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Mortality Reductions, Educational Attainment, and Fertility Choice*

Abstract

This paper explores the role of life expectancy as a determinant of educational attainment and fertility, both during the demographic transition and after its completion. Two main points distinguish our analysis from the previous ones. First, together with the investments of parents in the human capital of children, we introduce investments of adult individuals in their own education, which determines productivity in both the goods and household sectors. Second, we let adult longevity affect the way parents value each individual child. Increases in adult longevity eventually raise the investments in adult education. Together with the higher utility derived from each child, this tilts the quantity-quality trade off towards less and better educated children, and increases the growth rate of the economy. Reductions in child mortality may have similar effects – or may only affect fertility – depending on the nature of the costs of raising children. This setup can explain both the demographic transition and the recent behavior of fertility in "post-demographic transition" countries, ignored by the previous literature and incompatible with most of its results. Evidence from historical experiences of demographic transition, and from the recent behavior of fertility, education, and growth supports the predictions of the model.

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1 Introduction

Major demographic changes swept the world in the course of the last century. Life expectancy at birth rose from 40 years to around 70 years. Total fertility rates plummeted from around 6 points to close to 2 points or below. Today, over 60 countries, comprising almost 50% of the world population, have fertility rates below replacement level (2.1), and the vast majority of people live in countries where population is expected to stabilize within the next fifty years (Robinson and Srinivasan, 1997). Furthermore, several developed countries have recently experienced increasingly low fertility levels. These include Austria, Canada, Greece, Japan, and Spain, all of which have fertility rates below 1.5. In short, recent reductions in fertility did not seem to be restricted to experiences of demographic transition. Time and again, developed countries, believed to have finished their transition long ago, experienced increasingly low fertility levels.

This phenomenon, largely overlooked both empirically and theoretically by the demographic and economic literature, points to the necessity of understanding the recent behavior of fertility from a more general perspective, not restricted to the demographic transition. The goal of this paper is to analyze the role of life expectancy gains, determined from technical developments in health technologies, as the driving force behind the changes in fertility, educational attainment, and growth observed during the process of demographic transition and thereafter[1] . The major role attributed to mortality in the empirical literature on the demographic transition suggests that life expectancy changes are indeed an independent driving force.[2] This key part played by life expectancy *vis-à-vis* income is further supported by the striking stability of the cross-sectional relationship between life expectancy, fertility and schooling, as opposed to the changing relationship between income and these same demographic variables (this evidence is discussed in detail in Section 2). In this paper, we look at how changes in child mortality and adult longevity affect the incentives of individuals to have children and to invest in education, and what the consequences of these changes are to the process of economic development. Changes in life expectancy can help explain the reductions in fertility that characterize the demographic transition, and the changes in demographic variables that accompany economic growth.

In the last decade, extensive work has been done on the determinants of fertility, and the relation between fertility and investments in human capital. A large part of this literature has tried to explain the demographic transition as a consequence of increased investments in human

[1] The direct welfare implications of the gains in life expectancy, and their impacts on the evolution of cross-country inequality, are discussed in Becker, Philipson and Soares (2002), and Philipson and Soares (2002).

[2] See, for example, Heer and Smith (1968), Cassen (1978), Kirk (1996), Mason (1997), and Macunovich (2000). In short, the view is that "if there is a single or principal cause of fertility decline, it is reasonable to ascribe it to falls in mortality, which was the major cause of destabilization" (Kirk, 1996, p.379).

capital due to technological change (Azariadis and Drazen,1990; Galor and Weil, 1996, 1999, and 2000; Hansen and Prescott, 1998; and Tamura, 1996).[3] A second strand of literature analyzes how changes in child mortality affect fertility decisions, occasionally incorporating investments of parents in the human capital of children (Blackburn and Cipriani, 1998; Boldrin and Jones, 2002; Ehrlich and Lui, 1991; Kalemli-Ozcan, 1999; Kalemli-Ozcan , Ryder, and Weil, 2000; Meltzer, 1992; Momota and Fugatami, 2000; and Tamura, 2001).

This paper improves upon this literature by stressing the importance of distinguishing between child and adult mortalities, and by explicitly incorporating adult investments in human capital into the analysis. This allows the model to addresses the recent phenomenon of small and decreasing fertility in developed countries, ignored by the literature cited here and incompatible with most of its results. Besides, it reveals the potential importance of adult longevity in determining the behavior of the economy after the demographic transition.

Two specific assumptions distinguish our model from the previous ones. First, we let adult longevity affect the way in which parents value each individual child, in much the same way that the number of children does in the traditional fertility literature.[4] This assumption is simply an extension of the widely accepted effect of child mortality on fertility to later ages. Intuitively, it can also be understood in these terms, once one considers that individuals are not only concerned with the survival of their children, but also with the continuing survival of their whole lineage. Specifically, we assume that the utility that parents derive from each child depends on the number of children and, additionally, on the lifetime that each child will enjoy as an adult. Acknowledging the importance of adult longevity to the way in which parents value each child has important consequences in terms of fertility choices. This hypothesis alone helps explain the behavior of fertility after the demographic transition.

Second, we incorporate explicitly the distinction between investments of parents' in the human capital of children and investments of adult individuals in their own human capital. This generates direct predictions about educational attainment and helps distinguish between the economic

[3] Galor and Weil (1999) discuss briefly that reductions in mortality could increase investments in human capital and reduce fertility via the quantity-quality trade-off.

[4] The issue of fertility choice in underdeveloped economies is controversial in the demographic literature. Nevertheless, evidence indicates that there is always some margin of choice. Several kinds of actions taken in 'pre-modern' societies, directly or indirectly, affect fertility outcomes, including marriage patterns, breast feeding habits, abortion, and sexual practices (see Demeney, 1979; Caldwell, 1981; Kirk, 1996; and Mason, 1997).

Also, although some individual decisions usually affect mortality, our interest here is focused on the gains in life expectancy observed in the last two centuries, which were largely due to scientific and technical developments. At the individual level, these were partly exogenous. Also, these gains were exogenous to the less developed countries, which experienced mortality reductions independent of improvements in economic conditions. The gains in life expectancy in less developed countries are thought to be consequence of the absorption of knowledge generated elsewhere and of the help provided by international aid programs (see Preston, 1975 and 1980; Kirk, 1996; and Becker, Philipson, and Soares, 2001).

impacts of changes in adult and child mortality.[5]

These two features of the theory play central roles in the mechanics of the model. Briefly, increases in adult longevity eventually raise the investments in education, which increase the productivity of individuals both in the labor market and in the household sector. Also, higher life expectancy tilts the quantity-quality trade-off towards less and better educated children and tends to move the economy out of a "Malthusian" equilibrium. Once the economy abandons the "Malthusian" regime, increases in adult longevity reduce fertility, increase educational attainment, and increase the growth rate of the economy. Reductions in child mortality may have similar effects, or may only affect fertility, depending on the nature of the costs of raising children. This setup can explain the demographic transition and the recent behavior of fertility in "post-demographic transition" countries. Besides, it reconciles theory with the evidence on the changing relationship between income and several demographic variables.

The paper also presents different sets of evidence to support the model. Recent work suggests that individuals' predictions of their own life expectancies are considerably accurate, and react to exogenous events in consistent ways (see Hamermesh, 1985; Hurd and McGarry, 1997; and Smith et al, 2001). Therefore, the role of life expectancy in explaining changes in behavior may indeed be empirically relevant. We argue that the exogenous role played by life expectancy in the model is justified by the fact that recent reductions in mortality were largely independent of improvements in economic conditions. Also, we argue that the historical experiences of demographic transition display patterns that agree with the predictions of the model. Indeed, life expectancy gains appear to be a driving force behind the changes observed in the other variables. Finally, we test the predictions of the model using a cross-country panel, with data between 1960 and 1995. The behavior of fertility, educational attainment, and growth in 'post-transition' economies supports the theory. In brief, the estimated model implies that a 10 year gain in adult longevity implies a reduction of 1.7 points in total fertility rate, an increase of 0.7 year in average schooling in the population aged 15 and above, and a growth rate higher by 4.6%. A reduction of 100 per one thousand in child mortality implies a reduction of 2 points in the total fertility rate.

The structure of the paper may be outlined as follows. Section 2 motivates the analysis by presenting a very simple but striking fact: while the cross-sectional relationship between income and some key demographic variables (life expectancy, fertility, and schooling) has been consistently shifting in the recent past, the relationship between life expectancy and fertility and schooling has remained considerably stable. This observation suggests that there is a dimension of changes in

[5] Furthermore, this approach is more realistic and brings the theory closer to the empirical accounts that justify the impacts of life expectancy on educational investments (see, for example, the discussion on rates of return in Meltzer, 1992).

life expectancy that is not explained by material development (income), but that seems to explain changes in fertility and educational attainment. Section 3 describes the structure of the model, and analyzes the effects of changes in adult longevity and child mortality. Section 4 discusses how well the model describes real demographic transition histories, and tests the predictions of the model using a cross-country panel. The final section summarizes the main results of the paper.

2 The Recent Behavior of Life Expectancy, Educational Attainment, and Fertility

The traditional growth literature looks at income as the single variable either driving or summarizing the changes in all relevant development outcomes. In this perspective, gains in per capita income improve nutrition and health consumption, which reduces mortality rates; income gains also change the quantity-quality trade off in terms of number and education of children, which reduces fertility and increases human capital investment. Statements like these are common places in the economics profession, and it seems fair to say that they give an accurate description of the consensus regarding the main changes taking place during the process of economic development.

Even though there is a lot of truth to this view, it is far from giving a complete picture of reality. Recently, the relationship between income and crucial demographic variables, such as life expectancy or fertility, has been clearly unstable. Figures 1 to 3 illustrate the changing relationship between income, life expectancy, fertility, and educational attainment.[6] To concentrate on economies that share the same demographic regime, the figures refer only to countries that had already started the demographic transition in 1960.[7]

Figure 1 shows that, for constant levels of income, life expectancy has been rising.[8] Logarithm curves are fitted to the 1960 and 1995 cross sectional relation between per capita GNP and life expectancy. For lower levels of income, life expectancy at birth has increased by more than five years in the period between 1960 and 1995. This means, for example, that a country with per capita GNP of US$5,000 in 1995 had a life expectancy roughly 10% higher than a country with per capita GNP of US$5,000 in 1960.

[6] The general results illustrated in Figures 1 to 5 do not depend in any way on the specific statistics used, or on the presence of any particular country in the sample. Detailed description of the variables is saved until the empirical section. The logarithm curves used are of the general form $y = \alpha + \beta \ln(x)$, and the power curves used are of the general form $y = \alpha x^{\beta}$.

[7] A more precise reason for the restricted sample is given in the theoretical section. Empirically, some objective criterion defining whether a country already started the demographic transition has inevitably to be chosen. Our choice is the cutoff point "countries that had life expectancy at birth above 50 years in 1960," also to be justified later on. The results do not depend on the specific criterion chosen, and there should not be much doubt regarding the countries actually included in the sample (see Appendix).

[8] This phenomenon was first noticed by Preston (1975), who analyzed data between 1930 and 1960.

Figure 2 tells an analogous story for the relationship between income and fertility. Again, curves are fitted to the 1960 and 1995 cross sectional relationship between income and fertility. For constant levels of income, fertility has been falling. These reductions have been as large as 2 points for countries with per capita income around US$3,000, and even larger for poorer countries.

Finally, as Figure 3 shows, the story is not different for the relationship between education and income. Logarithm curves are fitted to the cross sectional relationship between income and average schooling in 1960 and 1995. Gains in average schooling in the period were usually over 1 year, for constant levels of income.

One immediately wonders whether these changes in life expectancy, education, and fertility are interrelated, and what the specific mechanism connecting them is. An insight in this direction is gained by looking at the relation between life expectancy and the other two demographic variables.

In Figure 4, we plot the cross sectional relation between life expectancy and fertility in 1960 and 1995. The lines are polynomials (3^{rd} order) fitted to the different years. At first sight, the shift in the position of the curve suggests that a change in the relationship is being portrayed. But if we look closely, there is not much overlapping of the two curves, and when the overlapping does actually occur, the points relative to the different years are more or less evenly distributed over the same area. The two segments look more like an approximation to a single stable nonlinear function than a description of a changing relationship. This point is further explored by fitting a single nonlinear function (3^{rd} order polynomial) to the whole data set, assuming that a stable relation is present throughout the period. Visually, the curve seems to have a good fit, and the functions estimated separately for each sub-period seem to merge into it. The single fitted line actually explains more of the overall variation in the data than the two polynomials fitted independently to each year (R^2 of 0.78, against 0.76 for 1960 and 0.21 for 1995). The interesting point is that this curve does not separate points from 1960 and 1995 as being below or above it, as a curve fitted to all the data in Figures 1, 2, or 3 would do. Points from the different years are distinguished as being more on its left portion or on its right portion, as if countries were sliding on this curve through time, via increases in life expectancy and reductions in fertility.

The results regarding life expectancy and educational attainment are even stronger. Figure 5 plots the cross sectional relationship between these two variables in 1960 and 1995, and fits a power curve to each year. The stability of the relationship through time is clear. Indeed, the two curves almost merge into each other for the region over which there are observations for both years. Again, countries seem to be sliding on this curve through time, as life expectancy and educational attainment rise simultaneously.

The figures presented illustrate that, for constant levels of income, life expectancy is rising, fertility is declining, and educational attainment is increasing. At the same time, changes in fertility and schooling are following very closely the changes in life expectancy. This has been happening in such a way that, for a constant level of life expectancy at birth, fertility and schooling have remained roughly constant.

In short, there is a dimension of changes in life expectancy that is not associated with income, but that seems to be associated with changes in fertility and educational attainment. When one thinks about these facts, one realizes that while fertility and education are direct objects of individual choice, life expectancy has a large exogenous component, related to scientific knowledge and technological development. This reasoning suggests that exogenous reductions in mortality, together with a stable behavioral relationship between life expectancy, educational attainment, and fertility, may be the driving force behind the observed changes. In what follows, we develop a theory along these lines. Our goal is to explain the facts discussed above, together with the triggering of the demographic transition, as being determined by exogenous increases in life expectancy.

3 Theory

3.1 The Structure of the Model

Assume an economy inhabited by adult individuals, who live for a deterministic amount of time, when they work, consume, invest in their own education, have children, and invest in the education of each child. The model is the usual 'one sex model,' common to the fertility literature. We abstract from uncertainty considerations, to concentrate on the impact of adult longevity and child mortality on the direct economic incentives at the individual level. To make the model treatable, we also abstract from the presence of physical capital. Individuals, or households, have an endowed level of what we call 'basic' human capital (determined from previous generations' decisions), based on which they decide on how much to invest in their own 'adult' education. Adult education determines productivity both in the labor market and in the household sector. Households possess backyard technologies for producing goods, adult human capital, and basic human capital, and they decide on how to allocate their time across these different activities in order to maximize utility. As we will see later on, changes in adult life expectancy and child mortality will change the incentives to engage in these different activities.

In the model, adults live for T periods, and at age τ they have children. A fraction β of the born children dies before reaching adulthood. Parents derive utility from their own consumption in each period of life ($\frac{c(t)^\sigma}{\sigma}$), and from the children they have. Childhood can be thought of as an instantaneous phase: as soon as individuals are born they become adults, and there is no decision to be made as a child.

We assume that adults are concerned directly with the level of human capital of their children, via a constant elasticity function $\frac{h_c^\alpha}{\alpha}$, what is sometimes called a paternalistic approach. The traditional literature on economics of fertility usually assumes that the value that parents place on the human capital (or utility function) of each child is an increasing and concave function of the number of children. Since we are incorporating longevity and child mortality into the analysis, we also take into account the effect of these variables. We assume that, together with the number of children, parents also care about how long each child will live, in such a way that the relevant variable is the total lifetime of the surviving children ($(1-\beta)nT$), or what we call the total of 'child-years.' How much adults value the human capital of each child is an increasing and concave function of the total lifetime of the children, where this function is given by $\rho(.)$. But as a fraction β of the children will not reach adulthood, not all of them will enjoy these T years of life. As we treat n here as a continuous variable, we simply assume that $(1-\beta)n$ out of n born children will reach adulthood, avoiding thus the problems related to the uncertainty regarding the survival of each individual child. Therefore, $(1-\beta)nT$ assumes the role usually played by n alone in the traditional economic analysis of fertility. Intuitively, this set up extends the logic usually applied to child mortality rate to later ages. It is a natural extension, once one considers that individuals are not only concerned with the survival of their children, but also with the continuing survival of their whole lineage.[9] Additionally, we assume that there is a tendency towards satiation in terms of the total of child-years, in the sense that for sufficiently high values, its marginal utility is zero. This seems to be a sensible hypothesis once, holding T constant, we think about the biological constraints that nature imposes on the bearing and timing of births. It will also be important to assure that increases in life expectancy will eventually move the economy out of a Malthusian equilibrium.

With these hypotheses, the utility function is given by the following expression:

$$\int_0^T \exp(-\theta t)\frac{c(t)^\sigma}{\sigma}dt + \rho[(1-\beta)nT]\frac{h_c^\alpha}{\alpha},$$

where θ is the subjective discount rate, and $0 < \sigma, \alpha < 1$; $\rho'(.) > 0$; $\rho''(.) < 0$; and $\rho'(x) = 0$ for some $x = \overline{x} > 0$. The first term denotes the utility that parents derive from their own consumption, and the second term denotes the utility that they derive from their children.[10]

[9] In this case, individuals take into account that their children will need enough time to have their own children and raise them.

[10] Additionally, if we assume that parents enjoy having children only to the extent that they share part of their lifetime, the second term in the expression has to be integrated over time from τ to T, and discounted at the rate

Individuals face goods and time constraints: they have to allocate their total lifetime (T) between working (l), raising kids (b), and investing in their own education (e); and they have to allocate their lifetime income (y) between their own consumption ($c(t)$) and fixed costs of having children (f). Borrowing from future generations and bequests are not allowed. The time and goods constraints are given, respectively, by:

$$\begin{aligned} T &\geqslant l + bn + e, \quad \text{and} \\ y &\geqslant \int_0^T \exp(-rt)c(t)dt + \exp(-r\tau)nf \ , \end{aligned}$$

where r is the interest rate.

Parents' income is determined by how much adult human capital they have (H_p) and by how much they work (l). Adult human capital, together with the time invested in the children's human capital (b), also determines the basic human capital that each child will inherit (h_c). Finally, adult human capital itself is produced from the basic human capital that parents had once they entered adulthood (h_p), and from the time they spend investing in their own education (e). We assume that human capital and time are complements in all the production functions, such that adult human capital increases the individual's productivity both in the labor market and in the household sector, and basic human capital increases the productivity of education in generating adult human capital. Production functions take on simple multiplicative forms on human capital and time, so that we can write:

$$\begin{aligned} H_p &= Aeh_p + H_o, \\ h_c &= DbH_p + h_o, \text{ and} \\ y &= lH_p, \end{aligned}$$

where $D, A > 0$, and h_p is given.

This setup distinguishes between basic human capital and adult human capital: h denotes the kind of human capital formed during childhood, in which parents can invest, related to basic education and skills, and emotional development; H denotes the kind of human capital obtained during young adulthood, related, for example, to college or graduate education, or to professional training. We assume that individuals enter adulthood with a given level of basic education (h_p),

θ. Another possible variation of the model would be to distinguish between parent's adult longevity and children's adult longevity. In this case, we could write T_p and T_c and analyze only the impacts of changes in children's adult life expectancy (T_c). Both variations of the model deliver the same qualitative predictions that we obtain here.

and then, by deciding on how much to invest in their own education, they choose a level of adult human capital (H_p). h_c is the level of basic human capital that parents give to each of their children. H_o and h_o denote the levels of adult and basic human capital that individuals have, even in the absence of investments of any sort in education, maybe determined from innate skills or natural learning throughout life. As will be clear in the following sections, these factors play an important role in allowing for the existence of a so called Malthusian steady-state, with no investment in human capital and zero growth.

To concentrate on the issues of interest, we depart from this formulation and introduce some simplifying assumptions. Since our central interest is the long run behavior of the economy, mainly the inter-generational fertility and human capital decisions, we abstract from life cycle considerations by assuming that subjective discount rates and interest rates equal zero. Given the separability of the utility function over time, this implies constant consumption throughout life.

Incorporating these hypotheses, the objective function and the goods constraint can be rewritten as:

$$\begin{aligned} & T\frac{c^{\sigma}}{\sigma} + \rho[(1-\beta)nT]\frac{h_c^{\alpha}}{\alpha}, \quad \text{and} \\ lH_p &\geqslant Tc + fn. \end{aligned}$$

This is the benchmark model that guides our theoretical discussion. In the next sections, we analyze the effects of adult longevity and child mortality on educational attainment, fertility, and economic growth.

3.2 The Role of Adult Longevity

3.2.1 Static Implications of Longevity Gains

In this subsection, we look at the individual decision taking the initial level of basic human capital as given (h_p). In the following subsections, we discuss the implications of this decision process to the growth rate and dynamic behavior of the economy, and look at the properties of an equilibrium with zero growth and no investments in human capital.

As we hold child mortality constant, we save in notation by omitting the parameter β. Also, given that we look at an equilibrium with growth, the parameters f, h_o, and H_o become irrelevant as time goes by, so we ignore them. Defining $A_p = Ah_p$, $D_p = DA_p = DAh_p$, substituting for l in the time constraint, and for h_c in the utility function, the first order conditions (foc's) for, respectively, c, n, b, and e can be written as:

$$
\begin{aligned}
Tc^{\sigma-1} &= \frac{T}{A_p e}\lambda, && (1)\\
T\rho'(nT)\frac{(D_p be)^{\alpha}}{\alpha} &= b\lambda, && (2)\\
\rho(nT)(D_p be)^{\alpha-1} D_p e &= n\lambda, && (3)\\
\rho(nT)(D_p be)^{\alpha-1} D_p b &= \left(1-\frac{Tc}{A_p e^2}\right)\lambda; && (4)
\end{aligned}
$$

where λ is the multiplier on the constraint above.

Using equations 2 and 3 from the foc's, we get:

$$
nT\frac{\rho'(nT)}{\rho(nT)} = \alpha. \tag{5}
$$

Define $\varepsilon(nT) = nT\frac{\rho'(nT)}{\rho(nT)}$, the elasticity of the altruism function ($\rho(.)$) in relation to its argument. The expression above states that the agent will equate the elasticity of the altruism function to the constant elasticity of the h_c sub-utility: $\varepsilon(nT) = \alpha$.

If $\varepsilon(.)$ is monotonic, this implies that nT will always be constant, and that exogenous changes in T will have the following effect on n:

$$
\frac{dn}{dT} = -\frac{\varepsilon'(nT)n}{\varepsilon'(nT)T} = -\frac{n}{T} < 0. \tag{6}
$$

The equalization of elasticities expressed in equation 5 comes from the fact that n and b enter in a multiplicative way both in the objective function (via the sub-utility functions) and in the constraint. But the simple expression obtained above hinges on the additional assumption of constant elasticity for the h_c sub-utility function. What this buys us is the independency of n in relation to all other exogenous variables apart from T. With a more general specification, h_c would show up in the right hand side of 5, and it would allow the other exogenous variables to affect the optimal choice of n. But also in this case, the force working towards a negative relationship between n and T would still be present, even though it could possibly be weakened by the adjustment on h_c. The important factor here is the presence of T in the discount function $\rho(.)$, and the way in which T and n enter inside this function. As long as we have a specification where n and T have similar effects on $\varepsilon(.)$, there will be a tendency for n and T to move in opposite directions.[11] This is the role played here by the assumption that parents see number of children and adult lifetime of each child in similar ways, such that the relevant variable in determining

[11] More precisely, if the altruism function assumes the general form $\rho(n,T)$, and $\varepsilon(n,T) = \frac{\rho_n(n,T)n}{\rho(n,T)}$ denotes its elasticity in relation to n, the condition for $\frac{dn}{dT}$ to be negative is that $sign\{\varepsilon_n(n,T)\} = sign\{\varepsilon_T(n,T)\}$, where the subscripts denote partial derivatives.

how much parents care for each individual child is the total lifetime of the children, or the total of 'child-years.'

Using equations 1, 3, and 4 from the foc's, we get:

$$\begin{aligned} A_p e^2 &= Tc + A_p ebn, &(7)\\ \rho(nT)(D_p be)^{\alpha-1} D &= nc^{\sigma-1}. &(8) \end{aligned}$$

The constraint gives us $Tc + A_p ebn = TA_p e - A_p e^2$. Together with equation 7, this implies

$$e = \frac{T}{2}, \text{ and } \frac{de}{dT} = \frac{1}{2}. \tag{9}$$

Educational attainment increases with longevity. This should be expected, since increases in longevity increase the period over which the returns from investments in education can be enjoyed. Technological parameters, such as A and D, do not appear in expression 9 because they affect the costs and benefits of investments in education in the same way.[12] Although we see e here as a measure of educational attainment, it can also be regarded in more general terms as the specialization of individuals in the social division of labor. In this sense, this result is analogous to the one observed by Becker (1985) and Becker and Murphy (1992), where increases in the total time available for labor market activities tend to increase the amount of specialization.

With expressions 6 and 9 in hand, we can use equations 7 and 8 to determine the effects of exogenous changes in T on c and b (see Appendix A.1). This gives us

$$\frac{db}{dT} = \frac{-\left\{nc^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p \frac{b}{2}\right\}}{\rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p \frac{T}{2} - (1-\sigma)n^2 c^{\sigma-2}\frac{A_p}{2}} \lesseqgtr 0,$$

and

$$\frac{dc}{dT} = \frac{A_p\left\{n^2 c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p(nb + \frac{T}{4})\right\}}{\rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p T - (1-\sigma)n^2 c^{\sigma-2} A_p} \lesseqgtr 0.$$

Both $\frac{dc}{dT}$ and $\frac{db}{dT}$ can be either positive or negative, but, as shown in Appendix A.1, they cannot be both negative at the same time. c or b must necessarily increase as T increases, and both can increase at the same time. This is an obvious result once we realize that an increase in T also means an expansion in the constraint set. Since n goes down as T increases, and e increases only proportionally to T, the additional resources have to be 'consumed' either *via* a raise in b or *via* a raise in c, and possibly both.

[12] This result is analogous to the one originally obtained by Ben-Porath (1967), regarding the effect of the price of services of human capital.

The specific signs of $\frac{dc}{dT}$ and $\frac{db}{dT}$ depend on the values of the parameters, but the forces at work can be understood by looking at the individual problem. We know that, as T increases, the shadow price of the time b invested in h_c (n) goes down, and the productivity of this investment goes up (e), so that h_c must increase in the new optimum, even though b itself may decrease. Depending on the magnitude of the decrease in this shadow price, and on the concavity of the sub-utility functions (σ and α), it will be worthwhile for the individual also to increase c together with h_c, or to let c decrease as h_c increases.

It is easy to show that h_c unequivocally increases as T increases. Since $h_c = D_p be$, we have that $\frac{dh_c}{dT} = D_p(b\frac{de}{dT} + e\frac{db}{dT})$, which gives:

$$\frac{dh_c}{dT} = \frac{-D_p\left\{2c^{\sigma-1}n\left[1+(1-\sigma)\frac{bn}{c}A_p\right]+(1-\sigma)nc^{\sigma-2}A_p\frac{T}{2}\right\}}{\rho(nT)(\alpha-1)(D_p be)^{\alpha-2}DD_pT+(\sigma-1)n^2c^{\sigma-2}A_p} > 0.$$

It may seem counter-intuitive that c may actually go down as T increases, but it is important to keep in mind exactly what this theoretical experiment corresponds to. Here, we are analyzing an increase in T holding constant the level of basic human capital of parents (h_p). So, the result means that individuals entering adulthood that face an increase in their life expectancy will increase their own education and the basic education that they give to their children. And it may even be the case that they reduce their own consumption in each period in order to be able to invest more in the children's human capital. This is different from analyzing what will be the effect of T on the consumption pattern across generations. As we will see now, the model predicts that increases in T increase the growth rate of consumption across generations.

3.2.2 Dynamic Implications of Longevity Gains

In order for a steady-state to exist in this economy, preferences have to be homothetic over c and h_c. This guarantees that, as the economy grows, individuals from different generations will make optimal decisions such that c and h_p will grow at the same constant rate, and b, n, e, and l will be constant. In our set up, this is equivalent to imposing the condition $\sigma = \alpha$.[13]

Assuming that this condition holds, the production function of h_c implies that the growth rate of basic human capital is given by[14] $(1+\gamma) = \frac{h_c}{h_p} = DAbe$. From the goods constraint, we have that $Ah_ple = Tc$, which implies that, in steady-state, c will grow at the same rate of h_p, namely, $(1+\gamma)$. The same will also be true for the level of adult human capital (H_p), as can be seen from the production function $H_p = Aeh_p$.

[13] The existence of a steady-state is not essential. Nevertheless, it greatly simplifies the discussion. A formal analysis of the codition $\sigma = \alpha$ and of the consequences of deviating from this assumption is contained in Appendix A.2.

[14] If $DAbe < 1$, there is no growth in steady-state. In this case, H_o and h_o will be important in determining the human capital and consumption levels in equilibrium.

The effect of longevity gains on the growth rate of this economy is given by

$$\frac{d(1+\gamma)}{dT} = DA\left(b\frac{de}{dT} + e\frac{db}{dT}\right) > 0,$$

where the sign comes from the fact that, as proved in subsection 3.2.1, $\left(b\frac{de}{dT} + e\frac{db}{dT}\right) > 0$. Longevity gains increase the steady-state growth rates of consumption and all forms of human capital across generations.

We see the intuition for this result as follows. As longevity increases, incentives to invest in adult human capital increase, so that e – the amount of time devoted to parent's own education, or the educational attainment – increases. Once educational attainment and adult human capital (H_p) are higher, the individual becomes more productive in investing in children's human capital. The higher life span of each child also tilts the quantity-quality trade off towards less and better educated children, which reduces fertility. Together with the higher adult productivity in the household sector, this increases the level of basic human capital given to each child. Higher basic human capital, and more investments in adult education (higher educational attainment), end up increasing the growth rate of the economy.

The goal of this section is to stress the role played by adult longevity, through changes in the return to education and the way parents value each child, in the fertility and educational choices. Even though the definite sign of some of the effects depends on the functional forms adopted, these forces will always be at work, no matter how the model is specified. Our approach shows that, under reasonable assumptions, the role played by longevity gains is important enough to reduce fertility, increase educational attainment, and increase the growth rate of the economy.

3.2.3 The Malthusian Equilibrium

The model developed in the previous subsections can, with little modifications, accommodate a so called Malthusian equilibrium, where investment in all forms of human capital are at corner solutions and fertility varies positively with consumption and production. Besides, the model allows the characterization of the fertility transition as a natural consequence of the escape from such a steady-state, caused by successive increases in adult longevity.

We reincorporate the goods fixed cost of children (f) and the lower bound levels of basic and adult human capital (h_o and H_o) into the model. As mentioned before, in an equilibrium with consumption and all forms of human capital growing, these constant terms become irrelevant, and all conclusions discussed in the previous subsections hold. But in an equilibrium with zero growth and no investment in human capital these elements play a key role.

A Malthusian equilibrium in this set up is a situation where $h_p = h_o$, and the optimal choice of the individual implies $b = e = 0$. Collapsing all the constraints into only one and writing the problem in terms of $\{c, n, b, e\}$, this equilibrium is characterized by the following foc's, where λ is still the multiplier on the constraint:

$$\begin{aligned} c^{\sigma-1} &= \frac{\lambda}{H_o}, \\ T\rho'(nT)\frac{h_o^{\alpha}}{\alpha} &= \frac{f}{H_o}\lambda, \\ \rho(nT)h_o^{\alpha-1}DH_o &< n\lambda, \\ 0 &< \left[1 - \frac{Ah_o(Tc+fn)}{H_o^2}\right]\lambda. \end{aligned}$$

We call this corner solution a Malthusian equilibrium because, in a situation like this, changes in productivity – brought about, for example, by exogenous changes in H_o – will be positively correlated with changes in both consumption and fertility (for proof and further discussion, see Appendix A.3).

While this corner solution holds, changes in T will only be associated with changes in c and n. Working with the first two foc's and the constraint, we get the effects of T on c and n:

$$\begin{aligned} \frac{dn}{dT} &= \frac{\frac{f^2 n}{T^2}(\sigma-1)c^{\sigma-2} - \frac{h_o^{\alpha}}{\alpha}[nT\rho''(nT) + \rho'(nT)]}{T^2\rho''(nT)\frac{h_o^{\alpha}}{\alpha} + \frac{f^2}{T}(\sigma-1)c^{\sigma-2}} \lesseqgtr 0, \text{ and} \\ \frac{dc}{dT} &= \frac{f\frac{h_o^{\alpha}}{\alpha}[2nT\rho''(nT) + \rho'(nT)]}{T^3\rho''(nT)\frac{h_o^{\alpha}}{\alpha} + f^2(\sigma-1)c^{\sigma-2}} \lesseqgtr 0. \end{aligned}$$

Appendix A.3 shows that $\frac{dc}{dT}$ and $\frac{dn}{dT}$ may be positive or negative, but both cannot be negative at the same time. Either c or n must increase as T increases, since an increase in T corresponds to an outward shift in the constraint. Besides, $-nT\rho''(nT) < \rho'(nT) < -2nT\rho''(nT)$ is a sufficient condition for both $\frac{dc}{dT}$ and $\frac{dn}{dT}$ to be positive. The specific signs of $\frac{dc}{dT}$ and $\frac{dn}{dT}$ depend on the properties of the $\rho(.)$ function. This is expected, since the only way by which T changes the equality between marginal rate of substitution and price ratios of n and c is via the marginal utility of n (see foc's above).

While stuck in this Malthusian equilibrium, an economy can behave in many different ways as longevity increases: c and n may increase, c may increase and n decrease, or n may increase and c decrease. But as T keeps growing, no matter what happens to n and c, the inequalities characterizing the Malthusian equilibrium (last two foc's above) are eventually broken. When this happens, the economy enters in the dynamic process described in the previous subsections, where consumption and human capital grow from one generation to the next, and fertility declines with increases in longevity. Appendix A.3 proves this claim.

The intuition for the escape from the Malthusian regime is the following. As adult longevity increases, returns from investment in adult education also increase, because of the longer period over which education is productive. So, if gains in adult longevity are big enough, parents will start investing in their own education, and we will have $e > 0$. In relation to investments in basic human capital, the story is not so simple. As adult longevity gains take place, the total number of 'child-years' (nT) certainly increases, from the expansion of the constraint set and the concavity of the sub-utility functions. Generally, depending on the properties of $\rho(.)$, it could be the case that fertility would also keep growing and the corner solution on b would never be broken. The role played by the assumption "$\rho'(x) = 0$ for some $\overline{x} > 0$" is exactly to guarantee that, for nT sufficiently high, fertility will stop increasing and investments in children's human capital will be eventually undertaken (making $b > 0$). If this assumption holds, sufficiently large adult longevity can always guarantee positive investments in adult and basic human capital (b and $e > 0$). After this threshold point is reached, further increases in longevity trigger the demographic transition, and the economy moves into a sustained growth path.

In this case, the only engine behind the demographic transition and the escape from the Malthusian steady-state is the exogenous change in longevity. In the next subsection, we show that reductions in child mortality can play a similar role, both in terms of the steady-state with growth and the escape from the Malthusian equilibrium.

3.3 The Role of Child Mortality

3.3.1 Child Mortality in the Equilibrium with Growth

We now reintroduce child mortality into the analysis, under the assumption that costs related to having and educating children depend on the total number of born children. Under this assumption, the individual problem is exactly the same stated in the beginning of section 3. We start by analyzing the static implications of child mortality reductions, and then go on to discuss its effects on the growth rate of the economy and on the possibility of escape from the Malthusian steady-state. First order conditions for the equilibrium with growth are identical to the ones from section 3.2.1, apart from equation 2, which becomes

$$(1-\beta)T\rho'[(1-\beta)nT]\frac{(D_p be)^{\alpha}}{\alpha} = b\lambda, \tag{2'}$$

and from the fact that $(1-\beta)$ should be introduced multiplying nT inside $\rho(.)$, whenever $\rho(.)$ appears.

To explore the properties of this equilibrium as β changes, we follow the same steps from subsection 3.2.1. Using equations 2' and 3, we get

$$\varepsilon[(1-\beta)nT] = \alpha,$$

so that $\frac{dn}{d\beta} = \frac{n}{1-\beta} > 0$. The model implies constant total lifetime of surviving children. In a sense, parents have a target of 'child-years,' and they increase fertility when child mortality increases, to guarantee the achievement of this 'goal.'

Using foc's 3, 4, and the constraint, we get the same expression for e that we had before ($e = T/2$), which implies that $\frac{de}{d\beta} = 0$. Together with equation 1 and the constraint, this yields:

$$\begin{aligned}
\frac{db}{d\beta} &= \frac{(\sigma-1)bnc^{\sigma-2} - \frac{2c^{\sigma-1}}{A_p}}{(1-\beta)[(1-\sigma)nc^{\sigma-2} + \frac{\rho[(1-\beta)nT](1-\alpha)h_c^{\alpha-2}D^2T}{n}]} < 0, \text{ and} \\
\frac{dc}{d\beta} &= \frac{\rho[(1-\beta)nT](\alpha-1)h_c^{\alpha-2}D_pDeb + nc^{\sigma-1}}{(1-\beta)[(1-\sigma)nc^{\sigma-2} + \frac{\rho[(1-\beta)nT](1-\alpha)h_c^{\alpha-2}D^2T}{n}]} \lesseqgtr 0.
\end{aligned}$$

Also, since $h_c = DAeh_pb$, we have $\frac{dh_c}{d\beta} < 0$.

In an equilibrium with growth, reductions in child mortality will reduce fertility, increase investments in basic human capital, and leave adult educational attainment unchanged (so that h_c will increase). Parents' consumption may go either up or down, depending on the value of the parameters.

The growth rate of this economy is given by $(1+\gamma) = DAeb$, so it is easy to see that $\frac{d(1+\gamma)}{d\beta} = DAe\frac{db}{d\beta} < 0$. Increases in child mortality reduce the steady-state growth rate of the economy, via reductions in the investment in basic human capital.

Here, the main engine is the reduction in fertility. As child mortality decreases and fertility is reduced, resources are freed up to be used either in producing c or h_c. But the reduction in n also represents a reduction in the shadow price of h_c in relation to c, such that h_c will certainly increase (via an increase in b), and c may go either up or down, depending on how strong the income effect is.

3.3.2 Child Mortality and the Malthusian Equilibrium

We use the same strategy adopted in subsection 3.2.3 to characterize the Malthusian equilibrium in this economy. In this case, the corner solution yields:

$$\begin{aligned}
\varepsilon[(1-\beta)nT] &> \frac{\alpha Df}{h_o}, \text{ and} \\
TAh_o &< H_o,
\end{aligned}$$

which are analogous to the inequalities obtained before. The behavior of n and c in this equilibrium can be analyzed using the foc's and the constraint:

$$\begin{aligned}
\frac{dn}{d\beta} &= \frac{T\frac{h_o^\alpha}{\alpha}\{\rho'[(1-\beta)nT]+(1-\beta)nT\rho''[(1-\beta)nT]\}}{(1-\beta)^2T^2\rho''(nT)\frac{h_o^\alpha}{\alpha}+\frac{f^2}{T}(\sigma-1)c^{\sigma-2}} \lesseqgtr 0, \text{ and} \\
\frac{dc}{d\beta} &= \frac{-f\frac{h_o^\alpha}{\alpha}\{\rho'[(1-\beta)nT]+(1-\beta)nT\rho''[(1-\beta)nT]\}}{(1-\beta)^2T^2\rho''(nT)\frac{h_o^\alpha}{\alpha}+\frac{f^2}{T}(\sigma-1)c^{\sigma-2}} \gtreqless 0.
\end{aligned}$$

Note that these two expressions will never have the same sign: if one is positive, the other must be negative. This had to be the case, since changes in β do not change the individual constraint, so that if one wants to increase the 'consumption' of some 'good', one has to decrease the 'consumption' of the other.

Anyhow, no matter what happens to n and c, reductions in child mortality will increase the total number of surviving 'child-years' ($(1-\beta)nT$), and will push the economy away from the Malthusian steady-state, into a steady-state with growth and positive investments in human capital. The difference here is that, at first, when β changes, nothing happens to the incentives to invest in adult human capital (second inequality), and only investments in basic human capital are undertaken. Only after basic human capital (h_c) is accumulated from one generation to the next, the incentives to invest in adult education increase. And if child mortality reduction is large enough, the economy enters a sustained growth path. These claims are proved in Appendix A.4.[15]

3.3.3 Costs of Children Depending on Number of Surviving Children

In our analysis of the effects of child mortality, we assumed that costs of children depend on the number of born children. Our results would change considerably if costs of having children depended on the number of surviving children. Which one of the two specifications is the most accurate description of reality is an empirical matter. It probably depends crucially on which phase of childhood concentrates most of the reductions in mortality. We come back to this discussion in the empirical section. For now, we briefly explore the theoretical consequences of changing the assumptions related to the costs of having children.

Once we assume that costs of children depend on the number of surviving children, the time and goods constraints have to be substituted by the following:

[15] There are some appealing variations of the basic model that do not introduce any major change in terms of the qualitative results. For example, if instead of facing increases in their longevity together with their children's, parents face only increases in children's longevity, we arrive at similar conclusions. Generally, increases in future generations' adult longevity have the same short run effects of reductions in child mortality, and the same long run effects of overall increases in adult longevity. Also, if utility from children depends only on shared lifetime (between parents and children), there is no change at all in the qualitative results.

$$\begin{aligned} lH_p &\geqslant Tc + f(1-\beta)n, \text{ and} \\ T &\geqslant l + b(1-\beta)n + e, \end{aligned}$$

and the rest of the problem remains unchanged.

The only role of a change in child mortality in this set up will be to change the fertility rate, in such a way as to maintain exactly the same number of surviving children ($\overline{n} = (1-\beta)n$, the net fertility rate), given constant values of the other parameters. Since child mortality affects the costs and benefits of having children in the same way, parents have a target number of surviving children that is kept no matter what is the child mortality rate. Reductions in child mortality reduce the fertility rate, and leave the other variables unchanged. There is no effect on growth or human capital accumulation, and reductions in child mortality do not tend to move the economy out of a Malthusian regime.

4 Empirical Evidence

4.1 The Nature and Timing of Mortality Changes

The theory presented here predicts that a Malthusian economy experiencing increases in life expectancy ($(1-\beta)T$) would go through an initial phase with consumption and fertility changing in different ways – depending on the particular value of the parameters – and with population increasing rapidly.[16] This population increase would be driven mainly by the gains in life expectancy itself. If these gains were significant enough, individuals would start investing in human capital and the economy would move to a new equilibrium with the possibility of long run growth. From this point on, educational attainment would rise with gains in adult longevity, and fertility would be reduced by either reductions in child mortality or increases in adult longevity. Further increases in life expectancy in this new equilibrium would be associated with further reductions in fertility, and increases in human capital accumulation and growth.

For this theory to be empirically relevant, it must be the case that longevity gains actually preceded fertility reductions in the real experiences of demographic transition. Besides, it must

[16] At any point in time, population is an intricate function of the cumulative effect of past fertility and child mortality rates on initial population levels, and also a function of adult longevity. If we normalize our model in such a way that parents have children in the end of their first period of life ($\tau = 1$), and we call P_s the population at period s, we have that:

$$P_s = \sum_{j=s-T}^{s-1} \left[\prod_{i=s-T}^{j} (1-\beta_i) n_i \right] P_{s-T-1} = \sum_{j=s-T}^{s-1} \left[\prod_{i=0}^{j} (1-\beta_i) n_i \right] P_0,$$

where $s > T$, and P_0 is the initial population.

also be the case that mortality reductions were somewhat exogenous to economic development.

Figure 1 presents the most obvious evidence that a large share of the changes in life expectancy was not determined by development. If we add to this the evidence from Preston (1975), we realize that a large part of the mortality changes throughout the twentieth century was unrelated to changes in income.[17] Similar evidence is available regarding the relation between life expectancy and nutrition. Preston (1980, p.305) presents data on life expectancy at birth and nutrition for a cross-section of countries in 1940 and 1970. He shows that life expectancy gains took place at every nutrition level. For the lowest nutrition level (less than 2,100 calories daily), there was an increase of 10 years in life expectancy at birth. He also relates life expectancy changes to both income and calories consumption, and concludes that approximately 50% of the changes in life expectancy were due to what he calls 'structural factors,' unrelated to economic development.

Further evidence is related to the nature of the diseases responsible for mortality reductions in the different countries. Preston (1980, p.300-313) argues that the role of economic development in reducing mortality probably operated mostly through influenza/pneumonia/bronchitis, for which there was no effective deployment of preventive measures, and diarrheal diseases, for which the improvements came mainly through improvement in water supply and sewerage. Apart from these diseases, preventive measures were probably the most effective ones. Simple changes in public practices and personal health behavior, brought about by knowledge previously inexistent, allowed for significant reductions in mortality at very low costs (Preston, 1996, p.532-4).[18] This view generates numbers similar to the ones obtained in the income–nutrition–mortality analysis, with a little more than 50% of the life expectancy gains being unrelated to economic development *per se*.[19]

Regarding the timing of events during the transition, the usual description depicts mortality reductions starting the process, implying a period of intense population growth, which progressively diminishes as fertility starts to decline. Also, initial economic conditions are seen as being

[17] We do not claim that improvements in living conditions do not affect life prospects. This relation is, indeed, an important part of the mechanism of checks and balances behind the Malthusian model. Our claim is just that changes in life expectancy at birth from 40 to more than 70 years, like the ones experienced during the demographic transition, are largely not due to material improvements.

[18] Most dramatically, the acceptance of the germ theory – developed on the turn of the nineteenth to the twentieth century – allowed for inexpensive gains in life expectancy via simple preventive measures (Vacher, 1979; Ram and Schultz, 1979; Preston, 1980 and 1996; Ruzicka and Hansluwka, 1982). Also, throughout the twentieth century, health programs became increasingly dissociate of the countries' economic conditions, and more dependent on the concerns of the developed world. Even though the monetary value of the help was relatively small, the larger contributions came in the form of development of low cost health measures, training of personnel, initiation of programs, and more effective and specific interventions (see Preston, 1980, p.313-5; and Ruzicka and Hansluwka, 1982). This, to some extent, helped to dissociate gains in life expectancy from improvements in economic conditions.

[19] The evidence presented in Becker, Philipson, and Soares (2002), regarding the diseases responsible for the cross-country convergence in life expectancy, also supports this view.

extremely diverse in the different cases (see Heer and Smith, 1968; Cassen, 1978; Kirk, 1996; Mason, 1997; and Macunovich, 2000). In this direction, if we look at the more recent experience of developing countries, we see cases of modest longevity gains without fertility reductions, but we do not see cases of fertility reductions without longevity gains (see Soares, 2002a). The features of the data are consistent with the theory. Initial life expectancy gains, while the economy is still in the Malthusian equilibrium, may have distinct effects on fertility. But, inevitably, further mortality reductions end up moving the economy out of this equilibrium. Once this threshold is reached, fertility decreases with gains in life expectancy.

Additionally, the data supports the idea that there may be a cut off level of life expectancy that determines the escape from the Malthusian equilibrium. Strictly, this cut off level could be country specific, depending on cultural and natural aspects. But the evidence discussed above is consistent with a common threshold around 50 years of life expectancy at birth. If this is the case, reaching this level of life expectancy would mark the transition of a country from a Malthusian regime to an equilibrium with investments in human capital and the possibility of sustained growth.

In Figures 6 and 7 we explore this point, by analyzing the behavior of fertility and educational attainment before and after the year when life expectancy at birth reaches 50. Obviously, we do not imply that this specific number is the precise point at which all the different countries start their demographic transition. Rather, we think of it as a reasonable approximation to the moment of change in the demographic regime. Every country that reaches this level of life expectancy within the interval 1960-95, and for which data is available, is included in the Figures. Countries are aligned in time according to the year when the threshold was reached, such that the year T is the 'year when life expectancy at birth reached 50.' Other years are measured as deviations from this reference point.

Figure 6 shows the behavior of fertility before and after year T, measured as the deviation of fertility from its initial transitional level (year T). The pattern arises clearly. While fertility behaves very erratically before the year when life expectancy reaches 50, it shows a consistent downward trend for all countries after this cut off is reached. Figure 7 does the same exercise for average schooling in the population aged 15 and above. The result shows an analogous pattern: while educational attainment does not have any clear trend before life expectancy at birth reaches 50, it shows a consistent upward trend for all countries after this cut off point is reached.

The overall historical evidence is consistent with the predictions of the model regarding the behavior of the economy before and after the triggering of the demographic transition.[20] Besides,

[20] The behavior of population in the second half of the twentieth century is also consistent with the theory. Heuveline (1999) uses counter factual projections of the behavior of mortality and fertility between 1950 and 2000 to disentangle the effect of these two variables on the world population. He extends the methodology applied

the data suggest that the transition usually starts at some moment around the time when life expectancy at birth reaches 50 years. This point will be important in our investigation of the recent behavior of fertility, educational attainment, and growth in "post-demographic transition" countries.

4.2 The Behavior of the Economy after the Demographic Transition – Evidence from a Panel of Countries

4.2.1 Estimation Strategy

In this section, we analyze the behavior of fertility, educational attainment, and growth in a panel of countries, between 1960 and 1995. Our goal is to test whether the relation between these variables and child mortality and adult longevity agrees with the predictions of the model. In the model, the behavior of the economy suffers a significant change as we move from the Malthusian equilibrium to the equilibrium with positive investments in human capital. For this reason, it does not make sense to compare pre to post-transition economies, since they respond differently to changes in the exogenous variables. Therefore, we look at economies that had already started the demographic transition in 1960 and should behave according to the properties of the model in the equilibrium with growth.

We concentrate on the endogenous variables for which we have observable statistics: fertility, educational attainment, and growth. The data are averages for five year periods between 1960 and 1995. Variables corresponding to child mortality, adult longevity, fertility, and growth are taken from the World Bank's *World Development Indicators – 1999*. These are, initially: child mortality rate before 1 year ($mort$), life expectancy conditional on survival to 1 year ($adult1$), total fertility rate ($fert$), and growth rate of the real GNP per capita ($growth$). Educational attainment is measured by the average schooling in the population aged 15 and above ($schl$), from the Barro and Lee data set (see Barro and Lee, 1993). Other variables are incorporated along the way, to check the robustness of the initial results. The sample is restricted to countries for which data is available for all the variables and years. This leaves 70 countries and 8 points in time, which gives a total of 560 observations. Summary statistics for the relevant variables are presented in Table 4. Appendix B describes the data in more detail, and enumerates the countries included in the

by White and Preston (1996), by dividing the world population into regions, and projecting four counter factual scenarios for each of them separately. The projections are obtained by applying age and sex specific survival rates to the populations of the different regions, and applying age specific fertility rates to the female population by age. His analysis shows that mortality reductions of the second half of the twentieth century contributed to increase the world population by, at least, 33%, while fertility changes reduced it by 26%. Interestingly, had the fertility and mortality levels remained at their 1950 values, the world population today would be virtually the same as it actually is. Contrary to the common belief in the economics profession, the population explosion of the twentieth century was caused almost entirely by gains in life expectancy, with fertility changes working towards slowing down the process.

sample.

The first order conditions for the individual problem give implicitly a set of reduced form equations that express fertility, education, and growth as functions of child mortality, adult longevity, and the other exogenous variables:

$$\begin{aligned} fert &= f(mort, adult1, X), \\ schl &= g(mort, adult1, X), \text{ and} \\ growth &= q(mort, adult1, X), \end{aligned}$$

where X denotes all other exogenous variables apart from child mortality and adult longevity.

Our strategy is to take the model seriously and estimate these reduced form equations. Apart from the life expectancy variables, the only exogenous factors in our model are related to tastes (parameters of the utility function) and technology (parameters of the production functions). To account for shifts in these exogenous variables across countries, we use country fixed effects, so that any systematic difference due to culture, religion, and technology is washed away. Also, to account for technological development or absorption through time, we include time dummies.

The issue of exogeneity of the life expectancy gains becomes extremely important here. To control for the changes in life expectancy that are simply a consequence of economic development, we include the natural logarithm of the real GNP per capita ($\ln gnp$) in the reduced forms above. This will isolate the changes due to life expectancy, from those directly attributable to development and to behavioral changes induced by increases in income.

With these considerations in mind, the basic specification for our empirical model is given by the following system:

$$\begin{aligned} fert_{it} &= \beta_0^f + \beta_1^f mort_{it} + \beta_2^f adult1_{it} + \beta_3^f \ln gnp_{it} + \alpha_i^f + \alpha_t^f + \varepsilon_{it}, \\ schl_{it} &= \beta_0^s + \beta_1^s mort_{it} + \beta_2^s adult1_{it} + \beta_3^s \ln gnp_{it} + \alpha_i^s + \alpha_t^s + \upsilon_{it}, \text{ and} \\ growth_{it} &= \beta_0^g + \beta_1^g mort_{it} + \beta_2^g adult1_{it} + \beta_3^g \ln gnp_{it} + \alpha_i^g + \alpha_t^g + \omega_{it}, \end{aligned}$$

where the β's are coefficients, the α's are country and time fixed effects, and ε_{it}, υ_{it}, and ω_{it} are random shocks.

Since these three equations are reduced forms from a system of simultaneous equations, ε_{it}, υ_{it}, and ω_{it} are likely to be correlated with each other. But the fact that the same regressors are included in the right hand side of each equation implies that Zellner's GLS approach for seemingly unrelated regressions and simple OLS estimation generate the same results. Therefore, this issue is of no concern.[21]

Finally, our goal is to test the model predictions in relation to economies in the steady-state with growth, where there are positive investments in human capital. Not all the countries included in the sample had already left the Malthusian regime in 1960, and this may bias the estimates. For this reason, we estimate the model both for the whole sample and for a sample of selected countries, that supposedly had already started the demographic transition in 1960 (post-transition countries). Although it is always difficult to define a precise criterion that identifies a country as being or not in the Malthusian regime, this is a problem we cannot avoid. We assume that countries with life expectancy at birth above 50 years in 1960 had already escaped the Malthusian equilibrium, as the evidence from section 4.1 suggests. The list of countries included in the selected sample is contained in Appendix B, and it shows that the criterion chosen seems to be a reasonable one.

4.2.2 Analysis of the Results

For illustrational purposes, Table 2 presents regression results for the whole sample. The first column presents regressions of the three endogenous variables on only child mortality and adult life expectancy, the second column includes per capita income in the right hand side, and the last column includes country and time fixed effects.

Table 3 presents the results for the selected sample (post-transition countries), using the full specification discussed above. The model performs well empirically. All coefficients on adult longevity are significant and have the expected sign. In relation to child mortality, the coefficient of the fertility equation is significant and have the expected effect. The coefficients of the growth and schooling equations are not significant.

The evidence that adult longevity reduces fertility and increases educational attainment and growth, while child mortality only has a significant effect on fertility, supports the version of the model discussed in subsection 3.3.3. There, we argued that when costs of having children depend on the number of surviving children, changes in child mortality will only affect fertility, and leave educational attainment and growth unchanged. This could be a consequence of the fact that we are dealing here only with child mortality before 1 year, when probably not many investments in children have been undertaken. But, since reductions in child mortality have been largely concentrated on very early ages (mainly below 1 year), and mortality rates between 5 years and young adulthood are extremely low, we do believe that such a version of the model may be,

[21] All the results discussed here remain the same once we allow for panel specific AR1 auto-correlation in the residuals.

empirically, the most relevant one. We come back to this point later on.

The comparison of the results from the same specification in the whole sample (Table 2, column 3) with the ones in the selected sample (Table 3) also agree with the theory. Regarding adult longevity, the coefficient of the schooling equation in the whole sample is not significant, and the coefficients of the fertility and growth equations are considerably smaller than the ones obtained in the selected sample. Also the child mortality coefficient of the fertility equation is smaller in the whole sample when compared to the selected sample. Since the predictions being tested apply only to economies that have already started the demographic transition, we should expect the whole sample to deliver results weaker than the ones found in the selected sample.

Nevertheless, the results may still be due to spurious correlation or to omitted variable bias. The theory developed here implies that adult longevity gains should increase investments in education, reduce fertility, and spur economic growth only if these gains took place during productive lifetime. Longevity gains concentrated at very old ages, when individuals do not or cannot work anymore, should not have the same effects, since they do not affect the horizon over which investments in human capital can be used. Given that significant reductions in mortality at old ages have been observed in the more developed countries, this issue should be of concern. If this is what is driving our empirical results, the evidence does not support the causal links predicted by the model. Also, as mentioned before, the evidence regarding child mortality may be driven by the fact that we are considering only child mortality before 1 year, and significant mortality rates still occur until the age of 5.

To check whether our results reflect the causal relations stressed by the model, we repeat the exercise from Table 3 breaking down adult longevity into productive life expectancy and old age life expectancy, and using both child mortality before 1 year and child mortality before 5 years. This is done using data on adult mortality rates between 15 and 60 years, together with child mortality and life expectancy at birth (see Appendix B).

The first two variables constructed are expected years of life between 15 and 60 years ($adexp$), and life expectancy conditional on survival to 60 years ($oldexp$). We estimate a regression similar to the one presented in Table 3, breaking down adult longevity into these two variables. The inclusion of the new variable reduces the sample considerably, so much so that we are left only with observations for the years 1960, 1970, 1980, 1990, and 1995, for 46 countries. The results are presented in the first three columns of Table 4. As should be expected if the results were driven by gains in longevity during productive life, old age life expectancy ($oldexp$) is not significant in any of the equations. The effect of child mortality ($mort$) on fertility is extremely close to the one observed in Table 3. All the results on productive adult life expectancy ($adexp$) are still significant, and the effects on fertility and educational attainment are considerably larger than the ones obtained before.

To check whether our child mortality variable affected the results, we repeat the exercise described in the previous paragraph using child mortality rate before 5 years. This redefines the child mortality rate and old age life expectancy as, respectively, $mort5$ and $oldexp5$. The choice of this variable reduces the sample even further, and we are left with observations for the years 1960, 1970, 1980, 1990, and 1995, for only 41 countries. Nevertheless, the results – presented in columns 4 to 6 of Table 4 – are still extremely similar to the ones from Table 3. The only noticeable difference is the fact that productive life expectancy ($adexp$) is only borderline significant for the fertility regression.[22]

This evidence is supportive of the causal links established by the theory. It shows that the effects captured in Table 3 come from longevity gains during productive years, and not from old age mortality reductions. This is the precise mechanism on which the logic of the model relies. Also, the results show that the choice of the child mortality variable did not introduce any bias.

Finally, we try a last robustness check. We instrument for adult life expectancy using the percentage of the population with access to safe water. It is very difficult to find an instrument for adult longevity that performs well in the first stage once we are already controlling for income. We tried several other variables (immunization rates, physicians per capita, pollution measures, percentage of the population with access to sanitation, and percentage of population and area affected by malaria) unsuccessfully. The variable chosen – percentage of population with access to safe water – performs reasonably well in the first stage: it is significant and adds 1.5% to the other variable's explanatory power in relation to adult longevity. Nevertheless, the second stage results are poor. The three last columns of Table 4 present the results of the IV estimation. Adult life expectancy has a negative and significant effect on fertility and a positive and borderline significant effect on schooling. But the magnitude of these coefficients is implausibly large, and the coefficient on growth is negative, though not significant. We do not take these results too seriously, and present them mainly as an evidence of the difficulty of using instrumental variables in this context.

Going back to Table 3, the quantitative implications of the estimated coefficients are also of interest. The model predicts that a 10 year gain in adult longevity implies a reduction of 1.7 points in total fertility rate, an increase of 0.7 year in average schooling in the population aged 15 and above, and a growth rate higher by 4.6%. A reduction of 100 per one thousand in child

[22] It is difficult to tell whether this is caused by the change in the variable or by the reduction in the size of the sample.

mortality implies a reduction of 2 points in the total fertility rate.

These results are in line with a vast array of evidence from studies that try to estimate the economic impacts of life expectancy gains. Most notoriously, these include the positive effect of life expectancy on growth in the traditional empirical growth literature, summarized and discussed in Barro and Sala-i-Martin (1995). Other examples are the case study for India of the effects of life expectancy gains on schooling and productivity (Ram and Schultz, 1979), and the simulation exercises performed by Bils and Klenow (2000), analyzing the role of life expectancy in explaining cross-country differences in schooling, productivity, and fertility.

Elsewhere (Soares, 2002b), we show that the relation between adult longevity, fertility, and educational attainment portrayed here is also present in individual level data. We use family and state specific mortality indicators and data from the *Brazilian Demographic and Health Survey* to show that adult longevity is positively related to educational attainment and negatively related to fertility, after child mortality and a large set of demographic variables are accounted for.

5 Concluding Remarks

This paper explores the link between life expectancy, educational attainment, and fertility choice. We show that, under reasonable conditions, mortality reductions can explain the movement of economies from a Malthusian equilibrium, with no investments in human capital, to a steady-state with growth. Further reductions in mortality in this steady-state with growth reduce fertility, increase educational attainment, and, thus, increase the growth rate of the economy. These features of the model help explain the demographic transition throughout the world and the recent behavior of fertility in post-demographic transition countries.

Two aspects of the model drive these effects, and distinguish our theoretical work from the previous literature. The utility that parents derive from each child is allowed to depend on the number of children and, additionally, on the lifetime that each child will enjoy as an adult. The way number of children and lifetime of each child interact in the parent's utility function is an important force behind the mechanics of the model.

Also, human capital investments are broken down in two pieces: basic investments, that take place during childhood and are done by parents; and adult investments, that take place during adulthood and are done by the individuals themselves. We interpret educational attainment as the time that adult individuals spend on their own education. Besides being more realistic, this approach allows the model to distinguish between the effects of adult longevity and child mortality on investments in education and growth.

Through these two channels, gains in adult longevity can move an economy out of a steady state without growth and with no investments in human capital (Malthusian equilibrium) into an equilibrium with growth. Also, increases in adult longevity in the equilibrium with growth reduce fertility, increase educational attainment, and increase the growth rate of the economy. Child mortality reductions may have similar effects, or may only affect fertility, depending on the nature of the costs of raising children.

We present different sets of evidence to support the model. First, we justify the exogenous role played by life expectancy by arguing that roughly 50% of the changes in this variable during the last century were unrelated to economic development. Also, we argue that the chronology of events in the experiences of demographic transition agree with the patterns generated by the theory.

Finally, we test the predictions of the model in the equilibrium with growth. These predictions are that gains in adult longevity tend to reduce fertility, increase educational attainment, and enhance economic growth. Reductions in child mortality may have similar effects, or may only affect fertility, depending on the theoretical specification. We use a panel of countries between 1960 and 1995, with observations in each five year interval. The basic specifications estimated are reduced forms obtained from the first order conditions of the model. The results support the predictions of the model.

The theory and evidence presented here support the idea that gains in life expectancy are a major force determining the onset of the demographic transition. Also, they suggest that life expectancy changes may be relevant in determining the behavior of the economy after the transition. In particular, adult longevity – a variable largely overlooked in both demographic and economic literature – seems to be an important factor determining fertility and educational choices.

A Appendix: Analytical Results

A.1 The Effect of T on c and b in an Equilibrium with Growth

Using equations 5 to 9, one can show that:

$$\frac{db}{dT} = \frac{-\left\{nc^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2}DD_p\frac{b}{2}\right\}}{\rho(nT)(\alpha-1)(D_p be)^{\alpha-2}DD_p\frac{T}{2} - (1-\sigma)n^2c^{\sigma-2}\frac{A_p}{2}} \lesseqgtr 0,$$

and

$$\frac{dc}{dT} = \frac{A_p\left\{n^2c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2}DD_p(nb + \frac{T}{4})\right\}}{\rho(nT)(\alpha-1)(D_p be)^{\alpha-2}DD_pT - (1-\sigma)n^2c^{\sigma-2}A_p} \lesseqgtr 0.$$

But note that, if $\frac{dc}{dT} < 0$, we have

$$n^2 c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p(nb + \frac{T}{4}) > 0.$$

Since $nb + \frac{T}{4} > \frac{nb}{2}$, this implies that

$$n^2 c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p\frac{nb}{2} > 0,$$

which in turn implies that $\frac{db}{dT} > 0$.

Also, if $\frac{db}{dT} < 0$, we have

$$n^2 c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p\frac{nb}{2} < 0.$$

Again, since $nb + \frac{T}{4} > \frac{nb}{2}$, this implies that

$$n^2 c^{\sigma-1}\left[\frac{1}{T} + (1-\sigma)\frac{A_p}{2c}(\frac{bn}{T} + \frac{1}{2})\right] + \rho(nT)(\alpha-1)(D_p be)^{\alpha-2} DD_p(nb + \frac{T}{4}) < 0,$$

which in turn implies that $\frac{dc}{dT} > 0$.

In words, $\frac{dc}{dT}$ or $\frac{db}{dT}$ may be negative, but both cannot be negative at the same time. If one of them is negative, the other must be positive.

A.2 The Possibility of a Steady-State

The possibility of a steady-state in this economy rests on the values of the parameters α and σ. Technological factors summarized by the goods constraint imply that, in any steady-state, c and h_p must necessarily grow at the same constant rate from one generation to the next. But the individual maximization problem tells us, through equation 8, that c and h_p growing at the same rate will not be consistent with the optimal choices of the different generations, unless $\alpha = \sigma$. Therefore, for a steady-state to exist in this economy, it must be the case that $\alpha = \sigma$, so that individuals from different generations will make optimal choices such that c and h_p will grow at the same constant rate, and b, n, e, and l will be constant.

This can be formally seen once we realize that, in terms of the individual's problem, for a steady-state to exist it must be the case that agents will not change their decisions regarding n, b, l, and e as h_p increases. This means that the different generations, who differ only in terms of their endowed h_p and see it as a given parameter, will translate the higher levels of basic human capital in increased consumption, leaving b, n, e, and l unchanged.

From the results obtained before, we already know that $\frac{dn}{dh_p} = \frac{de}{dh_p} = 0$. We can use equations 7 and 8 to show how b and c respond to changes in h_p. This gives the following expressions:

$$\begin{aligned}\frac{db}{dh_p} &= \frac{(\sigma-1)be}{h_p[(\sigma-\alpha)bn+(\alpha-1)e]} - \frac{b}{h_p} \gtrless 0, \text{ and}\\ \frac{dc}{dh_p} &= \frac{Ae^2(1-\alpha)(bn-e)}{T[(\sigma-\alpha)bn+(\alpha-1)e]} > 0,\end{aligned}$$

where the sign of $\frac{dc}{dh_p}$ comes from the fact that $\sigma < 1$.

As mentioned before, a steady-state requires a constant b with an increasing h_p. This will only happen here if $\sigma = \alpha$, in which case we have $\frac{db}{dh_p} = 0$ and $\frac{dc}{dh_p} = \frac{A}{T}e(e - bn)$. It is immediate to see that, in this case, c and h_p will grow at the same constant rate, given by $(1+\gamma) = \frac{h_c}{h_p} = DAbe$.

If $\sigma \neq \alpha$, there is no steady-state, and b will increase or decrease over time (with the increase in h_p) until a corner solution is reached. Rewrite $\frac{db}{dh_p}$ in the following way:

$$\frac{db}{dh_p} = \frac{b}{h_p}\frac{(\sigma-\alpha)(e-bn)}{[(\sigma-\alpha)bn+(\alpha-1)e]}.$$

So, if $\alpha > \sigma$, we have $\frac{db}{dh_p} > 0$; and if $\alpha < \sigma$, we have $\frac{db}{dh_p} < 0$, since $\sigma < 1$.

The intuition for this result is clear. If $\alpha > \sigma$, the sub-utility function related to h_c is less concave than the one related to c, such that when h_p grows from one generation to the next, younger generations tend to increase h_c more than proportionately to c, and this is achieved through increases in b. The same sort of argument works for the case where $\alpha < \sigma$, implying that h_c is increased less than proportionately to c, and that this is achieved through reductions in b. When $\alpha = \sigma$, every generation is just happy to increase c and h_p in the same proportion in relation to the previous generation, in which case b remains unchanged and we have a steady-state.

A.3 The Effect of T on the Malthusian Equilibrium

A.3.1 The Malthusian Equilibrium

We call the corner solution in human capital investments a Malthusian equilibrium because, in a situation like this, changes in productivity – brought about, for example, by exogenous changes on H_o – will be positively correlated with changes in both consumption and fertility. This can be seen by analyzing the effect of an exogenous change in H_o. Using the first two foc's and the constraint, we arrive at:

$$\begin{aligned}\frac{dn}{dH_o} &= \frac{f(\sigma-1)c^{\sigma-2}}{T^2\rho''(nT)\frac{h_o^\alpha}{\alpha} + \frac{f^2}{T}(\sigma-1)c^{\sigma-2}} > 0, \text{ and}\\ \frac{dc}{dH_o} &= \frac{T\rho''(nT)\frac{h_o^\alpha}{\alpha}}{T^3\rho''(nT)\frac{h_o^\alpha}{\alpha} + f^2(\sigma-1)c^{\sigma-2}} > 0.\end{aligned}$$

Fertility and consumption respond positively to exogenous increases in productivity. If we want this set up to display all the features of a so called Malthusian regime, including its checks and balances mechanisms and the zero long run growth in consumption, we can substitute H_o by some function $F(H_o, P)$. In this case, P denotes the aggregate population level, and $F_{H_o}(.,.) > 0$. Decreasing marginal product in the agriculture sector due to limited availability of land would be captured by $F_P(.,.) < 0$, such that, for a given level of H_o, individual productivity decreases with total population. This externality implies that exogenous increases in H_o generate short run increases on n and c, that are 'consumed' in the long run by the expanded population. With time, n returns to its long run equilibrium value – given by $(1-\beta)n = 1$, such that population is constant – which also pins down the long run value of consumption. In this equilibrium, there are no long run improvements on living standards, and population grows only to the extent allowed by exogenous technical improvements or positive natural shocks (increases on H_o). This additional feature of the model captures all the properties of what is known as a Malthusian regime, but to keep things simple we analyze the case where $F(H_o, P) = H_o$. As long as the effect of P takes some time to operate, our results will be quite general.

A.3.2 Changes on T while the Corner Solution Holds

In this case, only n and c will be affected by T. The effect of T on n and c in the Malthusian equilibrium can be obtained from the first two foc's and the constraint.

$$
\begin{aligned}
\frac{dn}{dT} &= \frac{\frac{f^2 n}{T^2}(\sigma-1)c^{\sigma-2} - \frac{h_o^\alpha}{\alpha}[nT\rho''(nT) + \rho'(nT)]}{T^2\rho''(nT)\frac{h_o^\alpha}{\alpha} + \frac{f^2}{T}(\sigma-1)c^{\sigma-2}} \lesseqgtr 0, \text{ and} \\
\frac{dc}{dT} &= \frac{f\frac{h_o^\alpha}{\alpha}[2nT\rho''(nT) + \rho'(nT)]}{T^3\rho''(nT)\frac{h_o^\alpha}{\alpha} + f^2(\sigma-1)c^{\sigma-2}} \gtreqless 0.
\end{aligned}
$$

If $\frac{dn}{dT} < 0$, it means that $nT\rho''(nT) + \rho'(nT) < 0$, which implies that $2nT\rho''(nT) + \rho'(nT) < 0$, which in turn implies that $\frac{dc}{dT} > 0$.

Also, if $\frac{dc}{dT} < 0$, we have $2nT\rho''(nT) + \rho'(nT) > 0$, which implies that $nT\rho''(nT) + \rho'(nT) > 0$, which in turns implies that $\frac{dn}{dT} > 0$.

In other words, $\frac{dc}{dT}$ or $\frac{dn}{dT}$ may be negative, but both cannot be negative at the same time. Either c or n must increase as T increases. Besides, a sufficient condition for both of them to be positive is that $-nT\rho''(nT) < \rho'(nT) < -2nT\rho''(nT)$.

A.3.3 The Escape from the Malthusian Steady-State

We want to look at what happens to the two last first order conditions as T increases. We start by analyzing the steady-state where investment in both forms of human capital is zero, and show that as T increases, an interior solution tends to be achieved both on b and e. We then go on to show that, when an interior solution is actually achieved in one of these variables, further increases on T still tend to break the remaining inequality ($e > 0$ and $b = 0$, or $b > 0$ and $e = 0$).

i) $e = 0$ **and** $b = 0$

The last equation can be rewritten as $Ah_o(Tc + fn) < H_o^2$. From the constraint, we have $TH_o = Tc + fn$, so substituting back on the inequality we have $Ah_oT < H_o$. A, h_o, and H_o are given parameters, so as T increases this inequality clearly will eventually be broken.

Substituting for λ from the second foc, the first inequality can be written as $\varepsilon(nT) > \frac{\alpha Df}{h_o}$. From the expression that we had before for $\frac{dn}{dT}$, we can obtain $\frac{d(nT)}{dT}$:

$$\frac{d(nT)}{dT} = \frac{2\frac{f^2n}{T^2}(\sigma-1)c^{\sigma-2} - \frac{h_o^\alpha}{\alpha}\rho'(nT)}{T\rho''(nT)\frac{h_o^\alpha}{\alpha} + \frac{f^2}{T^2}(\sigma-1)c^{\sigma-2}} > 0.$$

nT increases unequivocally as T increases. Since $\rho'(nT) = 0$ for big enough nT, $\varepsilon(nT)$ will eventually be arbitrarily close to zero, and the first inequality will be broken as T increases.

ii) $e > 0$ **and** $b = 0$

This solution is characterized by the following foc's:

$$\begin{aligned}
Tc^{\sigma-1} &= \frac{T}{Aeh_o + H_o}\lambda, \\
T\rho'(nT)\frac{{h_o}^\alpha}{\alpha} &= \frac{f}{Aeh_o + H_o}\lambda, \\
\rho(nT){h_o}^{\alpha-1}D(Aeh_o + H_o) &< n\lambda, \\
(Tc + fn)Ah_o &= (Aeh_o + H_o)^2;
\end{aligned}$$

and the constraint is $T = e + \frac{Tc+fn}{Aeh_o+H_o}$.

The constraint together with the last foc gives $e = \frac{T}{2} - \frac{H_o}{2Ah_o}$. Using this fact together with the first two foc's and the constraint, we get an expression for $\frac{d(nT)}{dT}$:

$$\frac{d(nT)}{dT} = \frac{[fn + \frac{(e+fn)}{2}]f(\sigma-1)c^{\sigma-2} - \frac{T^2}{2}\frac{h_o^\alpha}{\alpha}\rho'(nT)}{T\rho''(nT)\frac{h_o^\alpha}{\alpha} + \frac{f^2}{T^2}(\sigma-1)c^{\sigma-2}} > 0.$$

The second and third foc's characterize the corner solution with the same inequality that we had before: $\varepsilon(nT) > \frac{\alpha Df}{h_o}$. As we just showed that nT increases in this solution as T increases, and we know that $\varepsilon(nT)$ will tend to zero as nT increases, this inequality will tend to be broken and we will get an interior solution in b as T rises.

iii) $b > 0$ **and** $e = 0$

The third and fourth first order conditions in this case will be:

$$\begin{aligned}\rho(nT){h_c}^{\alpha-1}DH_o &= n\lambda, \\ \rho(nT){h_c}^{\alpha-1}DbAh_o &< \left[1 - \frac{(Tc+fn)Ah_o}{H_o^2}\right]\lambda;\end{aligned}$$

and the constraint will be $T = bn + \frac{Tc+fn}{H_o}$. Substituting for λ from one of the foc's into the other and using the constraint we can rewrite the inequality as $TAh_o < H_o$. So, as T increases, an internal solution on e tends to be achieved.

A.4 β and the Escape from the Malthusian Equilibrium

Starting from a position where the solution to the individual problem implies $e = b = 0$, changes on β will not affect the foc related to e. The effect on the foc for b will depend on the behavior of $(1-\beta)nT$. Given the expression for $\frac{dn}{d\beta}$, we have that

$$\frac{d[(1-\beta)nT]}{d\beta} = \frac{(1-\beta)T^2\rho'[(1-\beta)nT]\frac{h_o^\alpha}{\alpha} - f(\sigma-1)c^{\sigma-2}n}{(1-\beta)^2T^2\rho''(nT)\frac{h_o^\alpha}{\alpha} + \frac{f^2}{T}(\sigma-1)c^{\sigma-2}} < 0,$$

so that reductions on child mortality will increase the total number of 'child-years'. $(1-\beta)nT$ increases unequivocally as β decreases. So $\varepsilon[(1-\beta)nT]$ will also be arbitrarily close to zero for big enough $(1-\beta)nT$, and the first inequality will tend to be broken as β decreases.

So, differently, from increases in adult longevity, reductions in child mortality will tend unequivocally to take the economy to a transitional situation where $b > 0$ and $e = 0$. In this case, the corner solution in e will still be characterized by the same inequality above: $TAh_p < H_o$. As discussed before, for the first parents generation experiencing reductions in their children's mortality rate, $h_p = h_o$, and there is no tendency to break the corner solution on e. But as children who received positive investments in basic human capital become adults, this h_p in period t will assume some value $h_{c,t-1} > h_o$. If child mortality keeps being reduced from generation to generation, such that $h_{c,t+1} > h_{c,t} > h_{c,t-1}$ and so on, this inequality will also eventually be broken, and the economy will reach a steady-state with growth and positive investments in all forms of human capital.

B Appendix: Data

B.1 Definition of Variables

- child mortality rate (*mort*): Child mortality rate per 1,000, before 1 year – from the World Bank's *World Development Indicators*, 1999.

- child mortality rate before 5 years ($und5$): Child mortality rate per 1,000, before 5 years – from the World Bank's *World Development Indicators*, 1999.

- life expectancy at birth ($life$): Life expectancy at birth – from the World Bank's *World Development Indicators*, 1999.

- adult mortality rate ($admort$): Mortality rate per 1,000 between the ages 15 and 60 – from the World Bank's *World Development Indicators*, 1999.

- adult longevity ($adult1$): Life expectancy conditional on survival to 1 year. Calculated from $life$ and $mort$ according to the expression $life = \frac{mort}{1{,}000}1 + (1 - \frac{mort}{1{,}000})adult1$. It corresponds to assuming that these are the only two variables that compose life expectancy at birth. So, the component of life expectancy not related to child mortality is assigned to life expectancy conditional on survival to 1 year. It is assumed that the death of a child occurs at age 1. Results are not sensible to this normalization.

- young adult longevity ($adexp$): Expected years of life between 15 and 60 years. Calculated from $admort$ according to $adexp = (1 - \frac{admort}{1{,}000})45$.

- old adult longevity using child mortality rate before 1 year ($oldexp$): Life expectancy conditional on survival to 60 years. Calculated from $life$, $mort$, and $admort$ according to $life =. \frac{mort}{1{,}000}1 + (1 - \frac{mort}{1{,}000})[\frac{admort}{1{,}000}45 + (1 - \frac{admort}{1{,}000})oldexp]$. The logic is the same behind the calculation of $adult1$. It is assumed that the death of an adult individual occurs at age 45. Results are not sensible to this normalization.

- old adult longevity using child mortality rate before 5 years ($oldex5$): Life expectancy conditional on survival to 60 years. Calculated analogously to $oldexp$, according to $life =. \frac{und5}{1{,}000}5 + (1 - \frac{mort}{1{,}000})[\frac{admort}{1{,}000}45 + (1 - \frac{admort}{1{,}000})oldex5]$.

- fertility ($fert$): Total fertility rate – from the World Bank's *World Development Indicators*, 1999.

- educational attainment ($schl$): Average schooling years in the population aged 15 and over – from the Barro and Lee (1993) updated data set.

- income growth ($growth$): Growth rate of the GNP per capita (constant 1995 US$) – from the World Bank's *World Development Indicators*, 1999.

- income (gnp): GNP per capita (constant 1995 US$) – from the World Bank's *World Development Indicators*, 1999.

- Population with access to safe water ($water$): Percentage of population with access to safe water – from the World Bank's *World Development Indicators*, 1999.

B.2 Countries Included in the Sample

- Whole sample (70 countries) – Table 2: Algeria, Argentina, Australia, Austria, Bangladesh, Barbados, Belgium, Botswana, Brazil, Cameroon, Canada, Central African Republic, Chile, Costa Rica, Denmark, Dominican Republic, Ecuador, El Salvador, Fiji, Finland, France, Ghana, Greece, Guatemala, Guyana, Honduras, Hong Kong, Hungary, Iceland, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Kenya, Korea, Rep., Lesotho, Malawi, Malaysia, Mauritius, Mexico, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Norway, Pakistan, Panama, Papua New Guinea, Paraguay, Philippines, Portugal, Singapore, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Thailand, Togo, Trinidad and Tobago, Tunisia, United Kingdom, United States, Uruguay, Zambia.

- Selected Sample – Post-transition (life expectancy in 1960 > 50; 47 countries) – Table 3: Argentina, Australia, Austria, Barbados, Belgium, Brazil, Canada, Chile, Costa Rica, Denmark, Dominican Republic, Ecuador, El Salvador, Fiji, Finland, France, Greece, Guyana, Hong Kong, Hungary, Iceland, Ireland, Israel, Italy, Jamaica, Japan, Korea, Rep., Malaysia, Mauritius, Mexico, Netherlands, New Zealand, Norway, Panama, Paraguay, Philippines, Portugal, Singapore, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Trinidad and Tobago, United Kingdom, United States, Uruguay.

References

Barro, Robert, and J.W. Lee (1993). International Measures of Schooling Years and Schooling Quality. *American Economic Review Papers and Proceedings*, 86(2), 1993, 218-23.

Barro, Robert J. and Xavier Sala-i-Martin (1995). *Economic Growth*. New York, McGraw-Hill, Inc., 1995.

Becker, Gary S. (1985). Human capital, effort, and the sexual division of labor. *Journal of Labor Economics*, 3 (1985): S33-S58.

Becker, Gary S. (2000). "Declining population in a modern economy." Unpublished Manuscript, University of Chicago, August 2000.

Becker, Gary S. and Kevin M. Murphy (1992). The division of labor, coordination costs, and knowledge. *Quarterly Journal of Economics*, 107, n4 (November 1992): 1137-60.

Becker, Gary S., Kevin M. Murphy, and Robert Tamura (1990). Human capital, fertility, and economic growth. *Journal of Political Economy,* v98, n5 (Part 2, October 1990): S12-37.

Becker, Gary S., Tomas Philipson, and Rodrigo R. Soares (2002). "Growth and mortality in less developed nations." Unpublished Manuscript, University of Chicago, October 2001.

Ben-Porath, Yoram (1967). The production of human capital and the life cycle of earnings. *Journal of Political Economy*, v75, n4 (Part 1, August 1967): 352-65.

Bils, Mark and Peter J. Klenow (2000). "Explaining differences in schooling across countries." Unpublished Manuscript, University of Chicago, January 2000.

Blackburn, Keith, and Giam Pietro Cipriani (1998). Endogenous fertility, mortality and growth. *Journal of Population Economics*, 1998, 11:517-34.

Boldrin, Michele and Larry E. Jones (2002). "Mortality, Fertility and Saving in a Malthusian Economy." Unpublished Manuscript, University of Minnesota, February 2002.

Brown, E. H. and Sheila Hopkins (1956). Seven centuries of the price of consumables, compared with builders' wage-rates. *Economica*, November 1956, 296-314.

Caldwell, J.C. (1981). The mechanisms of demographic change in historical perspective. *Population Studies*, v35, Issue 1 (March 1981): 5-27.

Cassen, Robert H. (1978). Current trends in population change and their causes. *Population and Development Review*, v4, Issue 2 (June 19780: 331-53.

Demeny, Paul (1979). On the end of the population explosion. *Population and Development Review*, v5, Issue 1 (March 1979): 141-62.

Eckstein, Zvi, Pedro Mira, and Kenneth I. Wolpin (1999). A quantitative analysis of Swedish fertility dynamics: 1751-1990. *Review of Economic Dynamics*, 2, 1999, 137-65.

Ehrlich, Isaac, and Francis T. Lui (1991). Intergenerational trade, longevity, and economic growth (1991). *Journal of Political Economy*, v99, n5 (October 1991): 1029-59.

Fogel, Robert W. (1994). Economic growth, population theory, and physiology: The bearing of long-term processes on the making of economic policy. *American Economic Review*, v84 n3 (June 1994): 369-95.

Galor, Oded and David N. Weil (1996). The Gender Gap, Fertility, and Growth. *American Economic Review,* v86 n3 (June 1996): 374-87.

Galor, Oded and David N. Weil (1999). From Malthusian stagnation to modern growth. *American Economic Review,* v89 n2 (May 1999): 150-54.

Galor, Oded, and David N. Weil (2000). Population, technology, and growth: From Malthusian stagnation to the demographic transition and beyond. *American Economic Review*, v90 n4 (September 2000): 806-28.

Hamermesh, Daniel S. (1985). Expectations, life expectancy, and economic behavior. *Quarterly Journal of Economics*, v100, n2 (May 1985), 389-408.

Heer, David M., and Dean O. Smith (1968). Mortality level, desired family size, and population increase. *Demography*, v5, Issue 1 (1968), 104-21.

Heuveline, Patrick (1999). The global and regional impact of mortality and fertility transitions, 1950-2000. *Population and Development Review*, 25(4), December 1999, p681-702.

Hurd, Michael D. and Kathleen McGarry (1997). "The predictive validity of subjective probabilities of survival." NBER Working Paper 6193, September 1997.

Kalemli-Ozcan, Sebnem (1999). "Does mortality decline promote economic growth? A stochastic model of fertility and human capital investment." Unpublished Manuscript, Brown University, Novermber 1999.

Kalemli-Ozcan, Sebnem, Harl E. Ryder, and David N. Weil (2000). Mortality decline, human capital investment, and economic growth. *Journal of Development Economics*, v62 (2000), 1-23.

Keyfitz, Nathan, and Wilhelm Flieger (1968). *World population – An analysis of vital data*. The University of Chicago Press, Chicago, Illinois, 1968.

Kirk, Dudley (1996). Demographic transition theory. *Population Studies*, v50, Issue 3 (November 1996): 361-87.

Macunovich, Diane J. (2000). Relative cohort size: Source of a unifying theory of global fertility transition? *Population and Development Review*, June(2000), 26(2): 235-61.

Mason, Karen O. (1997). Explaining fertility transitions. *Demography*, v34, Issue 4 (November 1997): 443-54.

Meltzer, David (1992). "Mortality decline, the demographic transition, and economic growth". Thesis (Ph. D.), University of Chicago, Dept. of Economics, December 1992.

Momota, Akira, and Koichi Futagami (2000). Demographic transition pattern in a small country. *Economic Letters*, 67 (2000) 231-37.

Philipson, Tomas and Rodrigo R. Soares (2001). World Inequality and the Rise in Longevity. In: Pleskovic, Boris and Nicholas Stern (editors). *Annual World Bank Conference on Development Economics 2001/2002*, World Bank and Oxford University Press, New York, 2002, p.245-259.

Preston, Samuel H. (1975). The changing relation between mortality and level of economic development. *Population Studies*, v29, Issue 2 (July 1975), 231-48.

Preston, Samuel H. (1980). Causes and consequences of mortality declines in less developed countries during the twentieth century. In: Richard S. Easterlin (ed.): *Population and economic change in developing countries*. National Bureau of Economic Research, The University of Chicago Press, Chicago, 1980, 289-341.

Preston, Samuel H. (1996). Population studies of mortality. *Population Studies*, v50, Issue 3 (November 1996), 525-36.

Ram, Rati and Theodore W. Schultz (1979). Life span, health, savings, and productivity. *Economic Development and Cultural Change*, v27, n3 (April 1979), 399-421.

Robinson, J.A. and T.N. Srinivasan. (1997). Long-term consequences of population growth: Technological change, natural resources, and the environment. In: M.R.Rosenzweig and O. Stark (eds.). *Handbook of population and family economics*. Elsevier Science B.V.: Amsterdam, p1175-298.

Ruzicka, Lado T. and Harald Hansluwka (1982). Mortality transition in South and East Asia: Technology confronts poverty. *Population and Development Review*, (September 1982), 8(3): 567-88.

Sah, Raaj K. (1991). The effects of child mortality changes on fertility choice and parental welfare. *Journal of Political Economy*, v99, n3 (June 1991): 582-606.

Smith, V. Kerry, Donald H. Taylor, Jr., and Frank A. Sloan (2001). Longevity expectations and death: Can people predict their own demise? *American Economic Review*, v91, n4 (September 2001), 1126-34.

Soares, Rodrigo R. (2002a). “Life expectancy, educational attainment, and fertility choice – The economic impacts of mortality reductions.” Thesis (Ph. D.), University of Chicago, Dept. of Economics, June 2002.

Soares, Rodrigo R. (2002b). “The effect of longevity on fertility: Micro evidence from the Brazilian Demographic and Health Survey.” Unpublished Manuscript, University of Chicago, November 2001.

Tamura, Robert (1996). From decay to growth: A demographic transition to economic growth. *Journal of Economic Dynamics and Control*, 20 (1996): 1237-61.

Vacher, Leon-Clery (1979). Archives: A nineteenth century assessment of causes of European mortality decline. *Population and Development Review*,(March 1979), 5(1): 163-70.

White, K.M. and Samuel H. Preston (1996). How many Americans are alive because of twentieth-century improvements in mortality? *Population and Development Review*, 22(3), September 1996, p415-29.

Wrigley, Edward A. and Roger S. Schofield (1981). *The population history of England, 1541-1871* – A Reconstruction. Harvard University Press, Cambridge, Massachusetts, 1981.

Wrigley, Edward A., R.S. Davies, J.E. Oeppen, and Roger S. Schofield (1997). *English population history from family reconstitution, 1580-1837.* Cambridge University Press, Cambridge, United Kingdom, 1997.

Table 1: Descriptive Statistics

variables		mean	std dev	min	max
mort	overall	55.63	46.02	4.06	204.00
	between		41.36		
	within		20.72		
und5	overall	82.33	77.23	5.00	361.00
	between		70.21		
	within		36.87		
life	overall	63.98	10.80	35.96	79.67
	between		10.02		
	within		4.17		
adult1	overall	67.36	8.62	44.18	80.00
	between		8.04		
	within		3.23		
adexp	overall	34.71	5.98	19.08	41.72
	between		5.51		
	within		2.50		
oldexp	overall	73.06	8.23	42.74	82.75
	between		7.49		
	within		3.50		
oldex5	overall	75.35	5.44	53.73	82.89
	between		4.87		
	within		2.61		
fert	overall	4.03	1.91	1.21	8.12
	between		1.69		
	within		0.91		
schl	overall	5.27	2.79	0.12	11.89
	between		2.62		
	within		1.02		
gnp	overall	6811.71	8909.64	103.51	46665.15
	between		8414.91		
	within		3075.34		
growth	overall	2.35	3.20	-20.68	16.74
	between		1.71		
	within		2.71		

Notes: Complete sample is composed of 70 countries and 8 points in time (560 observations). Data are averages for five years periods, from 1960 to 1995. Variables are child mortality rate before 1 year (per 1,000), mortality rate under 5 years (per 1,000), life expectancy, life expectancy conditional on survival to 1 year, expected years of life between the ages 15 and 60, life expectancy conditional on survival to 60 calculated from *mort* and *adexp* , life expectancy conditional on survival to 60 calculated from *und5* and *adexp* , total fertility rate, average schooling in the population aged 15 and above, per capita GNP (in 1995 US$), and growth rate of the per capita GNP.

Table 2: Regressions, Full Sample, 1960-95

dep var	ind var	1	2	3
fert	mort	0.0226	0.0179	0.0090
		0.0021	0.0021	0.0022
	adult1	-0.0806	-0.0518	-0.0586
		0.0112	0.0113	0.0143
	lngnp		-0.3422	-0.3606
			0.0438	0.0950
	const	8.2034	9.1969	12.1525
		0.8659	0.8321	1.1781
	R Sq	0.7928	0.8132	0.9351
schl	mort	-0.0336	-0.0228	-0.0017
		0.0036	0.0034	0.0022
	adult1	0.1003	0.0336	-0.0016
		0.0191	0.0183	0.0142
	lngnp		0.7901	0.6679
			0.0709	0.0940
	const	0.3891	-1.9049	-2.8456
		1.4709	1.3466	1.1658
	R Sq	0.7195	0.7704	0.9702
growth	mort	0.0012	0.0045	0.0059
		0.0076	0.0079	0.0112
	adult1	0.0621	0.0421	0.2917
		0.0407	0.0430	0.0734
	lngnp		0.2367	-0.0229
			0.1671	0.4859
	const	-1.9032	-2.5905	-18.9877
		3.1405	3.1722	6.0267
	R Sq	0.0228	0.0263	0.3906
country & time fe		no	no	yes
N Countries		70	70	70
N Obs		560	560	560

Notes: Numbers below the coefficients are standard errors. Dependent variables are total fertility rate, average schooling in the population aged 15 and above, and growth rate. Data are averages for five years periods, from 1960 to 1995. Independent variables are child mortality rate before 1 year (per 1,000), life expectancy conditional on survival to 1 year, per capita GNP (in 1995 US$), and country and time fixed effects.

Table 3: Regression, Selected Sample - "Post-transition" Countries, 1960-95

	fert	schl	growth
mort	0.0201	0.0029	0.0196
	0.0028	0.0039	0.0158
adult1	-0.1653	0.0675	0.4572
	0.0192	0.0269	0.1104
lngnp	0.1585	0.4881	-0.6029
	0.1134	0.1585	0.6509
country & time fe	yes	yes	yes
R Sq	0.9333	0.9478	0.3972
N Countries	47	47	47
N Obs	376	376	376

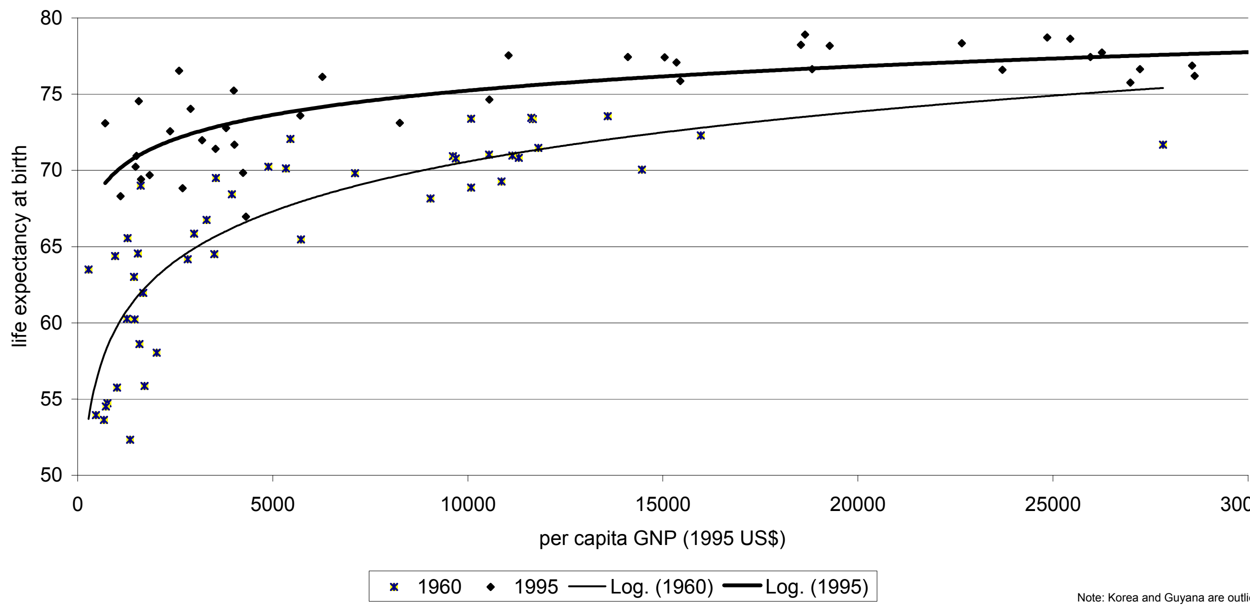
Notes: Numbers below the coefficients are standard errors. Only countries with life expectancy at birth above 50 in 1960 included in the regressions. Dependent variables are total fertility rate, average schooling in the population aged 15 and above, and growth rate. Data are averages for five years periods, from 1960 to 1995. Independent variables are child mortality rate before 1 year before 1 year per (1,000), life expectancy conditional on survival to 1 year, per capita GNP (in 1995 US$), and country and time fixed effects.

Table 4: Robustness Check, Regressions with Different Age Specific Mortality Rates or with Instrument, Selected Sample - "Post-transition" Countries, 1960-95

	child mortality before 1			child mortality before 5			IV		
	fert	schl	growth	fert	schl	growth	fert	schl	growth
child mort	0.0213	0.0022	0.0146	0.0144	0.0003	0.0002	-0.0036	0.0237	-0.0230
	0.0036	0.0054	0.0199	0.0020	0.0030	0.0112	0.0135	0.0195	0.0831
adult exp	-0.2092	0.1211	0.4412	-0.1847	0.0662	0.5973	-0.4933	0.4863	-0.2588
	0.0344	0.0519	0.1918	0.0329	0.0483	0.1826	0.2045	0.2954	1.2584
old age exp	-0.0129	-0.0322	0.3352	-0.0174	-0.0755	0.0321			
	0.0462	0.0696	0.2572	0.0426	0.0625	0.2362			
lngnp	0.1079	0.5935	-0.9545	0.3008	0.2712	-1.0717	0.7367	-0.1665	1.1785
	0.1331	0.2006	0.7417	0.1493	0.2191	0.8277	0.3963	0.5736	2.4384
country & time fe	yes	yes	yes	yes	yes	yes	yes	yes	yes
R Sq	0.9323	0.9409	0.4616	0.9334	0.9457	0.4643			
N Countries	46	46	46	41	41	41	40	40	40
N Obs	230	230	230	205	205	205	155	155	155

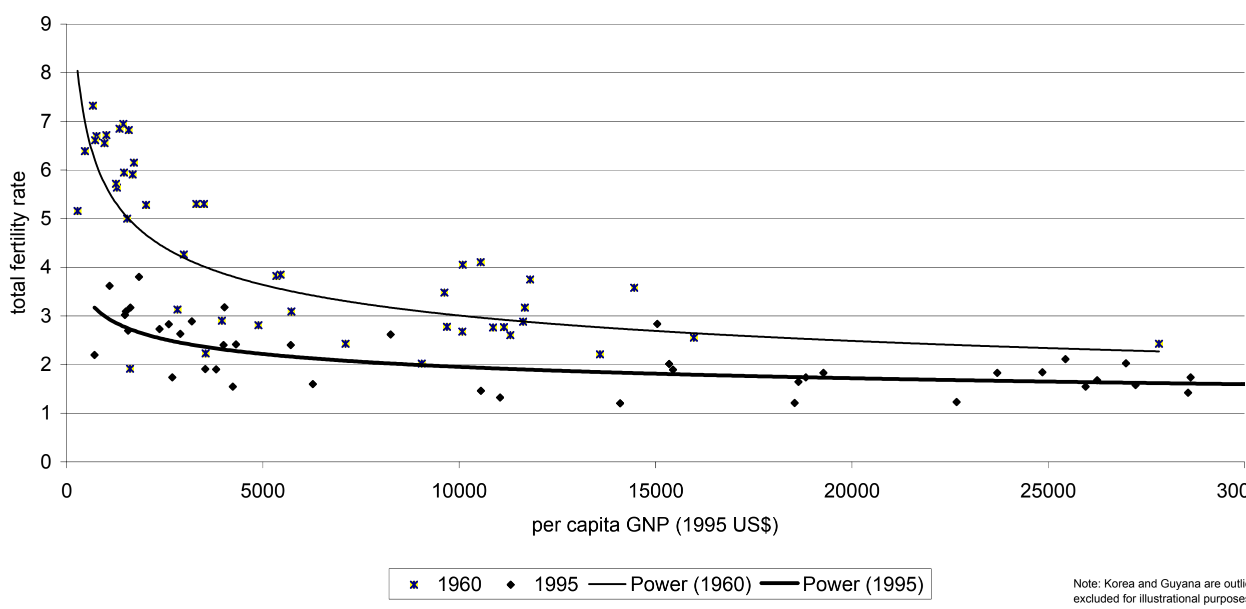
Notes: Numbers below the coefficients are standard errors. Only countries with life expectancy at birth in 1960 above 50 years included. Dependent variables are total fertility rate, average schooling in the population aged 15 and above, and growth rate. For the regressions including old age life expectancy (columns 1-6), data are averages for five year periods, for the years 1960, 70, 80, 90, and 95. For the instrumental variable regression (columns 7-9), data are averages for five year periods, for the years 1970-95 (unbalanced panel). Independent variables for columns 1-3 are child mortality rate before 1 year (per 1,000), expected years of adult life, and life expectancy conditional on survival to 60. Independent variables for columns 4-6 are child mortality rate before 5 years (per 1,000), expected years of adult life, and life expectancy conditional on survival to 60. Independent variables for columns 7-9 are child mortality rate before 1 year (per 1,000) and life expectancy conditional on survival to 1 (instrument: % of population with access to safe water). All include per capita GNP (in 1995 US$), and country and time fixed effects.

Figure1: Relationship Between Per Capita Income and Life Expectancy at Birth - Transitional Countries (1960-95)



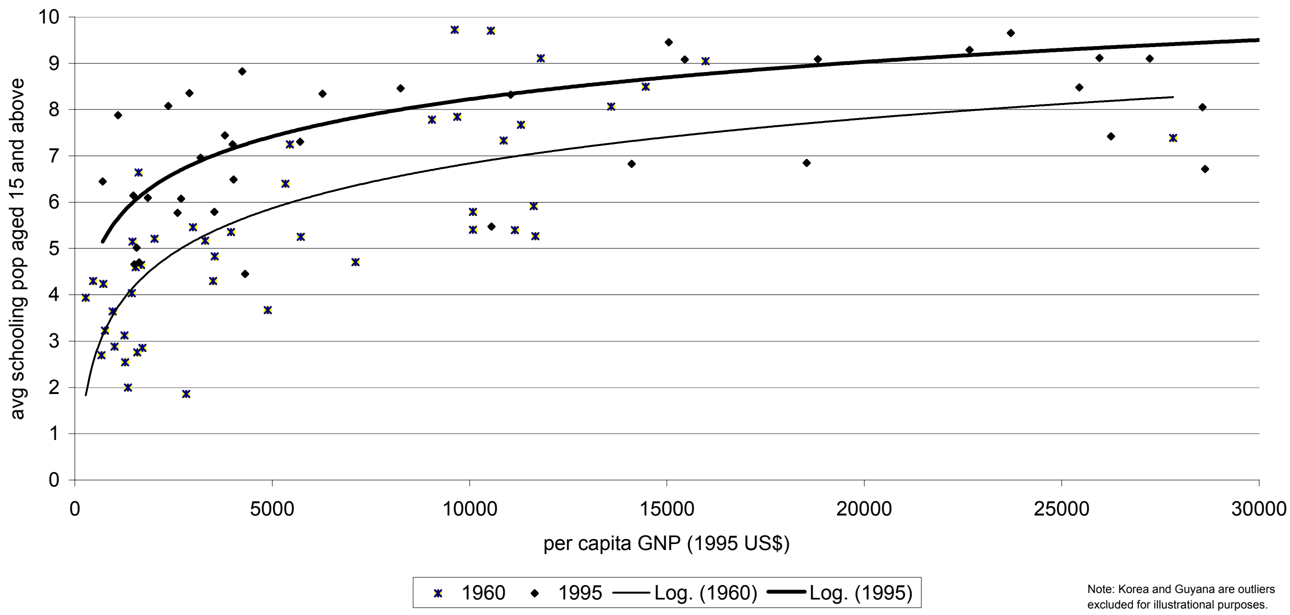
Note: Korea and Guyana are outliers excluded for illustrational purposes.

Figure 2: Relationship Between Per Capita Income and Fertility Rate - Transitional Countries (1960-95)



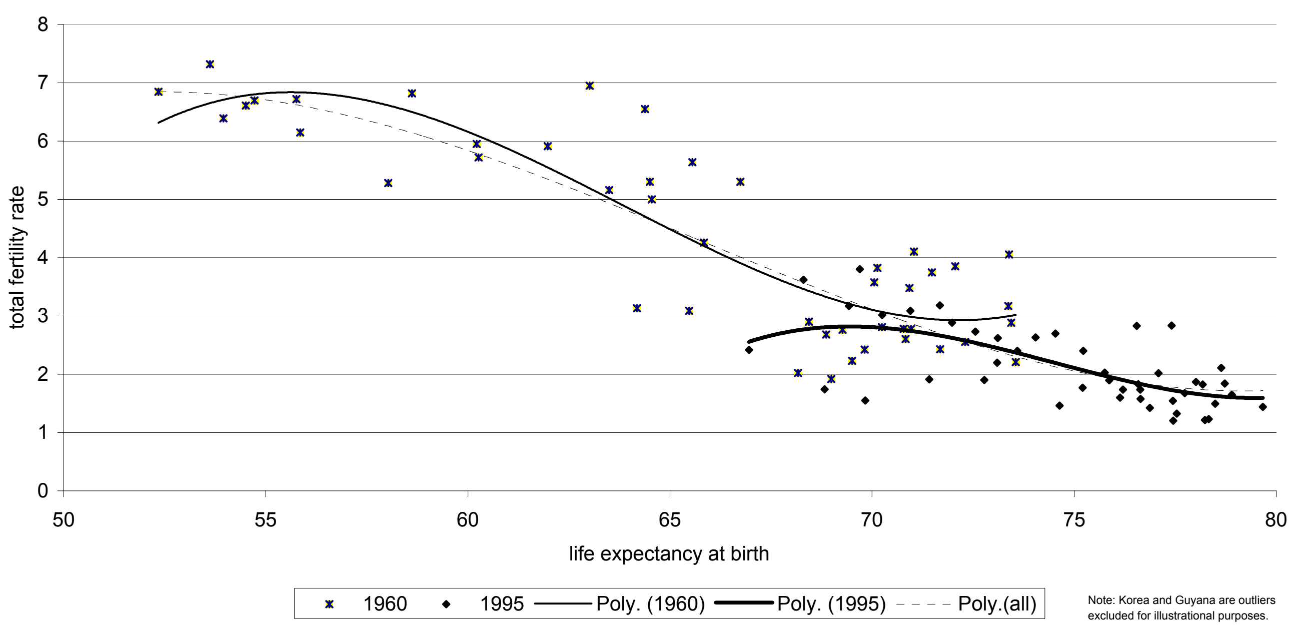
Note: Korea and Guyana are outliers excluded for illustrational purposes.

Figure 3: Relationship Between Per Capita Income and Educational Attainment - Transitional Countries (1960-95)



Note: Korea and Guyana are outliers excluded for illustrational purposes.

Figure 4: Relationship Between Life Expectancy at Birth and Fertility Rate - Transitional Countries (1960-95)



Note: Korea and Guyana are outliers excluded for illustrational purposes.

Figure 5: Relationship Between Life Expectancy at Birth and Educational Attainment - Transitional Countries (1960-95)

Note: Korea and Guyana are outliers excluded for illustrational purposes.

Figure 6: Fertility Deviation from Initial Transitional Level Before and After the Year when Life Expectancy at Birth Reached 50

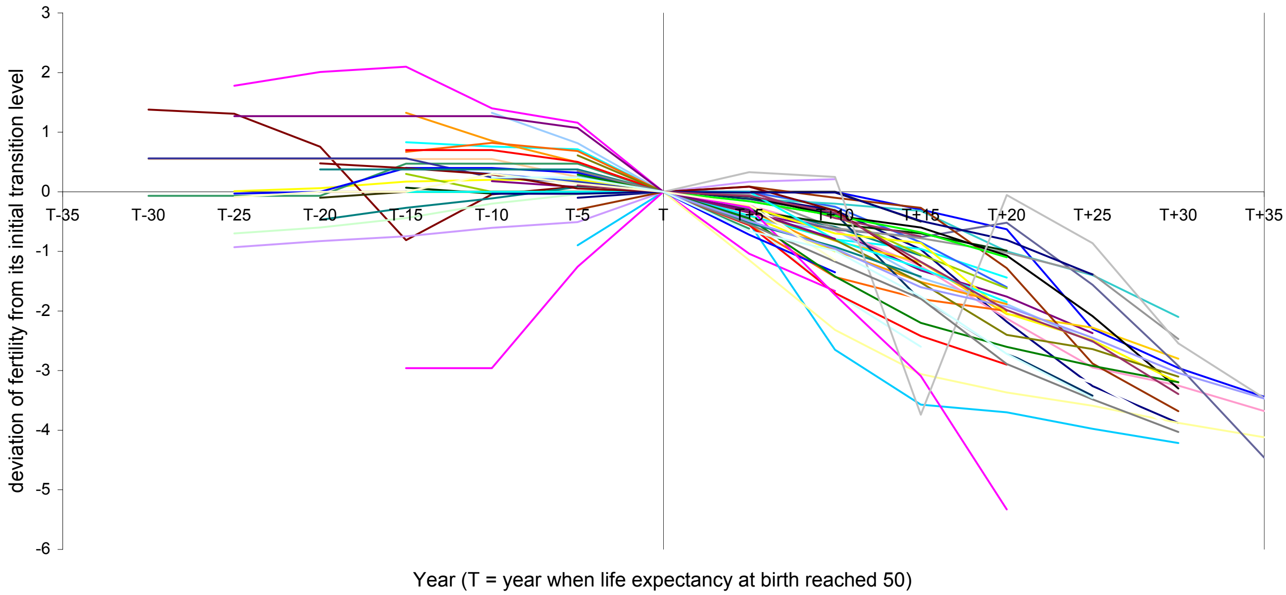


Figure 7: Schooling Deviation from Initial Transitional Level Before and After the Year when Life Expectancy at Birth Reached 50