The Effect of Fertility Reduction on Economic Growth

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How does population growth affect economic growth? More concretely, in the context of a high-fertility developing country, how much higher would income per capita be if the fertility rate were to fall by a specified amount? This is an old question in economics, going back at least to Malthus. Over the last half century, the consensus view has shifted from fertility declines having strong effects, to their not being very important, and recently back toward assigning them some significance (Sinding 2009; Das Gupta, Bongaarts, and Cleland 2011).

For an issue that has been studied for so long, and with such importance, the evidence base regarding the economic effects of fertility (or population growth more generally) is rather weak. In some ways, this should not be a surprise. Population growth changes endogenously as a country develops. Further, factors that influence population dynamics, such as changes in institutions or culture, are likely also to affect economic growth directly, and they are poorly observed, as well. Finally, the lags at which fertility changes affect economic outcomes may be fairly long. Thus, at the macroeconomic level, it is difficult to sort out the direct effects of population growth from those of other factors. Much of the current thinking about the aggregate effects of fertility decline relies on results from cross-country regressions in which the dependent variable is growth of GDP per capita and the independent variables include measures of fertility and mortality, or else measures of the age structure of the population. As discussed below, however, this approach suffers from serious econometric problems.

Our goal in this article is to quantitatively analyze the economic effects of reductions in fertility in a developing country where initial fertility is high. We ask how economic measures such as GDP per capita would compare in the case where some exogenous change reduces fertility to the case where no such exogenous change takes place. The answer to this question will be very different from simply observing the natural coevolution of fertility and economic development, because in our thought experiment we hold constant all the unobserved factors that in reality affect both fertility and economic growth.

To address our question, we construct an economic–demographic simulation model in which fertility can be exogenously varied.[1] We trace the paths of economic development under two scenarios: a "baseline" in which fertility follows a specified time path, and an "alternative" in which fertility is lower. Because we want to realistically model high-fertility developing countries in which fertility is likely to fall over the next several decades, both our baseline and alternative scenarios involve falling paths of fertility; the difference is that fertility falls faster in the alternative scenario. We use the United Nations (UN 2010) medium-fertility population projection as our baseline, and the UN low-fertility population projection as our alternative scenario.[2]

Our model takes account of the dynamic evolution of population age structure, accumulation of physical and human capital, and natural resource congestion. It is parameterized using a combination of microeconomic evidence and economic theory. Our focus throughout is on quantitative analysis of changes in fertility, so that we can estimate how much extra output a given fertility change will produce over a specific time period. The simulation approach also permits an analysis of the strength of the various mechanisms at work.

Our methodology proceeds in the tradition of Coale and Hoover (1958) and many others discussed below. We extend this earlier work in several dimensions. First, we trace the effects of changes in the population through many more potential channels than were addressed in previous literature.[3] Second, we ground our estimates of the magnitudes of effects in well-identified microeconomic studies of individual behavior. In much of the previous literature, key parameters were chosen either in an *ad hoc* fashion or based solely on theory. Third, we are able to measure the magnitude of the different channels that are analyzed. This makes the simulation rather less of a black box. Finally, the structure of our simulation is both transparent and flexible. The analysis includes a good deal of sensitivity analysis, and our full computer model is available and easily altered by anyone wishing to conduct further testing. The simulation model that we build is general, but it has characteristics that can be tailored to the situation of particular countries. In addition to country-specific demographic characteristics (vital rates, initial age structure), the model can incorporate country-specific measures of the role of natural resources in aggregate production and the openness of the capital market.

Our finding is that a reduction in fertility raises income per capita by an amount that some would consider economically significant, although the effect is small relative to the vast gaps in income between developed and developing countries. In the version of our model parameterized to match the economic and demographic situation of Nigeria, we find that shifting from the UN medium-fertility population projection to the UN low-fertility population projection raises income per capita by 5.6 percent at a horizon of 20 years, and by 11.9 percent at a horizon of 50 years. The simple dependency effect (fewer dependent children relative to working adults) is the dominant channel for the first several decades. At longer horizons, the effects of congestion of fixed resources (à la Malthus) and capital shallowing (à la Solow) become more significant than the dependency effect, although the latter remains important. The fourth most important channel in the long run is the increase in human capital that follows from reduced fertility.

Whether the overall effect of fertility on economic outcomes that we find in our model is large or small is mostly in the eye of the beholder, a point to which we return in our conclusion. One should also note the hurdles that stand between a finding that reductions in fertility would raise output per capita by an economically significant amount (if that is how one interprets the magnitude of our finding) and a conclusion that some policy intervention that achieved such a reduction in fertility would be desirable. First, our analysis says nothing at all about the methods, costs, or welfare implications of such interventions. Second, GDP per capita is not necessarily the best or only welfare criterion. The question of how a social planner should assess the welfare implications of a policy that changes both average well-being and the size of the relevant population is notoriously difficult (Razin and Sadka 1995; Golosov, Jones, and Tertilt 2007).

Relationship to previous literature

Attempts to assess the effect of fertility changes on economic outcomes can be divided into three categories: aggregate (macroeconomic) statistical analyses, microeconomic studies, and simulation exercises. We review these three approaches as well as a number of studies that have presented broad syntheses of research on the topic. Because the literature in all of these areas is vast, our summary is by necessity selective. We conclude the section by discussing how our approach compares to what has come before.

Macroeconomic analyses

In the best-known early aggregate analysis of the relationship between population growth and development, Kuznets (1967) found a positive correlation between growth rates of population and income per capita within broad country groupings. This he interpreted as evidence of a lack of a negative causal effect of population growth on income growth, contrary to the prevailing view at the time. A number of studies followed Kuznets in examining the relationship between population growth and different factors viewed as being determinants of income growth. For example, Kelley (1988) found no correlation between population growth and growth of income per capita, and similarly no relationship between population growth and saving rates. Summarizing many other studies, he concluded that the evidence documenting a negative effect of population growth on economic development was "weak or nonexistent."

Since the early 1990s, many analyses of the effect of population on economic outcomes have followed the "growth regression" model popularized by Barro (1991) and Mankiw, Romer, and Weil (1992). In these regressions, terms representing population growth, labor force growth, or dependency ratios are included as right hand side variables. For example, Kelley and Schmidt (2005) regressed the growth rate of income per capita on the growth rates of total population and the working-age population, incorporating both Solow effects (dilution of the capital stock by growth in the number of workers) and dependency effects. They found that the demographic terms are quantitatively important. Their regression explained approximately 20 percent of the growth of income per capita over the period 1960–1995. Bloom and Canning (2008) regressed the growth rate of income per capita on the growth rate of the working-age fraction of the population (along with standard controls), finding a positive and significant coefficient. Because high growth of the working-age fraction follows mechanically from fertility reductions, they interpreted this as demonstrating the economic benefits of reduced fertility.

Very little of the literature taking an aggregate approach to the effects of population growth on economic outcomes has dealt adequately with the issue of identification. The determinants of population growth, most notably fertility, are endogenous variables. Changes in fertility are not only themselves affected by economic outcomes, they are also affected by unobserved variables that may have direct effects on the economy. These could include human capital, health, characteristics of institutions, and cultural factors. Given these problems of omitted variables and reverse causation, it is inadvisable to draw inferences from the conditional correlations in growth regressions. The fact that changes in economic outcomes are sometimes regressed on lagged changes in fertility (as represented by population age structure) is only a slight improvement, since there is bound to be serial correlation in the unobserved factors that affect both fertility and economic outcomes.

A handful of studies have attempted to circumvent the identification problem in the macroeconomic context using instrumental variables. Acemoglu and Johnson (2007), using worldwide health improvements during the international epidemiological transition to instrument for country-specific reductions in mortality, concluded that higher population growth arising from mortality reductions has a significant negative effect on GDP per capita at a horizon of several decades. Li and Zhang (2007) used shares of non-Han populations (which were not subject to the one-child policy) across Chinese provinces to instrument for population growth, finding a negative effect of higher fertility on the growth of GDP per capita. Bloom et al. (2009), using abortion legislation as an instrument, found a negative impact of fertility on female labor force participation. They concluded that the extra female labor supply would be a significant channel through which lower fertility would raise income growth, although they mentioned that saving and human capital accumulation could be expected to be important channels as well.

Microeconomic analyses

A second approach to examining the relationship between population and economic outcomes has been to look to a finer level of analysis: usually households, rather than countries. Examination of household data often allows proper identification to be achieved in a way in which it cannot using macro data. Joshi and Schultz (2007) and Schultz (2009) studied the long-run effects of a randomized trial of contraception provision in Matlab, Bangladesh. They found that reduced fertility produced persistent and significant positive effects on the health, earnings, and household assets of women, and on the health and earnings of children. Miller (2010) used variations in the timing of the introduction of the Profamilia program in Colombia to identify both the effect of contraceptive availability on fertility and the effect of fertility on social and economic outcomes. For women treated at a young age, Profamilia was estimated to have reduced fertility by 11–12 percent and raised education by 0.08 years. Rosenzweig and Zhang (2009), examining data from China and using twins as a source of exogenous variation in the number of children, found that higher fertility reduces educational attainment. For rural areas, the elasticity of schooling progress with respect to family size was estimated at between –9 and –26 percent.

While cross-country regressions suffer from econometric problems, they do have the advantage—if one is interested in studying the aggregate effects of fertility decline—of focusing on the right dependent variable. By contrast, many microeconomic studies examine the link between fertility at the household level and various outcomes for individuals in that household (wages, labor force participation, education, etc.). These studies cannot directly answer the question of how fertility reduction affects the aggregate economy, for three reasons. First, many of the effects of such reduction run through channels external to the household—either via externalities in the classic economic sense (e.g., environmental degradation) or through changes in market prices, such as wages, land rents, and returns to capital (Acemoglu 2010). Second, even if one ignores external effects, aggregating the different channels by which fertility affects economic outcomes is challenging. Finally, as in the macroeconomic literature, the long time horizon over which the effects of fertility change are manifest limits the ability of a single study to capture them.

Simulation models

In principle, if one knows the structural channels that relate economic and demographic variables and can parameterize them, these can be combined into a single simulation model that will effectively deal with the issues of aggregation and general equilibrium.

The intellectual ancestor of modern economic–demographic simulation models is the Coale–Hoover model (Coale and Hoover 1958). Coale and Hoover set out to study the effect of fertility change in India. They started by making alternative population forecasts for India under three exogenous fertility scenarios: high (constant at its 1951 level), medium (declining 50 percent over the period 1966–1981), and low (declining 50 percent over the period 1956–1981). Total population in 1986 in their simulation was 22 percent higher in the high-fertility than the medium-fertility scenario, and 7 percent lower in the low-fertility than the medium-fertility scenario. The authors assumed a constant incremental capital–output ratio invariant to investment and population. Neither human capital nor fixed factors such as land played a role in their analysis. Their finding was that, at a time horizon of 30 years, income per capita was 15 percent higher in the low-fertility scenario and 23 percent lower in the high-fertility scenario as compared to the medium-fertility scenario. The primary mechanism driving their results was capital accumulation: with high population growth, a high dependency ratio negatively affects the saving rate and thus investment and economic growth. Of particular note, the model treated spending on child health and education as consumption rather than investment.

Enke (1971) compared paths of income per capita under two scenarios: a high-fertility scenario, in which the gross reproduction rate (GRR) stayed constant at about 3 from 1970 through 2000, and a low-fertility scenario in which the GRR fell from about 3 in 1970 to 2 in 1985 and 1.5 in 2000. Total population in 2000 was 37 percent higher in the high-fertility than in the low-fertility scenario. The underlying economic model used capital and labor as inputs in a Cobb–Douglas production function.[4] Population was divided into five-year intervals, with varying age-specific labor force participation rates. The effects he found were quite large: income per capita in the low-fertility scenario was 13 percent greater than in the high-fertility scenario in 1985, and 43 percent greater in 2000. Much of the force driving his results comes from a higher saving rate in the low-fertility scenario that is, in turn, attributable to a Keynesian consumption function in which the average propensity to consume falls as disposable income rises.

Simon's (1976) model was similar in many respects to that of Enke (1971), but with several alterations that reversed key results. In Simon's model, social overhead capital increased with population density to allow for economies of scale in production (specifically, better road networks that facilitate more efficient production). Similarly, technological change in the industrial sector was considered to be a function of the overall size of the population. The model also featured an explicit labor–leisure choice as well as separate agricultural and industrial sectors. Taking fertility as exogenous, Simon found that, for the first 60 years of the simulation, constant population size led to higher income per capita than a growing population, although the difference was quite small. For longer time horizons, a population growing at a moderate rate resulted in higher income per capita than a constant population.

Simulation models that developed further in this line included multiple productive sectors (agriculture, industrial, and service), a government sector, and urbanization. Several also included an endogenous fertility response. In reviewing a number of these models, Ahlburg (1987) argued that they "vary considerably in their complexity.... The cost of the models' increased complexity is that it is often very difficult to uncover the underlying assumptions and, particularly, since few carry out sensitivity analysis, the key assumptions." His summary of the concrete findings of these simulation models was that fertility decline would have modest positive effects on income per capita, although much smaller than predicted by those such as Enke who became known as "population pessimists."

In a similar vein, Kelley (1988) cited many obstacles to constructing a credible model to determine how rapid population growth affects development in developing countries. Among these obstacles are general equilibrium feedbacks, the difficulty of constructing credible long-range demographic forecasts, potential changes in policy or institutions that may occur over the forecast interval, and the lack of available data to specify and validate such a model. He concluded, "Clearly, providing a quantitative, net-economic-impact answer to the population-counterfactual question is at best a remote possibility."

As simulation models' popularity waned in academic circles after the mid-1980s, they also suffered a setback in applied policy circles. The BACHUE series of models for Kenya, the Philippines, and other countries, developed by the World Employment Programme of the International Labour Organization, were originally intended as planning tools in relevant government ministries. These models were generally judged to be *ad hoc* and opaque.[5] Strikingly, however, simulation models became popular as didactic or "awareness raising" models meant to illustrate the beneficial effects of fertility decline. The RAPID model (Abel 1999) allowed for a variety of user-input demographic scenarios.[6] However, the path of total GDP in the simulation was completely invariant to population, thus delivering the inevitable result that reduced population growth increased income per capita *pari passu*. Ironically, RAPID had its origins in the then sophisticated model of Enke (1971), whose economic components were stripped out when they were judged to add mere complication to the desired message.

With recent renewed interest in human capital and overlapping-generations approaches, simulation modeling has made a comeback. Lee and Mason (2010) incorporated a "quality–quantity" tradeoff in a model that excluded physical capital and land. The elasticity of human capital investment per child with respect to the total number of children was assumed to be close to negative one, implying that total spending on human capital of children is invariant to the number of children. Under this assumption a reduction in fertility of 10 percent raised schooling per child by 10 percent. Their model had a simple three-period age structure with a working-age generation as well as dependent children and elderly. Examining cross-country data, they derived an estimated semi-elasticity of human capital with respect to years of education of 7 percent. Their simulation considered a developing country in which there has already been a rapid rise in the net reproduction rate (NRR) as a result of falling child mortality. Their baseline scenario assumed continuing decline in mortality and an even more rapid fall in fertility that temporarily dropped below the replacement level. The authors then considered deviations involving a faster or slower decline in fertility from this baseline scenario. It was found that in the scenario with slowly falling fertility, consumption per adult-equivalent was roughly 12 percent lower than the baseline scenario for the first two generations of the simulation.[7]

In many of the models discussed above, one of the crucial channels through which demographic change affects economic outcomes is saving and capital accumulation. A question any such model must deal with is whether and how the consumption/saving decisions made by households are affected by their expectations of future demographic and economic developments. In modern macroeconomic models, the standard assumption is of rational or model-consistent expectations, although application of this assumption in the case of long-run demographic change can be complex. Auerbach and Kotlikoff's (1987) 55-period overlapping-generations model represents a methodology for calculating the rational expectations equilibrium in such a case, although their emphasis is on developed-country issues, in particular government-funded transfer programs.

Recent work by macroeconomists interested in long-run growth has extended this approach to create fully "micro-founded" (i.e., micro-foundation-based) computable general equilibrium models to analyze the interaction of population and economic outcomes (e.g., Doepke, Hazan, and Maoz 2007). In such work, utility-maximizing households are modeled as continuously reoptimizing their decisions (fertility, child education, consumption, labor supply) in response to changes in forecast paths of aggregate variables. The approach requires explicitly modeling household utility functions, including preferences regarding child quality and quantity, as well as budget constraints and credit market constraints faced by households and firms.

Broad syntheses

Two of the most influential syntheses of contemporary thinking on how fertility affects development in poor countries are those by the US National Academy of Sciences (NAS 1971) and the National Research Council (NRC 1986). NAS (1971) presented nuanced discussions of many of the potential channels through which rapid population growth can affect economic outcomes, including resource depletion, capital dilution due to rapid labor force growth, urbanization, and reductions in the saving rate caused by a large dependent population. In contrast to much of the literature up to that time, the NAS report placed strong emphasis on the role of human capital and on the increase in the fraction of national income that must be devoted to education when fertility is high. The authors were circumspect regarding the difficulties of long-range forecasting. They mostly limited themselves to a horizon of 2–3 decades, during which the dominant effects of fertility changes will be on the numbers of dependent children, and commented on the lack of credible models with which to make longer-term assessments. Although they firmly dismissed the idea of a global "population crisis" that was popular at the time, they nevertheless concluded that lower population growth in developing countries would significantly increase income per capita, and that reduced fertility should be a policy goal for most developing countries. Specifically, they urged countries with high population growth to reduce their annual rates of natural increase to less than 1.5 percent over the following two decades.

NRC (1986) is most notable for having crystallized a perspective skeptical of theorized negative effects of population growth, a perspective based both on available empirical evidence and on economic theory. The report also stressed the economic mechanisms that mitigate the negative effects of population growth, in particular the ability of markets and institutions to adjust to increased population. Much of the intellectual heft of the report was directed at the question of whether interventions in household fertility decisions are warranted. The authors focused in particular on the questions of externalities and imperfect information on the part of households. To the extent that couples take into account the effect of their fertility decisions on the health and economic success of their children (including, for example, the effect of lower fertility on education and land per capita), the authors did not see a role for government intervention. To an even greater extent than NAS (1971), the authors of NRC (1986) were reluctant to take a quantitative approach to discussing the effects of fertility change on long-term economic outcomes.[8]

NRC (1986) is often identified as the standard-bearer of the so-called revisionist view that fertility change has a relatively small effect on economic development. Recently, however, the pendulum has swung back in the other direction. Kohler (2012) starts by pointing out that although the majority of the world's population now live in countries where fertility has fallen below the replacement rate, there are substantial areas of the world in which fertility remains quite high—specifically, with an NRR above 1.5 and a growth rate of population above 2.5 percent per year. Regarding these areas, he assesses the degree to which continued high fertility or stalled fertility decline constitutes a threat to economic development (as part of a broader cost–benefit evaluation of policies targeted at reducing population growth). He pays particular attention to the views of a new generation of "population pessimists," typified by Campbell et al. (2007). Kohler's (2012) review of the different channels by which population affects economic outcomes includes natural resource scarcity, the "demographic dividend" from changes in population age structure (see definition and discussion below), and effects of population size on innovation. His admittedly rough conclusion is that in current high-fertility countries a reduction of one percent per year in population growth would yield an increase of one percent per year in growth of income per capita. Another synthesis of current research (Das Gupta, Bongaarts, and Cleland 2011) concludes, "At bottom, there is little fundamental disagreement on the issue. There is broad consensus that policy settings that support growth are the key drivers of economic growth, while population size and structure play an important secondary role in facilitating or hindering economic growth." Sinding (2009) also identifies an emerging consensus that fertility reduction, while not a sufficient condition for economic growth, may be a necessary one.

Structure of our model

In its basic structure, our model is in the tradition of the simulation studies discussed above. We construct an aggregate model in which fertility and mortality (and thus population size and age structure) are exogenous. The endogenous variables include physical and human capital, labor force participation, and wages. Output is produced with a neoclassical production function that takes physical capital, land, and a human capital aggregate (embodying education and experience) as inputs. Population is divided into five-year age groups, and the time interval is five years.

Our model differs from previous work in that we focus not only on the overall effect of fertility change, but on the different channels by which fertility influences the economy. This focus on channels allows for a more detailed discussion of how our results compare to the predictions of different theories. As described above, the literature has discussed a number of channels that lead from demographic change to economic outcomes. At the risk of some intellectual strait-jacketing, we classify these effects as follows. The most basic effect of population on output per capita is through the congestion of fixed factors, such as land. We call this the *Malthus effect*. A second channel is the capital shallowing that results from higher growth in the labor force. We call this the *Solow effect*. Four channels run through the age structure of the population, which is a function of past fertility and mortality rates. First, in a high-fertility environment, a reduction in fertility leads, at least temporarily, to a higher ratio of working-age adults to dependents. Holding income per worker constant, this mechanically raises income per capita. We call this the *dependency effect*. Second, a concentration of people in their working years may raise national saving, feeding through to higher capital accumulation and greater output. We call this the *life-cycle saving effect*. Work by Bloom and Williamson (1998) on the demographic dividend (referred to above) has stressed the combination of the dependency and life-cycle saving effects. Third, slower population growth shifts the age distribution of the working-age population toward higher ages. In developing countries, this increase in average experience would be expected to raise productivity, even though in more developed countries the shift into late middle ages might lower it. We call this the *experience effect*. Fourth, if older workers participate in the labor market at a higher rate than workers just entering the workforce, the shifting age distribution toward higher ages will lead to higher overall labor force participation, thereby increasing income per capita. We call this the *life-cycle labor supply effect*. Another effect of reduced fertility is to lower the quantity of adult time that is devoted to childrearing, freeing up more time for productive labor. We call this the *childcare effect*. Reductions in fertility are often associated with an increase in parental investment in education per child. We call this the *child-quality effect*. Another channel through which fertility declines could possibly affect output is through improvements in health, which we call the *health improvement effect*. These could result from the same quality–quantity shift that we model in the case of education. Finally, an increase in the size of the population may raise productivity directly, by allowing for economies of scale, or it may induce technological or institutional change that raises income per capita.[9] We call this the *Boserup effect* after Boserup (1965), who found that population pressure encouraged intensification and innovation in African agriculture.

In this article, we quantify seven of these effects (Malthus, Solow, dependency, experience, life-cycle labor supply, childcare, and child quality). The life-cycle saving effect is discussed in the working paper version of this article.[10] The agricultural Boserup effect seems inappropriate in an African setting where population growth is concentrated in cities and recent agricultural expansion has been onto marginally suitable land (Weil 2008a). Generalized technological Boserup effects (e.g., Simon 1976) are speculative, although Simon's idea that a larger population will lead to more technological progress because more people will be available to produce more ideas has been incorporated into the macro-growth literature (Jones 1995). In a typical developing country, most technological progress will be imported and hence unrelated to population size. More prosaically, we were unable to find quantitative estimates of their magnitude. While the health improvement effect is arguably better established, we have not found, in the African setting, quantitative estimates required for parameterization. Moreover, Joshi and Schultz (2007) found no effect of the fertility intervention in Matlab, Bangladesh on child health. Further, Ashraf, Lester, and Weil (2008) found only minor effects of health improvements on income per capita in a simulation model similar to the one that we analyze in this article.

A second significant difference between our model and previous simulation models lies in the parameterization of the underlying economic relations. We go much further in grounding our parameterization in well-identified microeconomic analyses. The channels that we parameterize in this fashion include the returns to schooling and experience, the effect of fertility on education, and the effect of fertility on female labor supply. We discuss the range of existing estimates and our procedures for choosing parameters in a later section.

Unlike in models in the tradition of Auerbach and Kotlikoff (1987), the saving and human capital investment decisions in our model do not have any forward-looking component. Similarly, we do not provide a complete foundation for the optimization of household decisionmaking. Rather, we draw on the applied microeconomics literature for estimates of the effects of contemporaneous variables on accumulation (including accumulation of human capital through education). In our view, economists' understanding of household decisionmaking in developing countries is too limited to produce a quantitatively useful model that incorporates a fully optimizing micro-founded setup.

A possible criticism of our approach is that we do not allow for the endogenous evolution of fertility in response to changes in income (that result from an initial change in fertility). We do not do so for two reasons: first, there is no well-identified measure of the extent to which fertility should respond to such a change; second, our basic analysis presented below concludes that the response of income to fertility declines is modest, so we would expect the "second-round" effect of income on fertility to be modest as well.

Unlike the NRC (1986) authors, we focus on output per capita rather than utility. The question of how utility would change in response to a reduction in fertility is complex: one must deal with externalities, household information sets, and the requirements of constructing a social welfare function that includes people who might not be born (Golosov, Jones, and Tertilt 2007). The question we pose—whether reducing fertility would raise output per capita—is much more easily addressed.

Following the analyses of NAS (1971), NRC (1986), and most of the simulation models discussed above, we focus on the effects of slowing population growth due to an exogenous decline in fertility. Much of our emphasis is on the channel of human capital, which was also emphasized by NRC (1986). Like Lee and Mason (2010), our analysis considers deviations of fertility from a path that is declining even in the baseline scenario. In contrast to their approach, however, we use a much more realistic demographic structure.

Demographic scenarios

For our analysis we tailor the model to fit Nigeria, taking the UN (2010) medium-fertility population projection as our baseline population scenario and the UN low-fertility variant as our alternative scenario. The UN reports population by five-year age group for every five-year period through 2100. The UN also reports age-specific fertility rates for every five-year period through 2100. Figure 1 shows the paths of the total fertility rate (TFR) in the two scenarios. The medium variant has the TFR declining rapidly at first, and then with some deceleration, from 5.6 in 2005–2010 to 4.5 in 2025–2030, and 3.4 in 2045–2050. The TFR in the low variant is the same as in the medium variant in 2005–2010, and then differs from the medium variant by 0.25 in 2010–2015, 0.4 in 2015–2020, and by a fixed 0.5 thereafter. The difference between the UN high- and medium-fertility variants is the same.[11]

The UN provides no guidance on how one should interpret the differences between the high-, medium-, and low-fertility projections. Nevertheless, we believe that using the TFR gap between the medium and low projections as a measure of the difference in fertility that might result from policy or other exogenous changes is not unreasonable. To give two examples, Miller (2010) estimated that the Profamilia program in Colombia reduced fertility by half a child, and Joshi and Schultz (2007) estimated that a contraception provision program in Matlab, Bangladesh reduced fertility by 15 percent, at a time when the TFR was slightly above 6, implying a reduction in the TFR of 0.9.

Figure 2 shows the paths of total population in the two scenarios. Population in the low variant is 4.4 percent lower than the medium variant at a horizon of 2030, and 10.6 percent lower in 2050. Figure 3 shows the paths of the working-age (15–64) fraction of the population in the two scenarios,

FIGURE 1 Time paths of the total fertility rate by demographic scenario, illustrated with the example of Nigeria

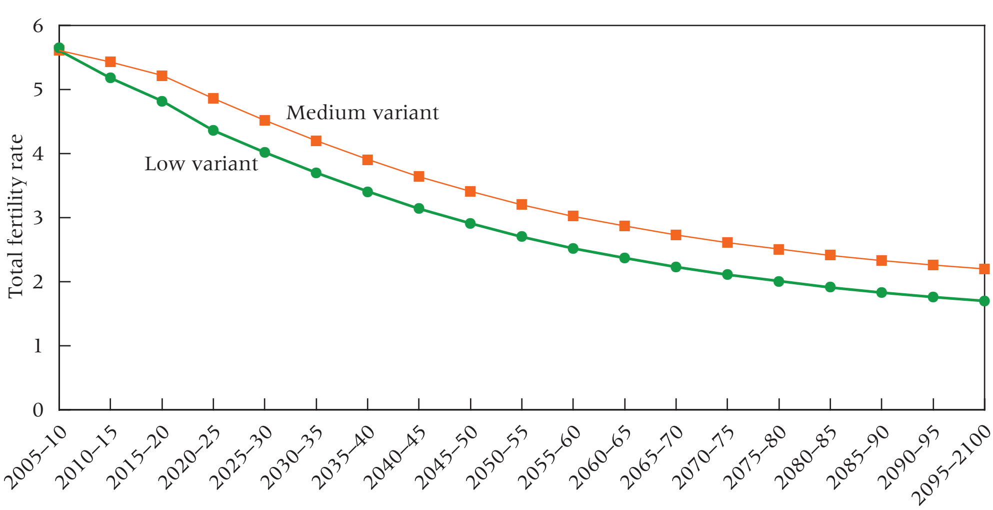
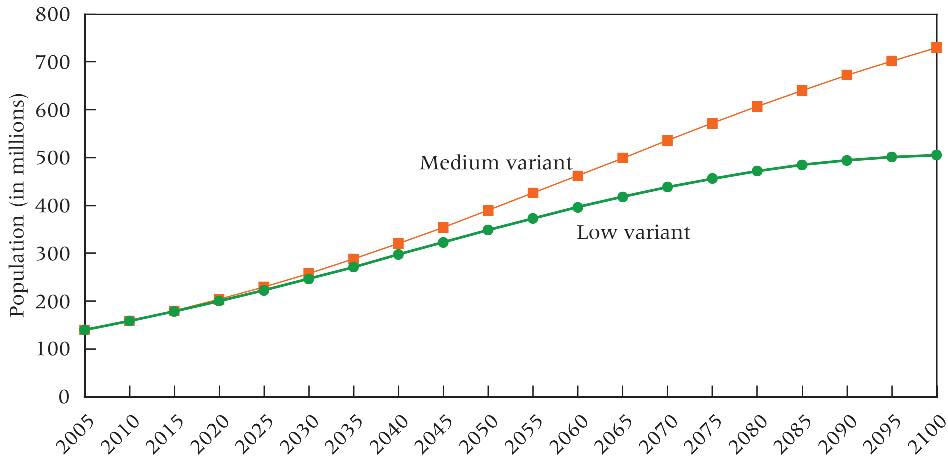


FIGURE 2 Time paths of population by demographic scenario, illustrated with the example of Nigeria



while Figure 4 does the same for the fractions aged below 15 and over 65. The change in the working-age share can be decomposed into a reduction in the share under 15 and an increase in the share over 65. In both the scenarios we examine, a significant increase in the working-age fraction of the population occurs over the next several decades, but the increase is larger in the low-fertility scenario. For example, in 2050, the working-age fraction is 60.6 percent in the medium-fertility scenario versus 63.2 percent in the low-fertility scenario (both relative to 53.9 percent in 2010).

FIGURE 3 Time paths of the working-age fraction of the population by demographic scenario, illustrated with the example of Nigeria

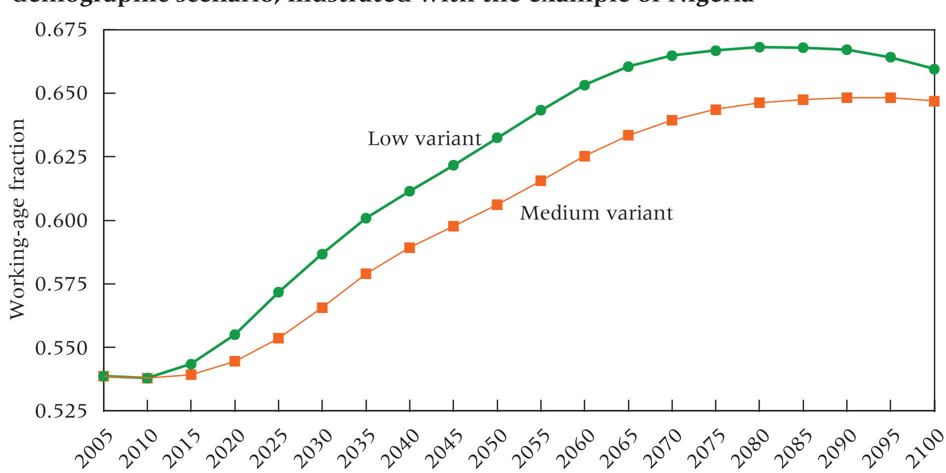
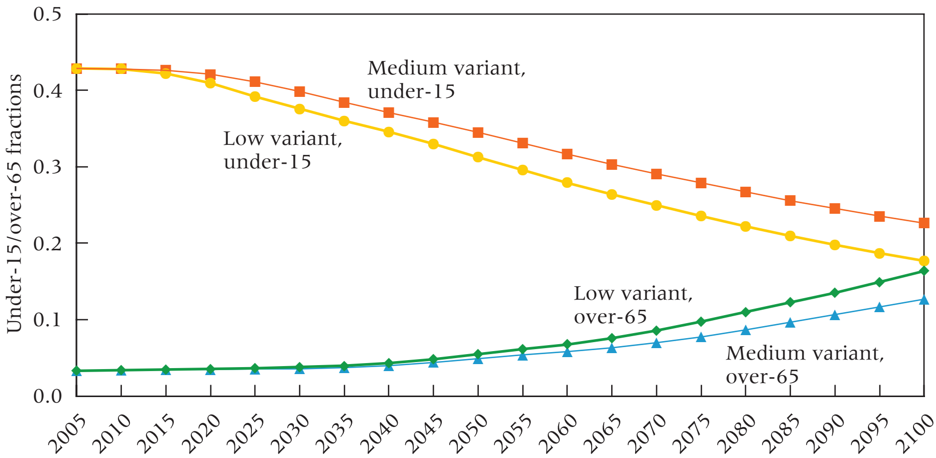


FIGURE 4 Time paths of the under-15 and over-65 fractions of the population by demographic scenario, illustrated with the example of Nigeria



The economic model and its parameterization

The quantitative results produced by a simulation model like ours depend on the details of the model's specification as well as the parameter values used. Our choices regarding these decisions, and the supporting rationale, are described in the sections below. We refer to the parameters and structure that we find most credible as the "base case." After showing the results of our simulation in this base case, we consider how deviations from the base case affect the model's predictions.

Production

Aggregate production is given by a standard Cobb–Douglas production function. The factor inputs are land (which we use as a shorthand for all fixed factors of production), physical capital, and effective labor, so that aggregate output in period t, Y_t, is

$$Y_t = A_t K_t^{\alpha} H_t^{\beta} X^{1-\alpha-\beta},$$

where $\alpha + \beta < 1$, X is a fixed arbitrary stock of land, and A_t is total factor productivity.

We assume fairly standard values for factor shares in our base case setup: we set α at 0.3 and β at 0.6, meaning that the implied share of land in total output is 10 percent.[12] For convenience, we set the growth rate of total factor productivity to zero. The speed of total factor productivity growth is clearly of paramount importance to the growth of income per capita over time, but reasonable variations in this parameter have only trivial effects on the quantity on which we focus: the ratio of income in the alternative scenario to income in the baseline scenario.

Physical capital accumulation

We model capital accumulation by following Solow (1956) in assuming that a fixed share of national income is saved in each period.[13] Specifically, the stock of capital in period t, K_t, evolves over time according to

$$K_{t+1} = sY_t + (1 - \delta)K_t,$$

where s and δ are the fixed saving and depreciation rates, respectively. We assume that the annual saving rate is 8.55 percent, which corresponds to the investment share of real GDP reported by Heston, Summers, and Aten (2009) for Nigeria in 2005. We assign a value of 5 percent to the depreciation rate.

Effective labor

We model an individual's effective labor as a function of his or her age-specific labor force participation rate and level of human capital. Human capital, in turn, is a function of his or her schooling and experience. We assume that human capital inputs of individuals with different characteristics are perfectly substitutable. Thus, the stock of effective labor in period t, H_t, is

$$H_t = \sum_{15 \le i < 65} (h^s_{i,t} \times h^e_{i,t} \times LFPR_{i,t}) N_{i,t},$$

where $N_{i,t}$ is the number of individuals of age i in the population in period t, $LFPR_{i,t}$ is their labor force participation rate, and $h^s_{i,t}$ and $h^e_{i,t}$ are, respectively, their levels of human capital from schooling and experience. We assume that children enter the labor force at age 15 and workers leave the labor force at age 65.

In our simulations, we use labor force participation rates reported by the International Labour Organization (2011) for Nigeria in 2005. We employ sex- and age-specific labor force participation rates to construct total labor force participation rates by age, using the fraction of males and females in each age group as population weights. Since our baseline and alternative scenarios both feature declining fertility, we modify the female labor force participation rates in each future period to reflect the effect of a decrease in time devoted to childrearing on total labor supply. This procedure is explained below.

Returns to schooling. Years of schooling are aggregated into human capital from schooling using a log-linear specification,

$$h^s_{i,t} = \exp[\theta S_{i,t}],$$

where θ is the return to an additional year of schooling. The return to schooling is relevant for the exercises we conduct because reductions in fertility will raise the average level of schooling. Psacharopoulos and Patrinos (2004) provided estimates of the returns to schooling in sub-Saharan Africa that range from 4.1 to 20.1 percent, with an average return of 11.7 percent. These results, however, were criticized for being derived from data of poor quality. Banerjee and Duflo (2005) improved on the quality of these estimates and found a range of 3.3 to 19.1 percent, with an average return of 9.75 percent.

One concern with these estimates is that they measure the average return to education in a country. If the change in fertility occurs mostly among low-education workers, and the returns to education differ with the level of education, using the average return to schooling for all workers may be misleading. Psacharopoulos and Patrinos (2004) estimated the returns to education by education level and found that the returns fall as the level of education rises. However, the higher-quality estimates from Schultz (2004) indicated the opposite. He estimated that the return to primary education in Nigeria is approximately 2.5 percent per year, while the return to university education is in the range of 10–12 percent. Moreover, the returns to primary education were estimated to vary between 2 and 17 percent over a sample of six African countries, with an average of approximately 8 percent.

Another concern with these estimates is that they are obtained by running OLS regressions and are therefore subject to bias from endogeneity and omitted variables. Duflo (2001) exploited a quasi-natural experiment involving a school building program in Indonesia, and estimated the returns to education to be between 6.8 and 10.6 percent. Oyelere (2010) used a similar research design, exploiting the provision and then revocation of free primary education in certain regions of Nigeria, to estimate the returns to education. Consistent with Schultz (2004), she estimated a return of only 2.8 percent.

We choose a value of $\theta = 10$ percent, which is the value applied in much of the growth literature and represents a rough average of the estimates discussed above. In testing for robustness, we examine both Oyelere's (2010) estimate of 2.8 percent, which has the advantages of being well identified, primary-education-specific, and based on data for Nigeria, and 20 percent, which is the upper bound of estimates from Banerjee and Duflo (2005) for sub-Saharan African countries.

Returns to experience. Human capital from on-the-job experience for a worker of age i in period t, $h^e_{i,t}$, is computed as

$$h^e_{i,t} = \exp[\phi(i-15)+\psi(i-15)^2].$$

Experience plays a role in our simulations because declines in mortality and fertility will lead to a population with higher average age and thus higher average experience.

Estimates of the returns to experience in African countries are highly unreliable owing to poor data quality. The seminal work remains Psacharopoulos (1994), who, in addition to estimating the returns to education, implicitly estimated the returns to experience for 45 countries. Although Psacharopoulos (1994) did not directly report his estimates, Bils and Klenow (2000) assembled these estimates, added estimates for seven other countries, and reported them in Appendix B of their paper. We use values of 0.052 for ϕ and –0.0009875 for ψ in our base case setup, corresponding to the average of the estimates for each of these coefficients across the four sub-Saharan African countries (Botswana, Côte d'Ivoire, Kenya, and Tanzania) in Bils and Klenow (2000).[14]

Effect of fertility on education. We 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. It does not follow from this observation, however, that the change in schooling that would result from an exogenous change in fertility is the same as the change that would accompany declining fertility when both measures are evolving endogenously.

A large literature analyzes the theoretical relationship between the number of siblings and educational attainment. However, few empirical studies from developing countries use natural experiments to establish causal estimates of the effect of fertility on years of schooling. Using data from India, Rosenzweig and Wolpin (1980) and Rosenzweig and Schultz (1987) found that an exogenous increase in fertility resulting from the birth of twins decreases the level of schooling for all children in a household. Unfortunately, they do not provide estimates in a form that can be imported into our model. In addition, this work has been criticized for the imprecision of estimates arising from a small sample size and methodological problems such as not controlling for birth order.

More useful to us are results from Joshi and Schultz (2007), who analyzed a randomized intervention in Matlab, Bangladesh. They found that a TFR reduction of 15 percent, resulting from the intervention, led to an increase of 0.52 years of schooling for males aged 9–14.[15] To illustrate how this finding is incorporated into our model, in the UN medium-fertility variant the TFR in Nigeria falls from 5.61 in 2005–2010 to 5.43 in 2010–2015, a reduction of 0.18. Since this corresponds to a reduction of 3.2 percent, the estimated increase in schooling over this period is 0.52 x 3.2/15.0 = 0.11 years of schooling. In the low-fertility variant, however, the TFR falls to 5.18 in 2010–2015, a reduction of 0.43. Using a similar calculation, the increase in years of schooling under the low-fertility variant is estimated to be 0.27 years. As fertility continues to fall over time in the two scenarios, years of schooling increase, with the increase being larger for the low-fertility scenario because it features a larger decline in fertility.

Childcare effects on labor supply

Childrearing labor is spread over many years and is divided among many individuals, but the largest responsibility usually rests with the child's mother. Reduced fertility should thus potentially increase the labor supply of women. A large literature has examined the effect of fertility on female labor supply in developed countries. Generally, these studies found a moderate to large negative effect.[16] However, little research has been done to assess the effect of fertility on female labor supply outside of Europe and the United States.[17]

Beyond the general lack of research in this area, assigning a quantitative magnitude to the effect of fertility on female labor supply is difficult for several reasons. Childrearing is often combined with other productive activities, and even time spent exclusively on childrearing may be subtracted from leisure, rather than from production. Most importantly, there are substantial economies of scale in childrearing. For example, Tiefenthaler (1997), examining data from Cebu, Philippines, found that 14 months after birth, female labor market hours had declined by 39 percent in the case of first births, but by only 10 percent if there were already children aged 0–5 in the household, and not at all if there were also children aged 6–17 in the household.

Despite these caveats, the time cost of childrearing may still be a significant component in the economic response to fertility decline. We measure the effect of fertility change on labor supply through the childcare channel by specifying a parameter we call the labor market time cost of a marginal child. Summarizing all these considerations in a single parameter is obviously simplistic but, in doing so, we at least have a concrete measure that can be implemented in our model. Specifying the time cost of the marginal child might also be considered problematic because the marginal cost would be expected to fall with the number of children. However, Holmes and Tiefenthaler (1997) concluded that the marginal time cost of children is roughly constant for the third and subsequent children; and for the simulation experiments we are implementing, the TFR generally remains above two.[18]

We implement the childcare effect by increasing female labor force participation in each year by the hypothesized change in age-specific fertility multiplied by the labor market time cost (in years) of a marginal child. For example, if in our experiment, the age-specific fertility rate of women aged 25–29 drops from 0.265 to 0.218 (as it does in the UN medium-fertility scenario between 2005–2010 and 2045–2050), and if the labor market time cost of a marginal child is one year, then the labor force participation rate for women in this age group would rise by 4.67 percentage points.

There remains only the question of choosing the parameter value for the time cost of children. In the Cebu data used by Tiefenthaler (1997), weekly labor market hours fell from 10.4 prenatally to 5.0 at two months after birth, 6.6 at six months, and 9.5 at 14 months for women who had other children

TABLE 1 Labor supply response to a decline in the TFR by one birth, illustrated with the example of Nigeria

Age group	Male LFPR (%), 2005	Female LFPR (%), 2005	Female LFPR (%) with TFR decline	Increase factor for female LFPR (col. 3 ÷ col. 2)
15–19	35.0	31.5	32.5	1.034
20–24	44.1	37.7	39.7	1.053
25–29	61.4	44.5	46.8	1.053
30–34	77.1	50.8	52.9	1.042
35–39	80.1	55.7	57.1	1.026
40–44	81.0	57.0	57.8	1.013
45–49	83.1	63.5	63.8	1.005
50–54	79.6	65.8	65.8	1.000
55–59	81.2	66.2	66.2	1.000
60–64	75.2	64.0	64.0	1.000

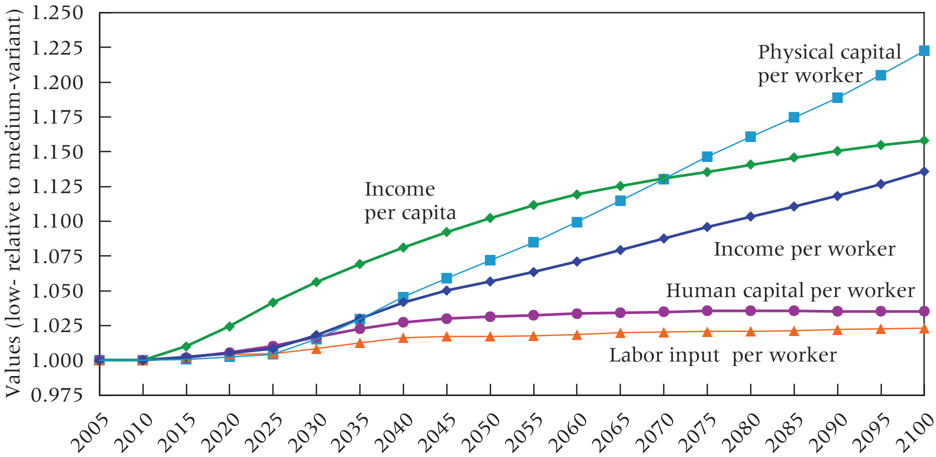
aged 0–5 in the household; and from 13.1 prenatally to 7.6 at two months, 11.3 at six months, and 13.8 at 14 months for those with children aged both 0–5 and 6–17 in the household. Crudely interpolating these data, and allowing for an almost total cessation of labor market activity in the first month after delivery, hours averaged over the first year were reduced roughly 5 per week in the first group and 3 per week for the second group. Weekly labor market hours for men in the same households did not change much in response to a birth and were equal to roughly 40. Thus, women in these two groups lost 0.125 or 0.075 years of full-time-equivalent labor market input in the first year after the birth of a marginal child. The complete or nearly complete recovery of labor hours by 14 months after delivery suggests that the decrement in subsequent years should be very small. On the other hand, there are a good number of these years. Further, we have data on neither the efficiency loss by women with small children who are working, nor any long-term health consequences of multiple pregnancies that might impede labor input for many years. As a rough guess for our base case parameterization, we specify a labor market time cost of 0.5 years per marginal child.[19]

Table 1 shows the age-specific labor force participation rate (LFPR) for Nigerian women in 2005 and the implied levels of the LFPR if the TFR were reduced by one birth (assuming a constant percentage reduction in each age-specific fertility rate), using our value of 0.5 for the time cost of a marginal child. For comparison, we also show the age-specific LFPR for men. The effect is linear in the size of the TFR change, and for a TFR change of one it is very small.

Simulation results

Figure 5 shows the paths of physical capital per worker, human capital per worker, labor input per worker, income per worker, and income per capita in

FIGURE 5 Base case economic scenario, illustrated with the example of Nigeria



our simulation, using the parameters discussed above. The path of output per worker reflects the dynamics of human and physical capital per worker, labor input per worker, and land per worker (which we do not show, but which can be inferred from Figure 5). As in all the figures that follow, we show the ratio of outcomes in the alternative scenario to outcomes in the baseline scenario. Further, in discussing our simulation results below, we refer to the year 2010 (that is, the last year before fertility in the baseline and alternative scenarios begins to diverge) as the start of our simulation, so references to time horizons in our simulation should be interpreted with respect to that year.

Figure 5 shows that, in our base case setup, the long-run effect of reducing fertility from the UN medium variant to the low variant is to raise income per capita by 11.9 percent at a horizon of 50 years. At a 20-year horizon, the increase in income per capita is 5.6 percent.[20] Because fertility in the alternative scenario is lower than in the baseline scenario for the entire period we examine, income in the two scenarios continues to diverge.

Before going further, we compare the findings of our simulation model with results from Bloom and Canning (2008), a widely cited cross-country regression study that appeared in this journal. In that paper, the independent variable of interest was the growth rate of the working-age fraction of the population, and the dependent variable was the growth rate of income per capita. The relevant coefficient was estimated at 0.996 using a simple OLS regression and at 1.394 when the authors used lagged endogenous variables as instruments.

To compare the findings of Bloom and Canning to our results, we first look at the growth rate of the working-age fraction of the population in our baseline and alternative scenarios. In both scenarios, the working-age fraction is 0.538 in 2010, the first year of our simulation. Under the medium-fertility scenario, the fraction rises to 0.625 in 2060, and to 0.653 under the low-fertility scenario. The implied annual growth rates of the working-age fraction are 0.301 percent per year in the medium-fertility variant and 0.389 percent per year in the low-fertility variant. To derive the effect of lower fertility on income growth, we multiply the difference between these two growth rates (that is, 0.088 percent per year) by the coefficient in Bloom and Canning. This yields an income growth differential between the two scenarios of 0.088 percent per year using their OLS estimate and 0.123 percent per year using their instrumental variables estimate. By contrast, in our simulation, the change in fertility from the medium to the low variant leads to a rise in income per capita of 11.9 percent over the first 50 years of the simulation, implying an increment to growth of 0.225 percent per year. In other words, the effect that we find in our simulation is roughly twice as large as theirs: about two tenths of a percentage point, as opposed to one tenth, in average annual growth.

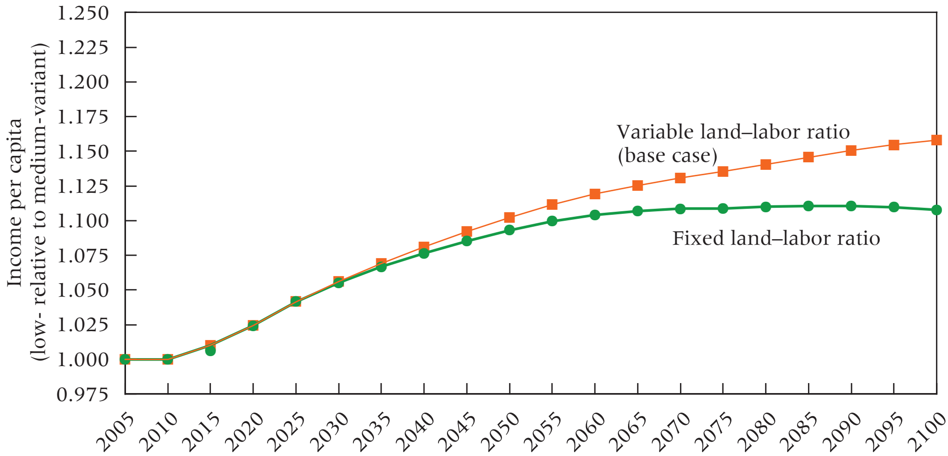
Component channels

As discussed above, demographic change affects economic outcomes through a number of channels, which may operate at different relative intensities at different time horizons. It is of interest to decompose the overall effect of fertility reduction into the parts that run through these different channels. Some caution is necessary, however, because there are clearly interactions among the different effects. In particular, the effect of fertility through any one channel will depend on which other channels are operative. For example, the effect of increased labor force participation of working-age adults will depend on the fraction of the population made up of such adults. To address this problem, we perform all of our analyses of the effects of fertility through each of the different channels under the assumption that all the other channels are operative. That is, we consider the results in our full simulation relative to the case where one channel is "deleted" (an alternative would be to assume that no other channels were operative).

We begin by looking at several channels individually. This allows us to analyze the sensitivity of our results to assumptions about key parameters. We then perform a full decomposition, showing the relative importance of the different channels at different time horizons.

To gauge the importance of non-reproducible factors, we conduct a simulation in which the level of land per worker in the alternative scenario follows the same path as it does in the baseline scenario. In other words, we ignore the effect of lower fertility in preventing the land–labor ratio from falling, while retaining all the other economic effects of fertility decline. Figure 6 compares the path of output per capita in this case to the base case. The figure illustrates the extent to which what we have termed the Malthus effect oper-

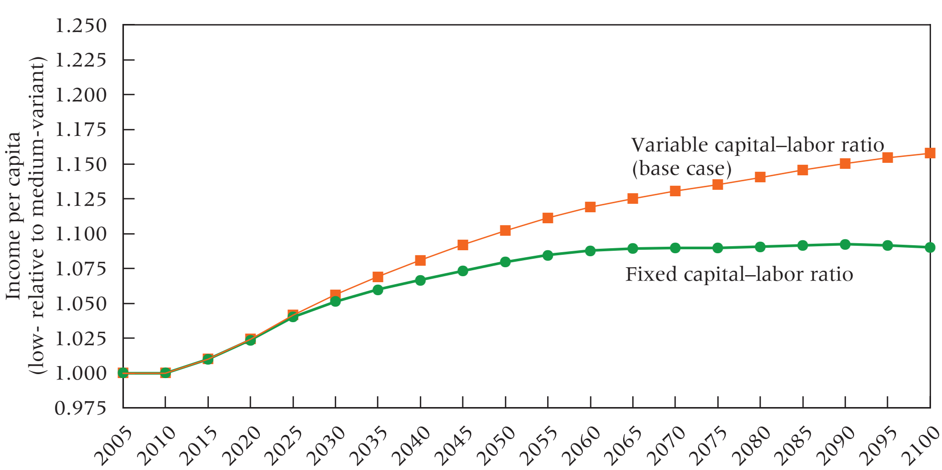
FIGURE 6 Effect of the land–labor ratio on income per capita, illustrated with the example of Nigeria



ates only over long time horizons. For the first 35 years of the simulation, the path of income per capita when the Malthus effect is suppressed looks only slightly different from its path when the effect is present (for the first 15 of these years, this is true because the ratio of land to labor is the same across the baseline and alternative scenarios). In the longer run, however, the effect of reduced congestion of the fixed factor becomes prominent. At an 80-year horizon, income per capita is only 11.1 percent above baseline with the effect suppressed, versus 15.1 percent above baseline with the effect present.

We conduct a similar exercise to examine the importance of the capital-shallowing channel or, as we called it, the Solow effect. Specifically, we ex-

FIGURE 7 Effect of the capital–labor ratio on income per capita, illustrated with the example of Nigeria



amine the case in which the level of physical capital per worker is the same in the alternative scenario as it is in the baseline. The result is shown in Figure 7. As with the Malthus effect, suppressing the Solow effect for the first 15 years of the simulation does not affect the level of income per capita, because the number of workers does not differ between the two scenarios. At year 50, output per capita is 8.8 percent above baseline when the Solow effect is suppressed, compared to 11.9 percent above baseline when the Solow effect is present.

Figure 8 shows the dependency effect, comparing the base case to the case where the dependency ratio in the alternative scenario is fixed to remain the same as in the baseline. Here, not surprisingly, the phase-in of the effect is almost immediate. Fifteen years after the beginning of the simulation, income per capita is only 1.8 percent above baseline when the dependency effect is suppressed, versus 4.2 percent above baseline when the effect is present. By year 50, the income per capita is 5.2 percentage points higher in the base case than in the case where the dependency effect is suppressed. From that point onward, the difference between the two paths appears roughly constant.

In Figure 9, we vary the amount of extra human capital that is produced by an additional year of schooling. As discussed above, our base case assumption is that the return to education is 10 percent per year of schooling. In the figure, we show alternative projections under three levels of the return to education: 20 percent and 2.8 percent, which are consistent with the upper-bound of estimates from Banerjee and Duflo (2005) and the estimate of Oyelere (2010), respectively, as well as a return of zero, which suppresses this channel completely. The figure shows that schooling plays an appreciable role in determining the economic effects from reduced fertility. At a horizon of 50 years, for example, income per capita is 9.4 percent above baseline in

FIGURE 8 Effect of the dependency ratio on income per capita, illustrated with the example of Nigeria

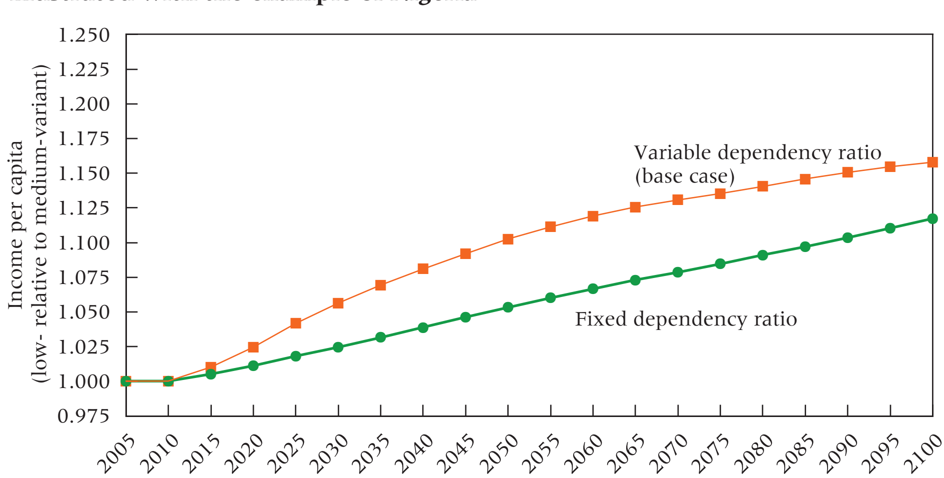
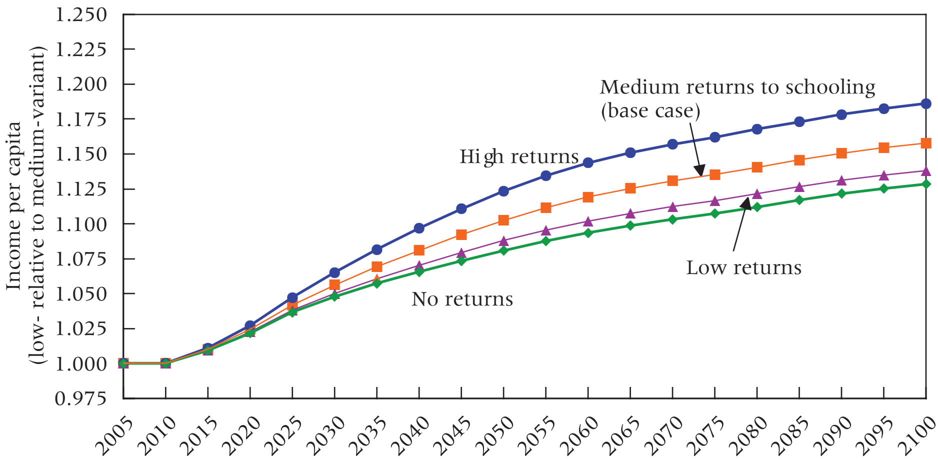


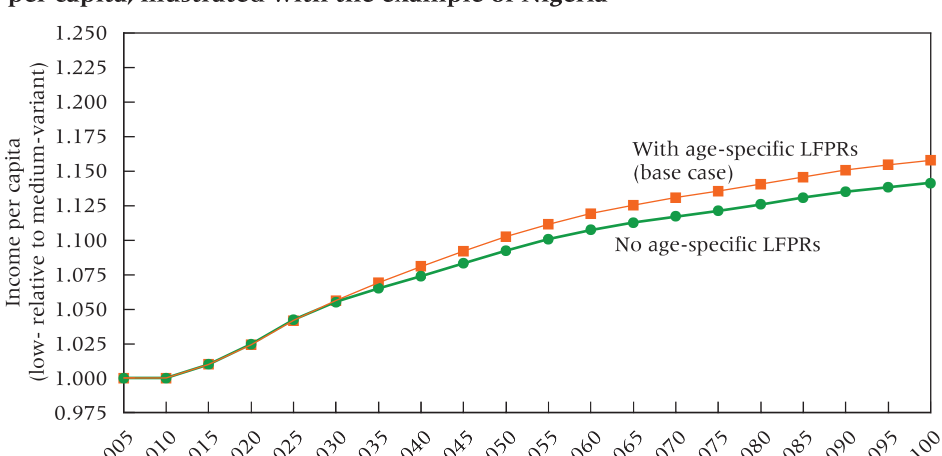
FIGURE 9 Effect of returns to schooling on income per capita, illustrated with the example of Nigeria



the case where the return to schooling is zero (which is the same as if there were no increase in schooling), versus 11.9 percent higher in the base case. Thus, roughly speaking, schooling accounts for one quarter of the income gain (from lower fertility in the alternative scenario relative to baseline) at 50 years. As would be expected, the effect of higher schooling resulting from lower fertility phases in as the cohorts that received the additional schooling enter the labor force and replace those that did not. Thus, for the first 15 years of the simulation, this channel contributes little to higher income.

Figure 10 shows the life-cycle labor supply effect. We compare the base case parameterization of our model to the case where labor force participation

FIGURE 10 Effect of age-specific labor force participation on income per capita, illustrated with the example of Nigeria



rates are constant across age groups. The life-cycle labor supply channel has a modest effect on income per capita. After a horizon of 50 years, income per capita is only 1.2 percentage points lower without the life-cycle labor supply effect than in the base case.

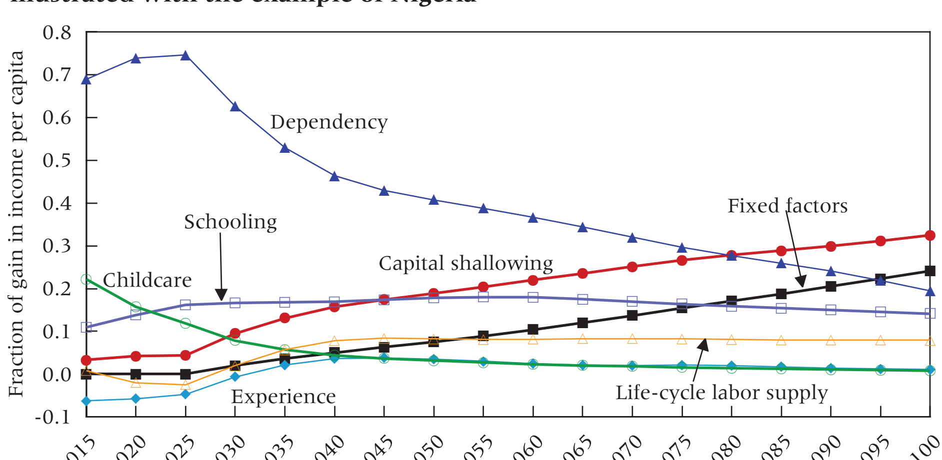
Finally, we conducted similar tests on the robustness of our assumptions regarding the experience and childcare channels, both of which showed much smaller effects than those examined above (see the working paper version for more details).

Decomposition of channels

Figure 11 presents a full decomposition of the fraction of the gain in income per capita at each point in time that is attributable to the different channels incorporated. Because of interactions among the channels, the individual channel effects that we study above do not sum to the total effect of a decline in fertility on income per capita. To conduct a decomposition of the fraction of the gain in income per capita that is due to each channel, we thus proceed as follows. As above, we calculate the importance of individual channels by comparing the level of income per capita in each year in our base case projection to the level of income per capita when the channel is suppressed. For each year, we then add up these individual effects to obtain a proxy for the total effect that ignores interactions. Finally, we divide the individual effects by the proxy (for the total) to produce a share of the total income gain attributable to each effect at each time horizon.

The figure shows that the dependency effect is by far the dominant channel in the short run, explaining roughly 70 percent of the income gain

FIGURE 11 Decomposition of the gain in income per capita by channel, illustrated with the example of Nigeria



in the first 15 years of the simulation, and only falling below 40 percent of the total after 45 years. The childcare effect, which is conceptually very similar to the dependency effect, has a somewhat comparable trajectory, although at a much lower level. At a horizon of 50 years, the four dominant effects are dependency (36.7 percent of the total gain), capital shallowing (22.0 percent), schooling (18.0 percent), and congestion of fixed factors (10.4 percent). At a horizon of 90 years, the same four effects are dominant, but in a different order: capital shallowing (32.4 percent), congestion of fixed factors (24.1 percent), dependency (19.5 percent), and schooling (14.2 percent).

Conclusion

For more than half a century, economists and demographers have debated the extent to which reducing fertility in a developing country would raise income per capita. There remains little agreement on the answer. One segment of the scholarly community views reduced fertility as an important factor contributing to economic development. Others go further and argue that reduced population growth is a necessary condition for achieving other development aims. However, another group of scholars view fertility reduction as a consequence, rather than a cause, of other underlying changes that produce development. Under this view, a reduction in fertility would not, by itself, contribute significantly to economic growth.

In this article, we have tried to reorient the discussion of how fertility affects growth along pragmatic and quantitative lines. We have sought to avoid both the methodological failings and the opacity that we see in much of the previous literature. We have argued that econometric analysis of aggregate data on fertility and economic outcomes (for example, in a cross-country regression) is unable to identify causal relationships. Fertility is an endogenous variable, so describing how it covaries with economic development is very different from being able to specify the causal link between the two. Instead, our chosen tool is a simulation model, an approach that harks back to the beginning of this literature. In the simulation approach, the channels by which changes in fertility affect economic outcomes can be individually specified, and identification can be achieved by looking at microeconomic evidence. In addition to this microeconomic evidence, we have brought to bear data on demographic structure and standard components of quantitative macroeconomic theory.

We dealt with the problem of opacity by setting out the model's structure and performing analysis of sensitivity to changes in parameters or elimination of different channels. Further, to a far greater extent than previous authors, we have parameterized our model on a base of well-specified microeconomic studies. In this sense, we have incorporated a good deal of literature that is relevant to the issue of how fertility affects economic growth but does not address that question directly. Finally, we offer readers a working version of our model in which users can suppress channels, change parameters, and alter the demographic scenarios.

We apply our simulation model to data from Nigeria. The reduction in fertility that we consider is the difference between the medium- and low-fertility variants of the UN's (2010) population scenarios. This is a difference in the TFR of 0.5, phased in over a period of 15 years, relative to a baseline of declining fertility. Under our base case model structure and parameterization, we find that this reduction in fertility would raise output per capita by 5.6 percent at a horizon of 20 years, and by 11.9 percent at a horizon of 50 years. The dependency effect, and to a lesser extent the labor supply effects, are the dominant channels by which reduced fertility affected income per capita in the short run (the first quarter century after a fertility reduction). At a horizon of 50 years, the four dominant effects were dependency, capital shallowing, schooling, and congestion of fixed factors. At a horizon of 90 years, capital shallowing is the dominant trend, followed by congestion of fixed factors.

Is the effect of fertility reduction that we find large? To some extent, the answer depends on what benchmark one is using. NRC (1986) framed the question as whether a reduction in fertility would be sufficient to "vault a typical country into the ranks of the developed" and concluded that the answer is definitely no. The results presented here are certainly consistent with this view. But the belief that fertility reduction alone could be the key to development probably has few adherents today. Authors such as Das Gupta, Bongaarts, and Cleland (2011) and Sinding (2009) use characterizations such as "important secondary role" and "necessary condition" in referring to the effect of slowing population growth on development. Although they do not quantify these characterizations, our sense is that the results we find are smaller than what these authors believe. For example, the effect on GDP per capita that we find, 11.9 percent over 50 years resulting from a TFR reduction of 0.5, amounts to a change in the growth rate of only about 0.2 percent per year. By contrast, between 1990 and 2009, GDP per capita in Nigeria grew at 2.9 percent per year (although during the two decades prior to that it actually fell slightly).

Another useful benchmark against which one can compare our results is the findings of cross-country regressions in which the growth rate of income per capita is the dependent variable and measures of demographic change (such as the growth rate of the working-age fraction of the population) are on the right hand side. Regressions like these are widely used in policy-oriented discussions of the effects of demographic change. In this article we applied the findings in one such study, Bloom and Canning (2008), to the demographic scenarios that we analyzed. We found that our estimate of the economic impact of fertility reduction is roughly twice as large as theirs.

Another way to benchmark our results is to look directly at poverty. This seems natural, given that we are focusing on poor countries, most of which will likely still be poor several decades hence. In 2010, the poverty rate in Nigeria was 68 percent. The World Bank (2000) estimated the elasticity of poverty rates with respect to average income to be in the neighborhood of two. Thus, the increase of 5.6 percent in income per capita at a horizon of 20 years would reduce the poverty rate by approximately 7.5 percentage points. This seems to us to be a significant magnitude. Of course, as we have stressed repeatedly, concluding that a given fertility reduction would have an economically significant effect on income per capita is very different from concluding that engineering such a fertility reduction would be a good thing. To address the latter question, one would have to know the costs, both financial and in terms of welfare, of lowering fertility, and one would also have to be able to assess the utility consequences of children not being born.

Finally, in discussing the magnitude of our results, we return to the issue of methodology. We contend that a key advantage of our simulation model is its transparency. If one believes that the effect of population on economic development is larger than what we have estimated, then there has to be a way to alter our model to produce that larger effect, either by changing the parameters or by introducing new channels that we have omitted. We believe that conducting the debate in terms of specific parameters and channels is likely to be far more enlightening than debating the overall effect of fertility changes.

Notes

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1 A fully functioning version of the model, which the user can manipulate to suppress channels, change parameters, and alter the demographic scenario, is available from the authors upon request.

2 An earlier draft of the working paper version of this article (Ashraf, Weil, and Wilde 2012) presented a baseline scenario of constant fertility (in a stable population) and an alternative scenario of the total fertility rate falling instantaneously by one and then remaining at that level indefinitely. While far less realistic, this setup allowed for a cleaner analysis of the time profiles with which different channels leading from fertility to economic outcomes operate. That earlier draft is available upon request.

3 Our analysis in this article is focused on developing countries, thus the particular economic channels in our model are those we consider most germane in this context. For more developed countries, which have lower

population growth, older population age structures, and large government-mediated transfers to the elderly, different issues are relevant. See, for example, Weil (2008b) and Coleman and Rowthorn (2011).

4 The exponents on capital and labor were 0.4 and 0.5, respectively, implying a 10 percent share for a fixed factor (presumably land).

5 In reviewing the BACHUE model (as applied to the Philippines) and other "second-generation" economic-demographic simulation models, Sanderson (1980) concluded that none of these models was of practical use to a developing-country policymaker, either because they featured an overly simplistic agricultural sector or because they suffered from other severe technical problems that made their policy implications highly questionable.

6 Kohler (2012) discusses how this model is still in active use in policy evaluation.

7 In most simulation models, the key characteristic that varies exogenously among scenarios is fertility. An exception is Young (2005), who simulated the effect of the AIDS epidemic in South Africa on per capita income, using a Solow model with human and physical capital (but no land). Relative to our work, Young (2005) was more concerned with long-run effects whereas we emphasize transition paths. Our methodological approach is also different in that we rely as heavily as possible on well-identified econometric estimates produced by other authors, rather than on producing our own estimates.

8 Birdsall (1988) and Kelley (1988) provided excellent summaries of contemporary thinking about the effect of fertility on economic outcomes.

9 There may also be a direct effect of the population age structure on productivity (Feyrer 2008).

10 See Ashraf, Weil, and Wilde (2012).

11 The UN does not provide explicit mortality schedules, but these can be "backed out" from the other data in their forecasts. The different fertility scenarios feature the same future paths of age-specific mortality, with life expectancy at birth (males and females) rising from 50 in 2005–2010 to 60 in 2030–2035 and 70 in 2065–2070.

12 In the working paper version of this article, we examine more extensively the role of fixed factors of production. We consider the sensitivity of our results to both the share of land in national income and the elasticity of substitution between land and other factors of production. We also examine data on natural resource shares of national income.

13 In the working paper version of this article, we consider two alternative models of investment. First, we allow for variable age-specific saving rates, with workers in their prime earning years having higher saving rates. This introduces the life-cycle saving channel through which demographic change additionally affects growth. Second, we consider the case of an economy that is fully open to international capital flows. This suppresses the Solow channel whereby slower growth of the labor force raises the level of capital per worker.

14 For their full sample of 48 countries, the average values are 0.0495 and –0.0007, respectively.

15 The coefficient of 0.52 is derived from Table 9, Column 2 in their paper. They report a standardized beta of 0.54, to which we apply the standard deviation for years of schooling of 0.95 from their summary statistics.

16 See Rosenzweig and Wolpin (1980) and Angrist and Evans (1998).

17 See Bloom et al. (2009) and Porter and King (2012).

18 Because of heterogeneity in completed fertility, a reduction in the TFR from three to two will not mean that all children not born would have been parity three. Instead, some would have been higher parity, while others would have been first or second children. Thus, our method will understate the increase in labor input that results from such a reduction in fertility.

19 Bloom et al. (2009) examined the effects of fertility decline on female labor force participation in cross-country data, using changes in abortion laws as an instrument for fertility. They estimated the change in the age-specific female labor force participation rate that results from a decrease in the TFR by one. Taking the weighted average by female population age structure, such a decline

produces an increase of 13.5 percent in total female labor force participation. Their estimates imply an average labor market time cost per marginal child of 4.4 years, which is far higher than the figure we use. However, the estimates in Bloom et al. (2009) are identified by variation in high-income countries, where baseline fertility levels are far lower and where separation between home and workplace generally means that childcare and labor market input are mutually exclusive.

20 Using the UN high-fertility and medium-fertility population projections as our baseline and alternative scenarios, respectively, the increase in income per capita resulting from lower fertility is 11.5 percent at a horizon of 50 years, and 5.4 percent at a horizon of 20 years. Since the difference in the TFR (at any point in time) between the high- and medium-fertility scenarios is the same as that between the medium- and low-fertility scenarios, and because all three scenarios have identical assumptions about mortality (and net migration) rates, the effect of fertility reduction under our base case setup is roughly linear in the size of the reduction.

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