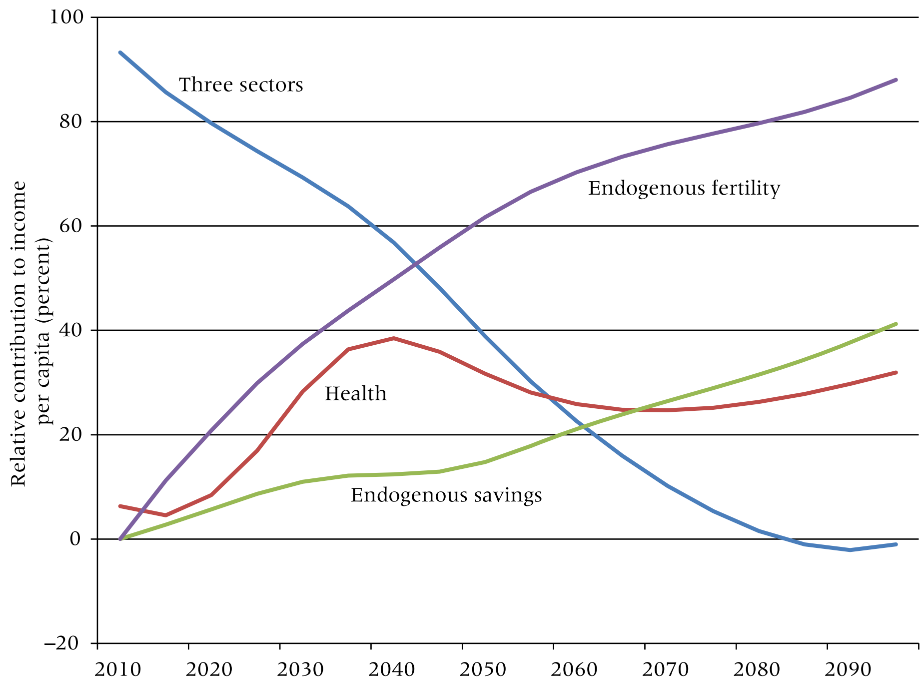


is suppressed; and a simulated base-case one-sector model in which all four key mechanisms from the KCW model are jointly suppressed. This base-case model presents a point of comparison for our results by replicating the conditions and results of the Ashraf et al. (2013) model.[5]

Under the KCW model, the long-run effect of reducing fertility from the baseline high-variant fertility scenario to the endogenous low-variant fertility scenario leads to a 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 KCW model over the entire time horizon. Eventually, most workers are in the modern 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

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



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 effect 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.

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 KCW 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 KCW model to the level that is predicted when the mechanism is suppressed. We then sum these individual mechanism effects to obtain an estimate of the total effect that ignores interactions. Because of 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 and Pack 1999; Stiglitz and 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 and Espenshade 2011).

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 is 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 parameterization in Tables A1 and A2.

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, 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). 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).

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.

Notes

The authors gratefully acknowledge funding from the World Bank for the research reported in this chapter. 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.

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

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.

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.

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).

5 The KCW 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.

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