forthcoming in Journal of Economic Growth

Does the Mortality Decline Promote Economic Growth?

Sebnem Kalemli-Ozcan*
University of Houston

July 2002

Abstract

This paper analyzes qualitatively and quantitatively the effects of declining mortality rates on fertility, education and economic growth. The analysis demonstrates that if individuals are prudent in the face of uncertainty about child survival, a decline in an exogenous mortality rate reduces precautionary demand for children and increases parental investment in each child. Once mortality is endogenized, population growth becomes a hump-shaped function of income per capita. At low levels of income population growth rises as income per capita rises leading to a Malthusian steady-state equilibrium, whereas at high levels of income population growth declines leading to a sustained growth steady-state equilibrium.

JEL Classification: O11, O40, I12, J11, J13
Keywords: Malthus, Survival Probability, Fertility, Education, Population Growth

*Department of Economics, University of Houston, Houston, TX, 77204 (e-mail: Sebnem.Kalemli-Ozcan@mail.uh.edu). The author thanks the referees, Oded Galor, Herschel Grossman, Harl Ryder, Peter Thompson, David Weil and seminar participants at Brown, Clemson, Colgate, Michigan State, Ohio State Universities; University of California at Santa Barbara; University of Houston; Wellesley College; the 2000 Conference on Demographic-Macroeconomic Modeling, Max-Planck Institute, Rostock, Germany; the 1999 International Conference in Economics at Middle East Technical University, Ankara, Turkey; and the 2000 Royal Economic Society Annual Conference, St.Andrews, U.K., for useful comments.

1 Introduction

During the last two centuries, the life expectancy at birth doubled in most parts of the world. For example, the life expectancy at birth in England rose from 37.3 in 1870 to 72.8 years in 1940. Averaging across lower income countries, the life expectancy at birth rose from 42.2 years in 1950 to 65.3 years in 1990.[1] The increase in the life expectancy at birth mostly comes from the reductions in infant and child mortality. This fact can be seen in figure 1 that shows the changes in the age-specific mortality patterns of Sweden, which resemble those of other developed countries in the nineteenth century.[2] In 1780, a newborn child had a 60% chance of living to age 20. By 1930, this figure had risen to 90%. Over the past few decades, infant and child mortality also fell dramatically in less developed regions (LDCs) of the world.[3]

Accompanying the decline in the mortality rates, there has been a sharp decline in the fertility rates (see figure 2).[4] Demographers view these declines in mortality and fertility as components of a single "demographic transition." There are many competing theories about why fertility declined. One theory that is favored by demographers is that the fertility decline is due to the mortality decline, i.e., it is the response to the improved survival chances of the offspring.[5] An alternative theory proposed by Becker (1981) suggests that the demographic transition occurs since at high levels of income, the adverse effect of the opportunity cost of children on child rearing dominates the positive income effect. This theory, however, is inconsistent with the simultaneous occurrence of the fertility transition in countries that markedly differed in their levels of income.[6] The old age security hypothesis, suggest that the demographic transition is associated with the decline in the need of old-age support from children due to the development of financial markets (Caldwell, 1976).[7]

Recently Galor and Weil (1999, 2000), Galor and Moav (2002) argue that the demographic transition was triggered by the increase in the return to education that was brought about by the acceleration of technological progress in the aftermath of the industrial revolution. The rise in the return to skills induced a quantity-quality trade-off and a demographic transition and therefore a fertility decline. The theory appears consistent with the significant increase in the investment in education prior to the fertility decline in most of the developed world. Another theory attributes the demographic transition to the decline in the gender wage gap. Galor and Weil (1996) show that higher wages for women raise the cost of children relatively more than they raise household income, and lead to a reduction in the number of children that couples choose to have. Their model is consistent with the empirical studies such as

Heckman and Walker (1990), who show a negative effect of women's wages on birth rates and Schultz (1985), who finds that an increase in the relative wages of women played an important role in Sweden's fertility transition.[8] For the developing countries the dissemination of the birth control methods is also proposed as an explanation. However studies found that family planning programs explain only 10%-40% of the decline in fertility in developing countries and the rest of the decline is explained by the changes in desired fertility, i.e., number of children families wanted to have (Weil, 2001).

Which of these explanations, including the mortality decline, can explain a bigger fraction of the decline in fertility is still an open empirical question. Answering this question is difficult because the causal factors of the fertility decline not only have varied across countries but also across time. To the best of my knowledge, there has been one study that try to shed light on the issue by comparing two causal factors for a given country. Eckstein et. al. (1998) in a study of Swedish fertility dynamics, show that the reduction in infant and child mortality explain more than two-thirds of the fertility decline, whereas increases in the real wages explain less than one-third of the fertility decline.

The link between the demographic transition and economic growth has been explored in several recent studies. In general, these studies attempt to present a unified model of industrialization and population dynamics that capture economic history from the early stagnation years to the modern growth of the 1800s. They are unified in the sense that they combine different regimes of population and economic growth within a single model.[9] In general mortality is not incorporated into these models and the fertility transition comes as a result of a quality-quantity trade off via technological progress, which then causes sustained growth in income. Therefore it is important to investigate the effect of mortality on fertility together with its implications for economic growth.

In addition to its effect on fertility, child mortality is also important for the human capital investment decision of parents. Lower mortality implies a higher rate of return to education, and thus declining child and youth mortality provides an important incentive to increase investment in the education of each child. Numerous researchers have emphasized that human capital accumulation is the prime engine for economic growth. They have not, however, rigorously investigated this particular mechanism through which increased survival chances promote growth by raising the human capital investment. Some researchers argue that since most of the mortality decline occurs in infancy, a decline in mortality should not matter for the human capital investment decision, which comes later in life. However, Heckman (2000) argues that the return to human capital investment is highest before age five. In addition, mortality changes around age fifteen are not small.[10] Ram and Schultz (1979) argue that improvements in mortality have been an important incentive to increase investment in education at any age, and the post-war experience of India is consistent with this incentive. Meltzer (1992) shows that mortality decline in Mexico from 1920 to 1965 is resulted in a 9.2% increase in the rate of return, which in turn implies a 20% increase in the enrollment rates. There is also evidence that during the faster mortality decline in developing countries between 1960-1990 compared to developed world in nineteenth century, the growth of human capital investment is also faster.[11]

I demonstrate that an exogenous mortality decline causes a fall in fertility, a fall in the net rate of production, and a rise in educational attainment. The model relies on individuals being prudent, as in Kimball (1990), in the face of uncertainty. If the marginal utility of a surviving child is convex in the number of survivors, then there will be a precautionary demand for children. As the mortality rate and thus uncertainty falls, this precautionary demand decreases, causing a quality-quantity trade off.[12] This uncertainty effect together with endogenous mortality lead to the potential co-existence of two steady states, one Malthusian and one with constant growth. Due to the uncertainty effect population growth is a hump shaped function of the survival probability in the partial equilibrium setup, given the assumption on high returns to education. By endogenizing mortality in the general equilibrium framework population growth becomes a hump-shaped function of income per capita, given the assumptions about the survival function. The hump-shaped pattern in the population growth is evident in the data (see figure 3).[13] However, what is important is to generate the hump-shaped relation between the population growth rate and the level of income per capita within a unified model, since the changing relation between these two variables is the central piece in the long development process from a Malthusian stagnation to modern growth. The hump-shaped pattern of population growth as a function of income per capita is the essential factor in determining the general equilibrium outcome. At low levels of income per capita population growth rises as income per capita rises. This in turn leads to dilution of resources and results in lower income per capita and hence in a stable Malthusian steady state. At this steady state, fertility is high and human capital investment is low. At high levels of income per capita population growth falls as income per capita increases. This leads to an unstable growth steady state with low fertility and high human capital investment, above which sustained growth is achieved.

The partial and general equilibrium models are also calibrated by using historical and contemporary data on income and on survival probabilities from 36 and 86 countries respectively. Survival functions for different age groups are estimated from these two data sets and then used to calibrate the general equilibrium model, since the results from this model are ambiguous. This estimation also provides the empirical basis for the endogenous mortality assumption. The calibration exercise shows that the real life mortality changes allow for multiple steady states, and the implied steady state values of the endogenous variables are consistent with the data. The calibration of the partial equilibrium model shows that reduced child mortality can cause economically significant changes in parents' fertility and schooling decisions.

The remainder of the paper is structured as follows. Section 2 introduces the basic framework. Section 3 introduces the general equilibrium model. Section 4 presents the estimation for the survival function followed by the calibration exercise. Conclusions are presented in Section 5.

2 The Model

Consider an OLG economy where activity extends over infinite discrete time. In every period, the economy produces a single homogeneous good by using two inputs: land and human capital. The supply of land is exogenous and fixed over time. The amount of human capital is determined by fertility and schooling choices of the individuals.

2.1 Production of Final Output

Production occurs according to a constant returns to scale neoclassical production technology. Thus the output produced at time (t), Y_t is

$$Y_t = AH_t^{\alpha} X^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{1}$$

where H_t is the aggregate amount of human capital at time (t) and X is the fixed amount of land. A is a fixed productivity parameter. Output per worker at time (t), y_t, is

$$y_t = Ah_t^{\alpha} x_t^{1-\alpha} \equiv y(h_t, x_t), \tag{2}$$

where $h_t = H_t/L_t$ is the human capital per worker and $x_t = X/L_t$ is the resources per worker at time (t).

The modeling of the production side follows Galor and Weil (2000) and hence it is based on two simplifying assumptions. Capital is not an input in the production function and return to land is zero. Thus the return to human capital per worker at time (t) equals to the average product,

$$w_t = A\alpha(\frac{x_t}{h_t})^{1-\alpha}. \tag{3}$$

2.2 Individuals

Individuals within a generation have identical preferences. Members of generation t live for two periods: in the first period of life, $(t-1)$, individuals consume a fraction of their parent's unit time endowment. In the beginning of the second period of life, (t), individuals make a one-time fertility decision and an education decision for their children.

The preferences of the altruistic member of generation t are defined over second period's consumption, C_t, and the future income of the surviving children, $N_t w_{t+1} h_{t+1}$, where N_t is the number of survivors, w_{t+1} is the future wage of a survivor per unit of human capital, and h_{t+1} is the human capital of a survivor. E_t denotes expectation as of time (t). The utility function for a member of generation t can be written as

$$U_t = \gamma \ln \Big[C_t\Big] + (1-\gamma) E_t \Big\{ \ln \Big[N_t w_{t+1} h_{t+1}\Big]\Big\}. \tag{4}$$

Human capital production is given by

$$h_{t+1} = e_t^{\beta} h_t, \qquad 0 < \beta < 1, \tag{5}$$

where e_t is the education level of a child and h_t is the level of parental human capital.

Households choose the number of children, n_t, and the optimal amount of education, e_t, to give to each child where each child's survival is uncertain. These choices are subject to a constraint on the total amount of time, which is unity. Assuming a fixed time cost, $v \in (0,1)$, for every child, the time left for the household after the child-bearing cost is incurred is $1 - v n_t$. This remaining time is divided between work to earn a wage income and educational investment. Therefore, the budget constraint is[14]

$$w_t h_t (1 - (v + e_t) n_t) = C_t. \tag{6}$$

With uncertainty, the number of survivors will be a random variable drawn from a binomial distribution. Thus, the probability that N_t out of n_t children will survive is

$$f(N_t; n_t, q_t) = \binom{n_t}{N_t} q_t^{N_t} (1 - q_t)^{n_t - N_t} \qquad N_t = 0, 1, \ldots, n_t, \forall t, \tag{7}$$

where $q_t \in (0, 1)$ is the survival probability of each child. The survival probability is assumed to be fixed over time. This assumption will be relaxed in the general equilibrium model.

The maximization of expected utility and the first order conditions are as follows.[15]

$$E_t(U_t) = \sum_{N_t=0}^{n_t} \left\{ \gamma \ln \left[C_t \right] + (1 - \gamma) \ln \left[N_t w_{t+1} h_{t+1} \right] \right\} f(N_t; n_t, q). \tag{8}$$

$$e_t - \frac{\beta(1 - \gamma)}{(\beta(1 - \gamma) + \gamma)} \frac{(1 - v n_t)}{n_t} = 0. \tag{9}$$

$$\frac{-\gamma(v + e_t)}{1 - (v + e_t) n_t} + \frac{(1 - \gamma)}{n_t} + \frac{(1 - \gamma)(1 - q)}{2 q n_t^2} = 0. \tag{10}$$

The population growth rate is,

$$\frac{L_{t+1}}{L_t} - 1 = E_t(N_t) - 1 = (n_t q) - 1, \tag{11}$$

where L_t is the size of the population at time (t). Given (9)-(11), an exogenous increase in the survival probability (a decline in mortality), causes parents to decrease their precautionary demand for children. Thus, they choose to have fewer children and provide them with more education. In addition at low levels of survival, an increase in the survival probability unambiguously raises the population growth rate, while at high levels of survival, an increase in the survival probability causes the population growth rate to decline if the returns to education are high enough.

Proposition:

$$\begin{aligned} \frac{dn_t}{dq} &< 0, \ \forall q, \\ \frac{de_t}{dq} &> 0, \ \forall q. \end{aligned} \tag{12}$$

$$\lim_{q \to 0} \frac{d(L_{t+1}/L_t)}{dq} > 0, \tag{13}$$
$$\lim_{q \to 1} \frac{d(L_{t+1}/L_t)}{dq} < 0 \quad \text{if } \beta \cong 1,$$

$$\frac{d^2(L_{t+1}/L_t)}{dq^2} < 0, \ \forall \ q.$$

Proof: See Kalemli-Ozcan (2002).

Therefore there is a Malthusian outcome, where the population growth rate depends positively on the survival chances and a non-Malthusian outcome, where the population growth rate declines with increased survival. The transition from the Malthusian outcome to the non-Malthusian outcome depends on the initial mortality rates and the returns to education. When the survival probability is low (a high initial mortality rate), the population growth rate increases with the increases in the survival rate due to the increase in the number of survivors. When the survival probability is high, although the population growth rate may increase due to the increased number of survivors, the negative response of fertility can offset this effect. Most quality-quantity trade off literature assumes high returns to education by assuming $\beta = 1$. Also Parente and Prescott (2000) argue that when β is near 1, the differences in the time allocated to human capital investment lead to large differences in the steady state levels of income per capita, which are consistent with the data. Therefore population growth is a concave function of the survival probability, and if the returns to education are high enough (β is close to 1) it is a hump-shaped function (see figure 4a).

3 General Equilibrium Analysis

What are the dynamic implications of these links from mortality to fertility and human capital investment for economic growth? The answer to this question is important since ultimately we want to understand the importance of the mortality decline in the development process. To be able to perform this kind of general equilibrium exercise survival probability should be endogenous.

3.1 Endogenous Mortality

Both time-series and cross-sectional empirical studies have found that as income per capita in a country rises, the mortality rates tend to fall.[16] Based on this evidence, q_t is assumed to be a concave function of income per capita for the general equilibrium analysis.

$$q_t \equiv q(y_t), \tag{14}$$

$$q_y(y_t) > 0 \ , \ q_{yy}(y_t) < 0.$$

where $q(y_t)$ maps into $[0,1]$, i.e., $\lim_{y_t \to 0} q_t = 0$ and $\lim_{y_t \to \infty} q_t \leq 1$.

Given the hump-shaped relationship between the survival probability and the population growth rate, the concave relationship between the survival probability and income per capita results in a hump-shaped relationship between the population growth rate and income per capita (see figure 4b). As shown in figure 4b, having a negative population growth rate ($\frac{L_{t+1}}{L_t}$ below 1) at high levels of income per capita, depends on the parameter values, specifically $v > (1-\gamma)(1-\beta)$.[17] This inequality says the following: for a given rate of return on education, if parents care about their own consumption a lot (high γ) or if the fixed cost of a child, v, is high then they prefer to have fewer children in order to increase their own consumption. On the other hand, if parents' valuation for their own consumption and the cost of children are fixed, then a high return to education (high β) also satisfies this condition. If this inequality holds with equality, $\frac{L_{t+1}}{L_t}$ asymptotes to 1 at high levels of income per capita, implying a population growth rate of zero. All of this is consistent with the current rates of zero or negative population growth in some European countries. In fact, over the next several decades much of Western Europe is forecasted to have negative population growth rates (Bongaarts, 1999).

3.2 The Evolution of Population Growth, Human Capital, and Output

The development of the economy is characterized by the evolution of output per worker, population, human capital per worker, and resources per worker. The evolution of human capital per worker and population are given in (5) and (11) respectively. The evolution of resources per worker is given by

$$x_{t+1} = \frac{X}{L_{t+1}} \tag{15}$$

The evolution of the economy is determined by a sequence $\{h_t, x_t, L_t\}_{t=0}^{\infty}$ that satisfies (5), (11) and (15). However, given (14), L_t and h_t evolve with respect to y_t via n_t and e_t. Therefore, substituting the equations for $\frac{L_{t+1}}{L_t}$, and h_{t+1} into the one-period iterated form of (2), y_{t+1} can implicitly be written as a function of y_t,

$$y_{t+1} = Ay_t \left[\frac{\beta(1-\gamma)}{\gamma + \beta(1-\gamma)} \right]^{\beta\alpha} \left[\frac{(1 - vn_t)}{n_t} \right]^{\beta\alpha} [n_t q_t]^{\alpha - 1} \equiv \psi(y_t). \tag{16}$$

where $q_t = q(y_t)$ and $n_t = n(q(y_t))$. Hence the evolution of the economy is governed by one dimensional nonlinear first-order difference equation as given in (16).

Income per capita growth comes from positive human capital accumulation and negative population growth. Both are going to be a result of the quality-quantity trade off due to increased survival chances. Unfortunately, solving the difference equation given in (16) analytically becomes intractable. Since the signs of the slope, ψ', and the curvature, ψ'' are ambiguous, the above setup can give different equilibrium outcomes depending on the parameter values as shown in Appendix. Figure 4c shows the possible equilibrium outcomes.[18] One of these possible cases is the two steady state case: a stable Malthusian steady state (denoted as y_m), with domain of attraction from point 0 to y_g, and an unstable growth steady state (denoted as y_g), above which persistent growth is achieved.

The hump-shaped pattern of population growth as a function of income per capita is the essential factor in determining the shape of $\psi(.)$ and thus the equilibrium outcome. The shape of the population growth rate, as a function of income per capita, in turn depends on the functional form $q(.)$ and the parameter restrictions. If $q(.)$ is concave and asymptotes to 1 at high levels of income per capita, and if the parameter restrictions for population growth to be a hump-shaped function of q_t are satisfied (high returns to education), then population growth is a hump-shaped function of income per capita as shown in figure 4b. If in addition the rate of population growth is negative (as shown in figure 4b) at high levels of income per capita, then there will be two steady states. At low levels of income per capita (either side of y_m), the survival chances are low. Therefore, an increase in the survival probability, as a result of an increase in income per capita, leads to an increase in the rate of population growth. This results in lower income per capita via the dilution of resources per worker due to the fixed factor of production, i.e., land. This is the stable Malthusian steady state. At high levels of income per capita (above y_g), the survival chances are high, so further increases in the survival probability cause population growth to decline via decreased fertility. This, together with increased levels of human capital investment, leads to higher income per capita and, therefore to endogenous growth. With negative population growth at high levels of income per capita, there is sustained growth beyond the growth steady state. Thus, one result out of this setup is that shrinking population over time generates sustained growth in income per capita.

There is neither exogenous nor endogenous technological progress. In principle, there can be an endogenous transition from a two steady state case to a one steady state case. The Malthusian steady state will disappear by the upward shifts of the survival function $q(.)$ over time. However, since there is no technological progress, there is not an endogenous transition between the two steady states. Also there is not sustained growth at any steady state. Both population growth and income per capita growth are zero at the steady states, implying aggregate income growth is also zero. What about outside the steady states? Around the Malthusian steady state there is a Malthusian regime and the economy stays close to the Malthusian steady state. The equal amount of increases in population and aggregate income bring income per capita growth to zero. Therefore, the economy is trapped at the Malthusian steady state. A negative rate of population growth above the growth steady state allows for sustained growth in income per capita.

If there is exogenous technological progress, $\psi(.)$ can shift up and create a jump from a Malthusian regime to a growth regime. If there is endogenous technological progress, an exogenous decline in mortality can serve as the basis for a unified growth model that describes the complete transition from a Malthusian world to the modern growth era. After an initial decline in mortality, population growth rises without the fertility response (as shown here). But the effect of lower mortality in raising the human capital investment is present. This leads to higher technological progress (technical change should be a function of education), and therefore, higher income further lowers mortality. Then the fertility response comes into play and population growth falls together with more human capital investment. As a result, a decline in mortality can transfer an economy from a Malthusian regime to a growth regime.[19] The aim here is to focus on the role of the mortality decline in the development process, which is ignored in the literature. While doing this, I want to abstract from all the usual suspects, in particular from technological progress, since I want to know if the mortality decline alone can promote growth by initiating a quality-quantity trade off.

The model depends on parameters and functional forms. It shows the possibility of two steady states, but this is not a definite outcome. Therefore, I have to study the data to see what the real life mortality changes imply about the general equilibrium dynamics.

4 Estimation of the Survival Function and Calibration

In order to calibrate the model, I need to estimate the survival probability, q_t, as a function of income per capita, as in (14).

4.1 Data

I use data on the mortality rates for different age groups and data on GDP per capita from a cross-section of countries for the years 1900 through 1997. I examined two different data sets.[20] The first, combined from various sources, covers 36 countries for 1900, 1930, 1960, and 1990. The second, from World Bank (2000), covers 86 countries for 1960, 1980, and 1997. The first data set, termed the "historical" data set because it goes back to 1900, features two variables: the survival rate for males, $q_{x,it}$, where i denotes the country and t denotes the time, and income per capita, y_{it}, from Maddison (1995). The survival rate for males represents the fraction of males who survive until age x out of 100,000 born. I use the survival rate for ages one, five, and fifteen ($x = 1, 5, 15$).

The World Bank data set also has two variables: The survival rate for males and income per capita. The survival rates are derived from the mortality rates that are conditional to reaching a given age. The survival rates in the historical data set, however, are not conditional. Thus, I will denote the survival rates in the World Bank data set with $q_{c-x,it}$, where c stands for the conditional survival age. The age five survival rate ($x = 5, c = 1$), for example, is the probability that a newborn baby will survive until age five. The adult survival rate ($x = 60, c = 15$) is the probability of a fifteen year old male surviving until age sixty. Income per capita, y_{it}, is just GDP per capita.

4.2 A Non-Linear Estimation of the Survival Function

By using the historical data set described above, each of the three dependent variables, $q_{1,it}, q_{5,it}, q_{15,it}$, is estimated as a function of income per capita. Hence, the following concave functional form is estimated cross-sectionally for each of these survival probabilities and for four different years separately: 1900, 1930, 1960, and 1990.[21]

$$q_{\bar{x},i\bar{t}} = a_0(1 - exp(-a_1 y_{i\bar{t}})). \quad (17)$$

In tables 1 and 2, I report results for ages five and fifteen. All coefficients are found to be significant.[22] Results are similar for age one. The first column of table 1 shows the estimation for the dependent variable $q_{5,1900}$. The other columns reports the same estimation for q_5 for 1930, 1960, and 1990. Table 2 does the same exercise for q_{15}.

Figures 5a and 5b show the fitted values for each year from the estimations of q_5 and q_{15} given in tables 1 and 2 respectively. In both figures, the thick line at the bottom is for 1900, the next one is for 1930, and the thickest one at the top is for 1960. The horizontal thin line is for 1990. It is evident from the figures that survival probabilities become more independent of per capita income with increasing levels of income per capita.

Next, using the World Bank data, I repeated the same exercise. Hence, the concave functional form in (17) is estimated cross-sectionally for q_{1-5}, and q_{15-60} for three different years separately. 1960, 1980, and 1997. As shown in tables 3 and 4, all coefficients are significant. Figures 5c and 5d show the fitted values for each year from these estimations. Now the thick line at the bottom is for 1960, the next one is for 1980, and the thickest one at the top is for 1997 in both figures. What is different here is that, even for the year 1997, there is a concave relationship instead of a linear relationship. This is because the World Bank data set contains more developing countries. In the historical data set, only 16 of 36 countries are developing countries, whereas the World Bank data set has 64 developing countries in a sample of 86 countries.

4.3 Calibrating the Model

The general equilibrium model is calibrated by using all of the estimated survival functions just described. I report only results that use the estimated survival function, q_5, from the historical data set and the estimated survival function, q_{15-60}, from the World Bank data set, as given in tables 1 and 4 respectively. The choices for the other parameters are explained below. The calibration results are given in four panels of figure 6. The purpose of this exercise is to see the implications of the real life mortality data and hence to see whether or not the general equilibrium model is consistent with the stylized facts of the development process.

Using the estimated survival function, q_5, for 1900, 1930, and 1960 from the historical data set, figure 6 shows the evolution of population growth as a function of income per capita.

The q_5 for 1990 cannot be used since the estimated relationship for that year is linear. For 1900 and 1930, a concave relationship exists between population growth and income per capita; for 1960, the relationship becomes hump-shaped. Why is this? Recall that there are two necessary conditions for population growth to be a hump-shaped function of income per capita (see section 3.2); the survival function $q(.)$ must be concave and asymptote to 1 with high values of income per capita and some parameter restrictions need to be satisfied. I start with the choice of the parameters. Parameters other then q_t are chosen from the literature and according to the restrictions of the model. As previously explained, some studies found returns to education, β, being close to 1. A high β is needed to have population growth as a hump-shaped function of the survival probability so β is chosen to be 0.9. For γ, I assume parents value their consumption and the future income of their survivors equally. Therefore, γ is chosen to be 0.5. Given β and γ, v is chosen to fit the restriction for having negative population growth at high levels of income per capita (as in figure 4b) i.e., $v > (1-\gamma)(1-\beta)$, hence v is chosen to be 0.1.[23] Finally, α is chosen according to the stylized facts of the cross-country growth literature. Thus, α is chosen to be 0.3. In figure 6a, the difference between 1900, 1930, and 1960 is due to the estimated value of the survival probability. Given the fact that β has a high value and the estimated survival function $q(.)$ for 1960 is concave and asymptotes to 1 with high values of income per capita, population growth is hump-shaped for 1960. It becomes negative with high values of income per capita given the fact that the above inequality holds. But for 1900 and 1930, it is concave and always positive, since for those years $q(.)$ is estimated to have a much lower value then 1 at high levels of income per capita (see figure 5a).

The calibration of (16) results in the multiple steady states given in figure 6b. Using the estimated survival function, q_5 for 1960 from table 1, the two steady states are shown for 1960. Since population growth is a hump-shaped function of income per capita and since it is negative at high levels of income per capita, there are two steady states, where sustained growth prevails beyond the growth steady state. For 1900 and 1930, there is not a growth steady state, since population growth is not a hump-shaped function of income per capita and thus stays always positive, implying that the calibrated $\psi(.)$ function stays below the 45 degree line.

Figures 6c and 6d, repeat the same exercise by using the estimated survival function, q_{15-60} from the World Bank data set. The results are similar. Here, for 1960 and 1980, population growth is always positive since it is a concave function and thus there is not a growth steady state. Recall that these data are mostly composed of poor countries. For 1997, population growth is a hump-shaped function and becomes negative at high levels of income per capita, so the growth steady state is there, above which sustained growth is achieved.

Therefore, the calibration exercise shows that the estimated survival probabilities allow for multiple steady states. The one at the lower level of income per capita is the locally stable Malthusian steady state and the one at the higher level of income per capita is the unstable growth steady state.[24] Thus, two countries with same parameters can have different outcomes depending on their mortality levels.

Table 5 gives the numerical results of the calibration exercise. This corresponds to the two steady states in figure 6b. Note that since the model abstracts from a variety of factors important for the development process, it will be impossible to match the data one-to-one. Income per capita is in natural logarithms, so the Malthusian steady state income corresponds to 20 dollars and the growth steady state income to 3,500 dollars. Remember that the growth steady state is an unstable threshold steady state. If the economy starts above the threshold growth steady state, it will have sustained growth forever. Otherwise it will be trapped in a Malthusian regime. The difference between these income levels match the data. In the real world, poor countries trapped in Malthusian type regimes have a subsistence income per capita around 100-500 dollars. Rich countries that grow have an income per capita of 20,000-30,000 dollars. The difference is around 200 fold, which is similar to the difference here. As a result of this income difference, survival probability differs 1.6 fold between the two steady states. This difference in the survival chances causes almost a 50% decrease in fertility and a doubling of the educational investment on each child (see table 5). This change between the two steady states and the implied values of the variables are consistent with the data of rich and poor countries.

The general equilibrium calibration exercise, as given in table 5, does not answer the following question: Can small changes in the survival probability cause bigger changes in parents' behavior, namely their fertility and educational investment choices? To answer this question, one must calibrate the partial equilibrium model, where mortality is exogenous. This is done in table 6. All of the elasticities in table 6 have the same sign as in the analytical solutions. The table shows that the effects of reduced mortality are economically significant. At low levels of the survival probability ($q = 0.51$), a one percent increase in the survival probability will lead to almost a one percent decrease in fertility and a one percent increase in the educational investment. At high levels of the survival probability, the effects are more profound. At $q = 0.83$, for a one percent increase in the survival probability there will be an almost two percent decrease in fertility and a two percent increase in the educational investment. At $q = 0.9$ fertility and education change by three percent with respect to a one percent change in mortality. Thus, although the reduction in mortality could not account for all of the decrease in fertility and the increase in schooling that have been observed, it can explain a significant fraction.

5 Conclusion

This paper shows that mortality decline working through the channels of education and fertility promotes economic growth. Individuals are prudent in the face of uncertainty about child survival, which causes a precautionary demand for children. As the mortality rate falls, precautionary demand decreases, and thus, parents choose to move along a quality-quantity frontier. This uncertainty effect together with endogenous mortality may lead to multiple steady states. Due to the uncertainty effect population growth is a hump shaped function of the survival probability in the partial equilibrium model. By endogenizing mortality in the general equilibrium model, population growth becomes a hump-shaped function of income per capita, given the parameter restrictions. Thus at low levels of income per capita population growth rises as income per capita rises. This in turn leads to dilution of resources and results in lower income per capita and hence in a Malthusian steady state. At this steady state the fertility is high and human capital investment is low. At high levels of income per capita population growth falls as income per capita increases. This leads to a growth steady state with low fertility and high human capital investment, above which sustained growth is achieved. Calibration exercises, based on the estimation of the survival probability from historical and contemporary data, show that the general equilibrium model is consistent with the stylized facts of the development process.

The paper provides an explanation for the demographic transition followed by sustained economic growth that occurred in developed countries in the nineteenth century and is occurring in developing countries today within a unified model. As a result the paper has important policy implications. Although demographic transition is complete in most parts of the world, there are still high fertility countries, especially in Africa. Some researchers show that the countries in Africa, where child mortality has declined in recent decades, have begun the demographic transition. But a mounting epidemic of HIV/AIDS threatens this progress.

In regions with the highest HIV prevalence, such as Botswana, Zimbawe and South Africa, approximately 36% of the young people (ages 15-24) are HIV positive (United Nations, 1999). What is more interesting is that in these countries, after an increase of 35% in gross primary school enrollment between 1975 and 1985, there is a 16% decline in this enrollment rate between 1985 and 1995, on average. The fertility rates declined initially during the same period in those countries from 7 children per women, on average, to 5.5, but then they stayed constant. Thus, reducing child mortality from the diseases like AIDS and Malaria will bring the additional benefits of increased educational investment and reduced fertility by parents, which in turn will cause lower population growth and higher economic growth.

Theoretical Appendix

I start by rewriting (16).

$$y_{t+1} = Ay_t \left[\frac{\beta(1-\gamma)}{\gamma+\beta(1-\gamma)}\right]^{\beta\alpha} \left[\frac{(1-vn_t)}{n_t}\right]^{\beta\alpha} [n_t q_t]^{\alpha-1} \equiv \psi(y_t). \tag{18}$$

It follows that $\lim_{y_t \to 0} y_{t+1} = 0$ since $\lim_{y_t \to 0} q_t = 0$ from (14) and $\lim_{q_t \to 0} n_t = 1/v$ from (10). Also $\lim_{y_t \to \infty} y_{t+1} = \infty$, since $\lim_{y_t \to \infty} q_t \leq 1$ from (14) and $\lim_{q_t \to 1} n_t = (1-\alpha)(1-\beta)/v$ from (10). But notice that if $\beta = 0$ there can be an indeterminate case, i.e., $\lim_{y_t \to \infty} y_{t+1} = 0$ or $\lim_{y_t \to \infty} y_{t+1} = \infty$.

I want to know the signs of total first and second order derivatives of $\psi(.)$ with respect to y_t, i.e., $\frac{dy_{t+1}}{dy_t} = \psi'$ and $\frac{d^2 y_{t+1}}{dy_t^2} = \psi''$. Taking the logarithm of (18) and then differentiating it with respect to y_t gives,

$$\psi' = y_{t+1} \underbrace{\left[\frac{1}{y_t} - \frac{dq_t}{dy_t} \overbrace{\left\{\frac{dn_t}{dq_t} \frac{\beta\alpha}{(1-vn_t)n_t} + \frac{(1-\alpha)}{P_{t+1}} \frac{dP_{t+1}}{dq_t}\right\}}^{Z}\right]}_{X}, \tag{19}$$

where $P_{t+1} = \frac{L_{t+1}}{L_t} = n_t q_t$.

Given that $\frac{dq_t}{dy_t} > 0 \; \forall q$ and $\frac{dn_t}{dq_t} < 0 \; \forall q$, and $\lim_{y_t \to \infty} q_t = 1$, $\lim_{y_t \to \infty} \frac{dP_{t+1}}{dq_t} < 0$, and hence $\psi' > 0$. But $\lim_{y_t \to 0} q_t = 0$, and thus $\lim_{y_t \to 0} \frac{dP_{t+1}}{dq_t} > 0$. Hence ψ' is ambiguous when $y_t \to 0$. The sign depends on the parameter values and relative magnitudes within the term Z.

To find out the curvature, I take the total derivative of (19) with respect to y_t

$$\psi'' = \psi' X + y_{t+1} \frac{dX}{dy_t}, \tag{20}$$

where

$$\frac{dX}{dy_t} = -\frac{1}{y_t^2} - \frac{d^2 q_t}{dy_t^2} \overbrace{\left\{\frac{dn_t}{dq_t} \frac{\beta\alpha}{(1-vn_t)n_t} + \frac{(1-\alpha)}{P_{t+1}} \frac{dP_{t+1}}{dq_t}\right\}}^{Z} -$$

$$\left(\frac{dq_t}{dy_t}\right)^2 \underbrace{\left\{\frac{d^2n_t}{dq_t^2}\frac{\beta\alpha}{(1-vn_t)n_t} + \left(\frac{dn_t}{dq_t}\right)^2\frac{\beta\alpha(2vn_t-1)}{(1-vn_t)^2n_t^2} + \frac{(1-\alpha)}{P_{t+1}}\frac{d^2P_{t+1}}{dq_t^2} - \frac{(1-\alpha)}{P_{t+1}^2}\left(\frac{dP_{t+1}}{dq_t}\right)^2\right\}}_{W}.$$

Notice that $X = \psi'/y_{t+1}$ thus I can write (20) as

$$\psi'' = (\psi')^2/y_{t+1} + y_{t+1}\frac{dX}{dy_t}.$$

Again the sign of ψ'' is ambiguous, and it depends on the parameter values. The first term is always positive but the second term is ambiguous since the sign of $\frac{dX}{dy_t}$ is ambiguous. When $y_t \to \infty$ the derivatives $\frac{dq_t}{dy_t}$ and $\frac{d^2q_t}{dy_t^2}$ become essential in determining the sign of $\frac{dX}{dy_t}$ and thus the sign of ψ''. I assume $q(.)$ is concave and asymptotes to 1 when $y_t \to \infty$ as given in (14). This implies $\lim_{y_t\to\infty}\frac{dq_t}{dy_t} = 0$ and $\lim_{y_t\to\infty}\frac{d^2q_t}{dy_t^2} = 0$. Also given $\lim_{y_t\to\infty} 1/y_t^2 = 0$, $\lim_{y_t\to\infty}\frac{dX}{dy_t} = 0$ and thus $\psi'' > 0$. But there can also be an indeterminate case since $\lim_{y_t\to\infty}\frac{dq_t}{dy_t} = 0$, hence ψ' is indeterminate.

Data Appendix

Historical Data Set

The male survival rates, $q_{x,it}$, are calculated from the life table variable $l_{x,it}$, which is the number of the male survivors until exact age x out of 100,000 born, for each country i and each year t. $l_{x,it}$ comes from a cross-sectional period life table. For example if $x = 15$ (given i and t, such as U.S. in 1900) it measures how many males would survive until age 15 if at each age they experienced the mortality rates of men who are currently that age. The survival data, $l_{x,it}$, are from various sources: Colin Clark (1970), Keyfitz and Flieger (1968, 1990), Haines (1994), Keyfitz et al. (1972). The income per capita data, y_{it}, from Maddison (1995) in 1990 dollars.

World Bank Data Set

The male survival rates are converted from conditional male mortality rates, which are the original data given by the World Bank. These come from cross-sectional period life tables as in the historical data set. For example, the adult survival rate, converted from the adult mortality rate, is the probability of a 15 year old man dying before reaching age 60, if subject to current age-specific mortality rates between ages 15 and 60. Thus, it is conditional on reaching age 15. The age five survival rate, also converted from the age five mortality rate, is the probability that a newborn baby will die before reaching age five, if subject to current age-specific mortality rates. The GDP per capita is constant at 1995 U.S. dollars.

Countries in the two Data Sets

Historical Data (1900, 1930, 1960, 1990)	World Bank Data (1960, 1980, 1997)	World Bank Data cont.	World Bank Data cont.
Argentina	Algeria	Honduras	Paraguay
Australia	Argentina	Hungary	Peru
Austria	Australia	Iceland	Philippines
Belgium	Austria	Indonesia	Portugal
Bulgaria	Bahamas	Ireland	Rwanda
Canada	Bangladesh	Israel	Singapore
Chile	Barbados	Italy	Spain
China	Belgium	Jamaica	Sri Lanka
Czechoslovakia	Benin	Japan	Sudan
Denmark	Botswana	Kenya	Suriname
Egypt	Brazil	Korea, Republic	Swaziland
Finland	Burkina Faso	Lesotho	Sweden
France	Burundi	Luxembourg	Switzerland
Germany	Cameroon	Madagascar	Thailand
Greece	Canada	Malawi	Togo
Hungary	Central African Republic	Malaysia	Trinidad and Tobago
India	Chad	Mauritania	United Kingdom
Ireland	Chile	Mauritius	United States
Italy	China	Mexico	Uruguay
Japan	Congo, Republic	Morocco	Zambia
Mexico	Costa Rica	Nepal	
Netherlands	Cote d'Ivoire	Netherlands	
New Zealand	Denmark	New Zealand	
Norway	Dominican Republic	Nicaragua	
Poland	Ecuador	Niger	
Portugal	Egypt, Arab Republic	Nigeria	
Romania	El Salvador	Norway	
South Africa	Fiji	Pakistan	
Spain	Finland	Panama	
Sweden	France	Papua New Guinea	
Switzerland	Gabon		
Taiwan	Ghana		
United Kingdom	Greece		
United States	Guatemala		
Venezuela	Guyana		
Yugoslavia	Haiti		

Notes

1. See Livi-Bacci (1997) and United Nations (1999).

2. The mortality decline in the developing world is much faster and occurs at lower levels of income compared to that of the developed world. This is due to the rapid transfer of the health technology from the West. In the developed world, however, the mortality decline was due to an increase in the standard of living. In the latter decades of the twentieth century, improvements in old age mortality shape the picture of the mortality decline in developed countries.

3. In these regions, both infant and child mortality fell approximately 60% between 1950 and 1990.

4. In developed countries, the fertility decline, which began by the end of the nineteenth century, was completed by World War II. During this period, the total fertility rate (TFR), which is defined as the number of children that a woman would have if she lived through all of her child-bearing years and experienced the current age-specific fertility rates at each age, declined from 5 children to 2.5 children. In the developing world, the fertility transition started around the 1950s, and over the past forty years TFR declined from 6 children to 3 children. See Livi-Bacci (1997) and United Nations (1999). The fertility decline is preceded by the mortality decline in general. France is an exception, where the fertility decline began early in the nineteenth century before the mortality had declined. Lesthaeghe and Van de Walle (1976) and Segalen (1992) argue that this is due to voluntary limitation of births. Mroz and Weir (1989) estimate after the initial decline in fertility in France 17% of the decline in fertility between 1840 and 1919 is due to the decline in mortality. The U.S. also has declining fertility early in the nineteenth century. Haines (1998) argues that during this time, fertility was being controlled mostly by adjustments in marital fertility. He reports after the initial decline in fertility in U.S., 30% of the later decline is due to the decline in the death rates.

5. Wolpin (1997), Galloway et. al. (1998), Coale (1986), and Preston (1978b) provide support for the causal effect of the mortality decline on the fertility transition. There may be two different strategies at work that generate the fertility response to reduced mortality. First, the “replacement strategy” is the response of fertility to experienced

deaths, where parents replace deceased children. Second, the "insurance strategy," or hoarding, is the response of fertility to expected deaths, where parents bear more children than their optimal number of survivors. If parents follow a replacement strategy, they can produce their target number of survivors with no error, and a change in child mortality will have no effect on the population growth rate. However, in the empirical studies using micro data, the estimated replacement effect is always smaller than 0.5 and generally it is around 0.2. But only a replacement effect of 1 means a fully working replacement strategy. (See Schultz, 1997.)

6. His alternative related theory that the elasticity of substitution between quantity and quality of children increases with income, is subjected to the same criticism.

7. There are inconclusive evidence about this theory. Kaplan (1994) provides evidence that rejects the hypothesis, whereas Cain (1977) shows support for the hypothesis.

8. Other theories explain the decline in fertility as a result of the aggregate consumption growth in the economy and/or the increase in the aggregate level of human capital. Examples are Becker and Barro (1988) and Becker et. al. (1990). Brezis (2001), Dahan and Tsiddon (1998) use the change in the structure of the economy, the role of the social classes and the effect of income inequality as explanations for the fertility transition, respectively.

9. Galor and Weil's (2000) model is the first unified growth model, where the evolution of population growth, technological progress and output growth is consistent with the developments in the last several centuries. Some elements of the long transition from stagnation to growth are also studied in Kremer (1993), Lucas (2002), Hansen and Prescott (2002), Tamura (2002), Lagerlof (2002), Kogel and Prskawetz (2001), and Morand (2002).

10. In Sweden around 1800, 5200 children died between ages 10 and 15 out of 100,000 births. By 1930 this number fell to 400.

11. The relevant comparison is between mortality and human capital in developing countries in the period 1960-1990 on the one hand versus the more developed countries at an earlier period, on the other. This kind of comparison is an empirical question, which should be handled in a multiple regression framework since there are many other factors

that affect growth of human capital investment during this period in the developing countries. However, if we look at the data we see the following pattern: Average years of schooling increased from 2.05 to 4.43 in the developing countries between 1960-1990. During the same period life expectancy at birth increased from 48 to 68 in those countries on average. In England life expectancy at birth increased from 48 to 69 between 1880 and 1950. The average years of schooling increased from 9.1 to 10.8 during the same period implying a smaller percentage increase compared to the percentage increase of schooling in the developing countries between 1960-1990. See Matthews et al. (1982) for England data and World Bank (2000) for LDC data.

12. Previous research, ignoring the role of uncertainty, fails to match the data in several key respects. Most of the existing growth models with endogenous fertility do not allow for mortality. Those that do allow it ignore the *uncertainty* about the number of surviving children present in a high mortality environment. In their model of fertility, Becker and Barro (1988) include mortality without considering the role of uncertainty and show that the decline in mortality lowers the cost of raising a survivor and thus increases the demand for surviving children. This implies that births rise in response to a decline in mortality, an implication that is not consistent with the data. See also O'Hara (1975), Ben-Porath (1976), and Sah (1991), among which Sah only considered the role of uncertainty. A recent paper by Portner (2001) extends Sah's setup by allowing dynamic aspects of fertility. Ehrlich and Lui (1991) show that without old-age support motivation for having children, there will not be a mortality effect on human capital investment. Meltzer (1992) extends Becker et. al. (1990) by introducing a relationship between adult mortality and education. However his setup cannot relate declining child mortality to declining fertility, but rather as the longevity of parents increases, their investment in the human capital of their children increases.

13. Note that whether fertility stays constant or increases in the first stage of the transition this hump-shaped pattern of population growth will be the case as long as mortality is declining during the first stage. Fertility may remain unchanged, at first, because of the lags and misperceptions. Fertility can also be increasing due to better health (Dyson and Murphy, 1985) or due to the income effect as a result of higher men's wages (Wrigley and Schofield, 1981). In UK fertility increased in the first stage of the demographic transition. Wrigley and Schofield (1981) argue that during this time there

was no change in the marital fertility. Instead the propensity to marry increased, which was the reason why the total fertility rate increased. The main reason of the increase in the marriages in UK around 1871 is the higher wages.

14. There can be two different scenarios regarding the educational investment. Education may be provided before or after the uncertainty about mortality is realized. If parents provide educational opportunities to every newborn child before the uncertainty about survival is realized, each child will have a fixed cost and an education cost regardless of whether he or she dies. This paper investigates this ex-ante case. If education is given to each survivor after the uncertainty is realized, then each child has a fixed cost but only survivors have an education cost. The ex-post case is considered in Kalemli-Ozcan (2000), which yields similar results. This is important since some researchers have argued that most of the mortality decline has occurred in infancy and therefore a decline in mortality should not matter for the human capital investment decision, which comes later in life.

15. The formulation in (8) implies that the number of children born and the number of surviving children are represented as nonnegative integers, which is a discrete representation. This causes analytical intractability. Sah (1991) followed this type of setup. Using the Delta Method allows me to have a continuous representation and to avoid the intractability. Also note that utility function in (8) is not well defined since the log form gives negative infinite utility in the case of zero survivors. The log utility function cannot be taken as literally correct since having no children cannot give negative infinite utility. Since I am using the Delta Method approximation to the binomial distribution, this problem will not prevent the analytics from working. See Kalemli-Ozcan (2002) for the application of the Delta Method.

16. See Preston (1978a).

17. The hump-shaped relation between the population growth rate ($\frac{L_{t+1}}{L_t}$) and the survival probability (q_t) causes the hump-shaped relation between the population growth rate and income per capita (y_t) since $\frac{dL_{t+1}/L_t}{dy_t} = \frac{dL_{t+1}/L_t}{dq_t}\frac{dq_t}{dy_t}$ and since $\lim_{q_t \to 0} \frac{dL_{t+1}/L_t}{dq_t} > 0$ and $\lim_{q_t \to 1} \frac{dL_{t+1}/L_t}{dq_t} < 0$; and $\frac{dq_t}{dy_t} > 0$. When $\lim_{y_t \to \infty} q_t = 1$, and at $q_t = 1$, $\frac{L_{t+1}}{L_t} = n_t = (1-\gamma)(1-\beta)/v$. Since the population growth rate is $\frac{L_{t+1}}{L_t} - 1$, the inequality $v > (1-\gamma)(1-\beta)$ implies negative population growth at $q_t = 1$.

18. Monotonicity of $\psi(.)$ cannot be shown analytically, thus the possibility of any finite number of steady states cannot be ruled out. As far as the shape of the policy function is concerned, the only case that can be ruled out is the case where $\psi(.)$ starts out convex and ends up concave. If $\psi'' > 0$ for low levels of y_t it will be the case for high levels of y_t as shown in Appendix.

19. A discussion of this is given in Galor and Weil (1999). In a recent growth paper with two sectors, Kogel and Prskawetz (2001) adopt the household problem of this paper using the methodology here to deal with uncertainty and then they add demand for an agricultural good together with endogenous technological progress in manufacturing sector. As a result, they can explain the entire transition from the Malthusian to post-Malthusian regime followed by the modern growth regime.

20. The World Bank data set is used for the purpose of having more developing countries since the historical data set is mainly composed of developed countries. The spans of the two data sets are consistent with the timing of the demographic transition since the demographic transition had occurred in the developed countries during the nineteenth and the twentieth centuries and it started in the developing countries after 1950s. See the Data Appendix for details.

21. $\bar{x}$ and $\bar{t}$ show that this equation is estimated for each age and year by using data on a cross-section of countries. This data fitting exercise is done to get an estimate value of q_t. If one wants to estimate any structural relationship, then IV estimation should be used due to the mutual dependence of q_t and y_t on each other.

22. Note that a more general form of logistic function, $q = a_0/(1+exp(-a_1 y))$ is estimated first, before enforcing the concave functional form in (17) on the data, to see if I really get concavity over the sample range. I decided to use the concave function in (17), which is also a logistic function, since it allows an intercept of 0, whereas the above logistic function's intercept is 0.5.

23. If v or γ changes, holding this inequality constant, the results will not change. But if β changes, then the results will change since the hump-shaped pattern of population growth as a function of q_t depends on β.

24. Note that the y_t axis starts at 0.5 in figures 6b and 6d. This is because at the exact

point 0 GAUSS will not solve the system due to non-linear production function. In Appendix, it is shown that when $y_t = 0, y_{t+1} = 0$. Thus the part between point 0 and 0.5 is concave in figures 6b and 6d, as shown in figure 4c.

References

Becker, G. S. (1981). "Altruism in the Family and Selfishness in the Market Place," *Economica* 48, 1–15.

Becker, G. S., R. J. Barro. (1988). "A Reformulation of the Economic Theory of Fertility," *Quarterly Journal of Economics* 103, 1–25.

Becker, G. S., K. M. Murphy, and T. Robert. (1990). "Human Capital, Fertility and Economic Growth," *Journal of Political Economy* 98, 12–37.

Ben-Porath, Y. (1976). "Fertility Response to Child Mortality: Micro Data from Israel," *Journal of Political Economy* 84, 163–178.

Bongaarts, J. (1999). "Fertility Decline in the Developed World: Where Will It End?" *American Economic Review (Papers and Proceedings)* 89, 256–260.

Brezis, S. E. (2001). "Social Classes, Demographic Transition and Economic Growth," *European Economic Review* 45, 701–717.

Cain, M. (1977). "The Economic Activities of Children in a Village in Bangladesh," *Population and Development Review* 3, 201–227.

Caldwell, J. (1976). "Toward a Restatement of Demographic Transition Theory," *Population and Development Review* 2, 321–366.

Clark, C. (1970). *Population Growth and Land Use.* London: Macmillan Press.

Coale, A. J. (1986). "The Decline of Fertility in Europe since the Eighteenth Century as a Chapter in Human Demographic History." In Ansley J. Coale and Susan C. Watkins (eds), *The Decline of Fertility in Europe: the revised proceedings of a conference on the Princeton European Fertility Project.* Princeton: Princeton University Press.

Dahan, M., D. Tsiddon. (1998). "Demographic Transition, Income Distribution, and Economic Growth," *Journal of Economic Growth* 3, 29–51.

Dyson, T., M. Murphy. (1985). "The Onset of Fertility Transition," *Population and Development Review* 11, 399–439.

Eckstein, Z., P. Mira, and K. I. Wolpin. (1998). "A Quantitative Analysis of Swedish Fertility Dynamics: 1751-1990." CEPR Discussion Paper 1832.

Ehrlich, I., F. T. Lui. (1991). "Intergenerational Trade, Longevity, Intrafamily Transfers and Economic Growth," *Journal of Political Economy* 99, 1029–1059.

Galloway, P. R., R. D. Lee, and E. A. Hummel. (1998). "Infant Mortality and the Fertility Transition: Macro Evidence from Europe and New Findings from Prussia." In Barney Cohen and Mark R. Montgomery (eds), *From Death to Birth: Mortality Decline and Reproductive Change*. Washington: National Academy Press.

Galor, O., O. Moav. (2002). "Natural Selection and the Origin of Economic Growth," *Quarterly Journal of Economics*, forthcoming.

Galor, O., D. N. Weil. (1996). "The Gender Gap, Fertility, and Growth," *American Economic Review* 86, 374-387.

Galor, O. and D. N. Weil. (1999). "From Malthusian Stagnation to Modern Growth," *American Economic Review* 89, 150–154.

Galor, O. and D. N. Weil. (2000). "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review* 90, 806-828.

Haines, M. R. (1994). "Estimated Life Tables for the United States, 1850-1900." NBER Historical Paper 59.

Haines, Michael R. (1998), "The Relationship between Infant and Child Mortality and Fertility: Some Historical and Contemporary Evidence for the United States." In Barney Cohen and Mark R. Montgomery (eds), *From Death to Birth: Mortality Decline and Reproductive Change*. Washington: National Academy Press.

Hansen, G. D., E. C. Prescott. (2002). *American Economic Review*, forthcoming.

Heckman, J. J. (2000). "Policies to Foster Human Capital," *Research in Economics* 54, 3-56.

Heckman, J. J., J. R. Walker. (1990). "The Relationship between Wages and Income and the Timing and Spacing of Births: Evidence from Swedish Longitudinal Data," *Econometrica* 58, 1411-1442.

Kaplan, H. (1994). "Evolutionary and Wealth Flows Theories of Fertility: Empirical Tests and New Models," *Population and Development Review* 20, 753–791.

Kalemli-Ozcan, S. (2000). "Uncertainty and Economic Growth." Ph.D. Dissertation, Brown University.

Kalemli-Ozcan, S. (2002). "A Stochastic Model of Mortality, Fertility and Human Capital Investment," *Journal of Development Economics*, forthcoming.

Keyfitz, N., W. Flieger. (1968). *World Population: An Analysis of Vital Data*. Chicago: The University of Chicago Press.

Keyfitz, N., W. Flieger. (1990). *World Population Growth and Aging*. Chicago: The University of Chicago Press.

Keyfitz, N., S. H. Preston, and R. Schoen. (1972). *Causes of Death: Life Tables for National Populations*. New York: Seminar Press.

Kimball, M. S. (1990). "Precautionary Saving in the Small and in the Large," *Econometrica* 58, 53–73.

Kogel T., A. Prskawetz. (2001). "Agricultural Productivity Growth and Escape from the Malthusian Trap," *Journal of Economic Growth* 6, 337–357.

Kremer, M. (1993). "Population Growth and Technological Change: One Million B.C. to 1990," *Quarterly Journal of Economics* 108, 681–716.

Lagerlof, N. P. (2002). "From Malthus to Modern Growth: Can Epidemics Explain the Three Regimes?" Mimeo, Concordia University.

Lesthaeghe R., E. Van de Walle. (1976). "Economic Factors and Fertility Decline in France and Belgium." In Ansley J. Coale (eds), *Economic Factors in Population Growth*. New York: John Wiley and Sons.

Livi-Bacci, M. (1997). *A Concise History of World Population*. Oxford: Blackwell.

Lucas, R. E. (2002). *Lectures on Economic Growth*. Cambridge: Harvard.

Maddison, A. (1995). *Monitoring the World Economy 1820-1992*. Paris: OECD

Matthews, R. C. O., C. H. Feinstein, and J. C. Odling-Smee. (1982). *British Economic Growth, 1856-1973*. Stanford: Stanford University Press.

Meltzer, D. (1992). "Mortality Decline, the Demographic Transition and Economic Growth." Ph.D Dissertation, University of Chicago.

Morand, O. (2002). "Evolution through Revolutions: Growing Populations and Changes in Modes of Production." Mimeo, University of Connecticut.

Mroz, A. T., D. R. Weir. (1990). "Structural Change in Life Cycle Fertility during the Fertility Transition: France before and after the Revolution of 1789," *Population Studies* 44, 61–87.

O'Hara, D. J. (1975). "Microeconomic Aspects of the Demographic Transition," *Journal of Political Economy* 83, 1203–1216.

Parente S. L., E. C. Prescott. (2000). *Barriers to Riches*. Cambridge: MIT Press.

Portner C. (2001). "Children as Insurance," *Journal of Population Economics* 14, 119-136.

Preston, S. H. (1978a). "The Changing Relation between Mortality and Economic Development," *Population Studies* 29, 231–248.

Preston, S. H. (1978b). *The Effects of Infant and Child Mortality on Fertility.* New York: Academic Press.

Ram, R., T. Schultz. (1979). "Life Span, Health, Savings and Productivity," *Economic Development and Cultural Change* 13, 399–421.

Sah, R. K. (1991). "The Effects of Child Mortality Changes on Fertility Choice and Parental Welfare," *Journal of Political Economy* 99, 582–606.

Schultz, P. T. (1985). "Changing World Prices, Women's Wages, and the Fertility Transition: Sweden 1860-1910," *Journal of Political Economy* 93, 1126-1154.

Schultz, P. T. (1997). "Demand for Children in Low Income Countries." In Mark R. Rosenzweig and Oded Stark (eds), *Handbook of Population and Family Economics.* Amsterdam: Elsevier Science.

Segalen, M. (1992). "Exploring a Case of Late French Fertility Decline: Two Contrasted Breton Examples." In John R. Gillis, Louise A. Tilly and David Levine (eds), *The European Experience of Declining Fertility, 1850-1970.* Cambridge: Blackwell.

Tamura, R. (2002). "Human Capital and Economic Development." Mimeo, Clemson University.

United Nations Population Division. (1999). *Demographic Indicators 1950-2050.*

Weil, D. N. (2001). *Economic Growth.* Addison-Wesley.

Wolpin, K. I. (1997). "Determinants and Consequences of the Mortality and Health of Infants and Children." In Mark R. Rosenzweig and Oded Stark (eds), *Handbook of Population and Family Economics, Volume 1A.* Amsterdam: Elsevier Science.

World Bank. (2000). *World Development Indicators 2000.*

Wrigley, E. A., R. S. Schofield. (1981). *The Population History of England 1541–1871: A Reconstruction.* Cambridge: Harvard University Press

Table 1: Estimation of the Survival Function (Historical Data Set)

Dependent variable—Survival Probability for Age 5

Observations	18	24	36	31
	$q_{5,1900}$	$q_{5,1930}$	$q_{5,1960}$	$q_{5,1990}$
CONSTANT	0.796	0.869	0.945	0.983
	(0.024)	(0.020)	(0.007)	(0.002)
INCOME PER CAPITA	0.168	0.155	0.267	0.0
	(0.033)	(0.033)	(0.025)	–

Note: Standard errors are in parentheses. $q_{5,1900}$ is the survival probability to age five in 1900, $q_{5,1930}$ is the survival probability to age five in 1930, $q_{5,1960}$ is the survival probability to age five in 1960, and $q_{5,1990}$ is the survival probability to age five in 1990.

Table 2: Estimation of the Survival Function (Historical Data Set)

Dependent variable—Survival Probability for Age 15

Observations	19	24	36	31
	$q_{15,1900}$	$q_{15,1930}$	$q_{15,1960}$	$q_{15,1990}$
CONSTANT	0.781	0.858	0.939	0.980
	(0.027)	(0.022)	(0.008)	(0.002)
INCOME PER CAPITA	0.138	0.135	0.248	0.0
	(0.024)	(0.020)	(0.024)	–

Note: Standard errors are in parentheses. $q_{15,1900}$ is the survival probability to age fifteen in 1900, $q_{15,1930}$ is the survival probability to age fifteen in 1930, $q_{15,1960}$ is the survival probability to age fifteen in 1960, and $q_{15,1990}$ is the survival probability to age fifteen in 1990.

Table 3: Estimation of the Survival Function (World Bank Data Set)

Dependent variable—Age Five Survival Rate

Observations	86	86	86
	$q_{1-5,1960}$	$q_{1-5,1980}$	$q_{1-5,1997}$
CONSTANT	0.87	0.90	0.96
	(0.01)	(0.008)	(0.01)
INCOME PER CAPITA	0.45	0.50	0.55
	(0.11)	(0.08)	(0.04)

Note: Standard errors are in parentheses. $q_{1-5,1960}$ is the conditional survival probability to age five in 1960, $q_{1-5,1980}$ is the conditional survival probability to age five in 1980, and $q_{1-5,1997}$ is the conditional survival probability to age five in 1997.

Table 4: Estimation of the Survival Function (World Bank Data)

Dependent variable—Adult Survival Rate

Observations	86	86	86
	$q_{15-60,1960}$	$q_{15-60,1980}$	$q_{15-60,1997}$
CONSTANT	0.74	0.76	0.82
	(0.02)	(0.01)	(0.01)
INCOME PER CAPITA	0.36	0.47	0.44
	(0.03)	(0.05)	(0.04)

Note: Standard errors are in parentheses. $q_{15-60,1960}$ is the conditional survival probability to age fifteen in 1960, $q_{15-60,1980}$ is the conditional survival probability to age fifteen in 1980, and $q_{15-60,1997}$ is the conditional survival probability to age fifteen in 1997.

Table 5: Calibration Results for the General Equilibrium Model

Historical Data Set—Survival Probability: $q_{5,1960}$

Variables	Malthusian Steady State Value	Growth Steady State Value
Income per capita (y_t)	3.0	8.0
Survival Probability (q_t)	0.51	0.83
Fertility (n_t)	2	1.2
Education (e_t)	0.2	0.4
Population Growth ($\frac{L_{t+1}}{L_t} - 1$)	0	0
Income per capita growth ($y_{t+1}/y_t - 1$)	0	0

Note: Income per capita (y_t) is in natural logarithm. The estimated functional form for the survival probability is $q_{\bar{x}i\bar{t}} = a_0(1 - exp(-a_1 y_{i\bar{t}}))$, where $x = 5$ and $t = 1960$ from the historical data set. For the parameters a_0, a_1 see table 1. $v = 0.1, \beta = 0.9, \gamma = 0.5$ and $\alpha = 0.3$.

Table 6: Calibration Results for the Partial Equilibrium Model

Elasticity with respect to survival probability (q)

Variables	$q = 0.51$	$q = 0.83$	$q = 0.90$
Fertility (n_t)	–0.78	–1.86	–2.72
Education (e_t)	0.94	2.06	2.96

Note: I use $q = 0.51$ and $q = 0.83$ since these values are the estimated general equilibrium values. Elasticity is calculated as $dc/dq(q/c)$ where $c = n, e$. The derivative dc/dq is calculated around the given q values by changing q an epsilon amount. Parameters are $v = 0.1, \beta = 0.9, \gamma = 0.5$ and $\alpha = 0.3$.

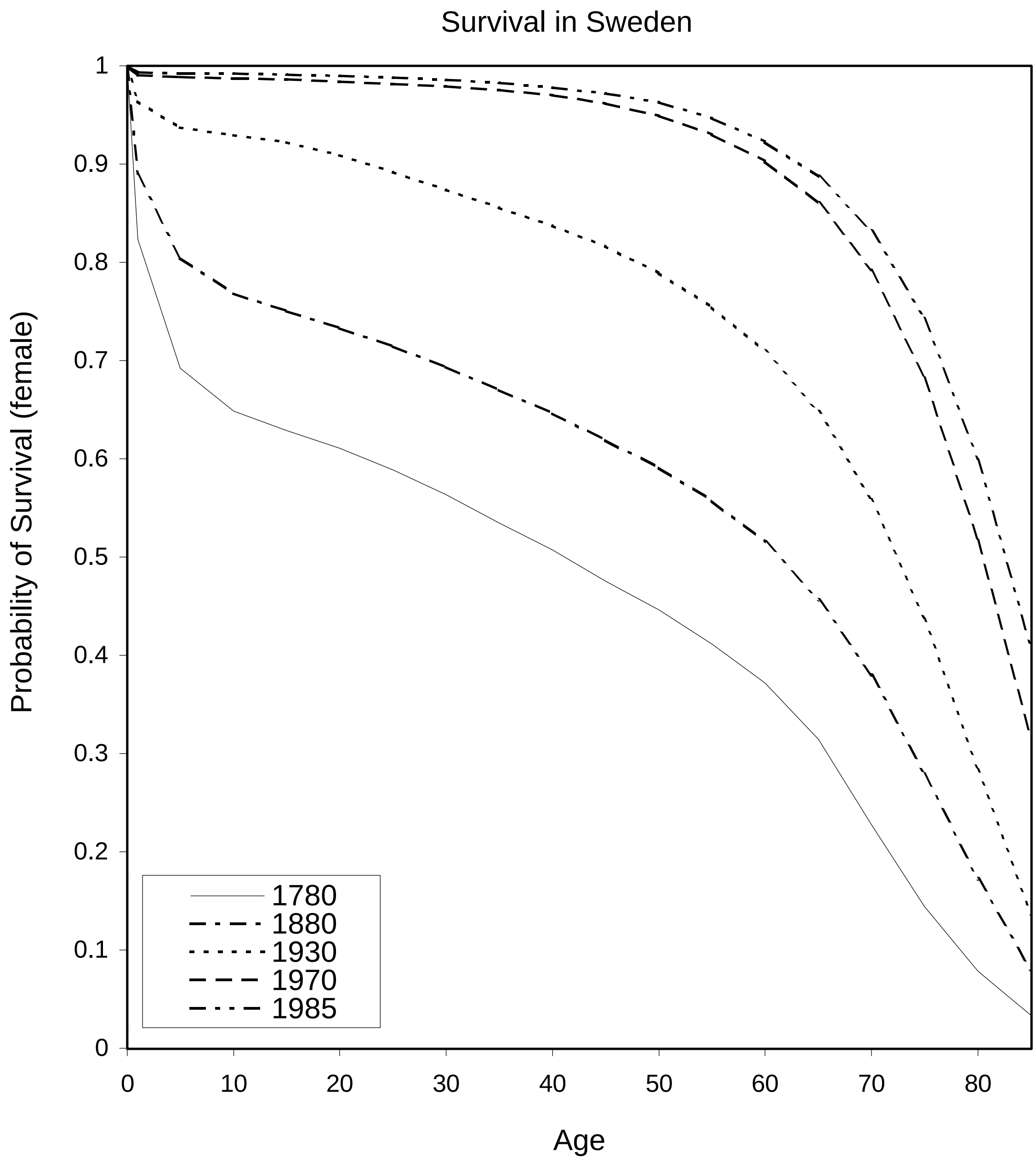


Figure 1: Mortality in Sweden

Notes: The survival function shows the probability that a person will be alive at a given age. Life expectancy at birth is the area under the survival function. Swedish data is from Keyfitz and Flieger (1968, 1990).

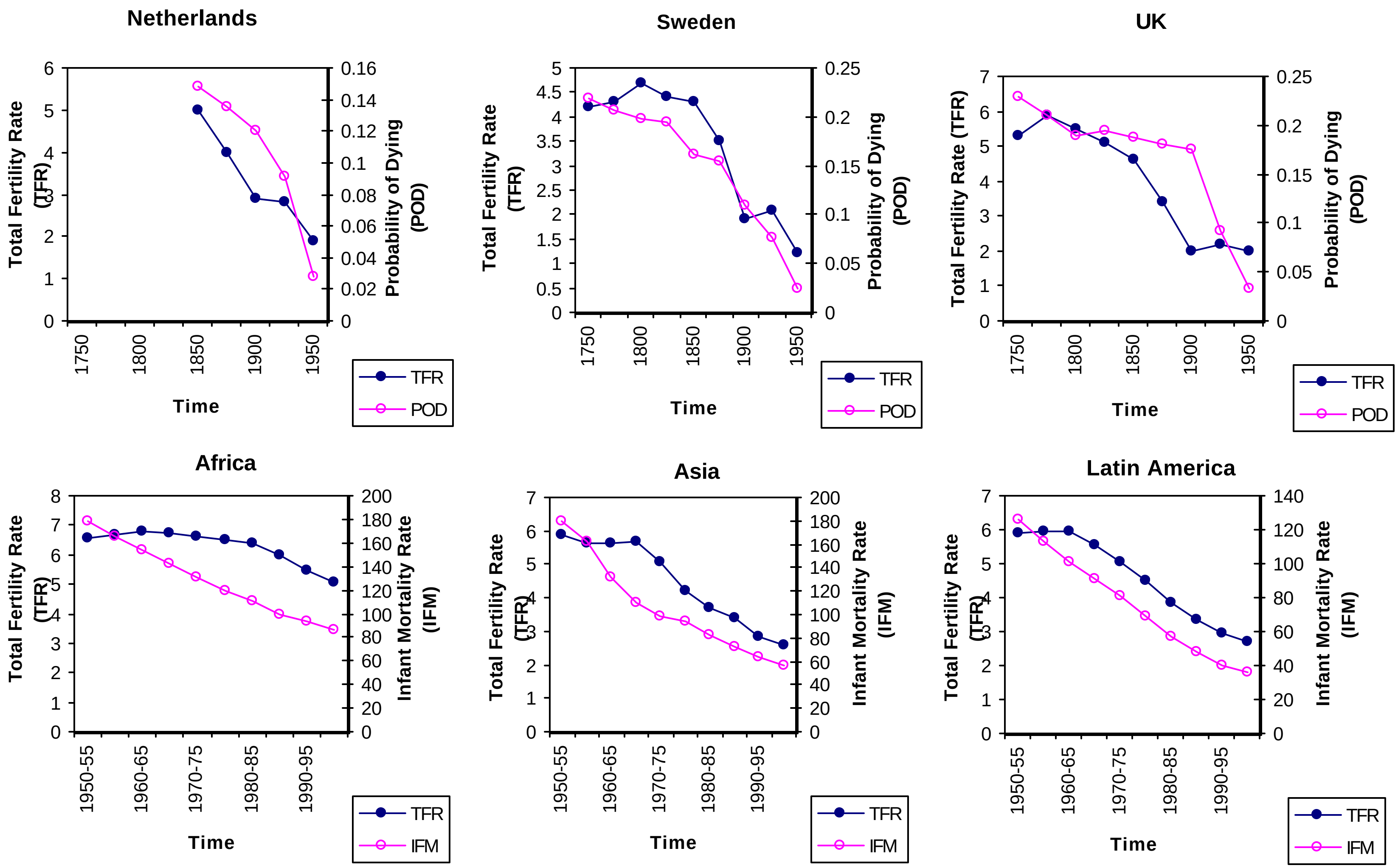
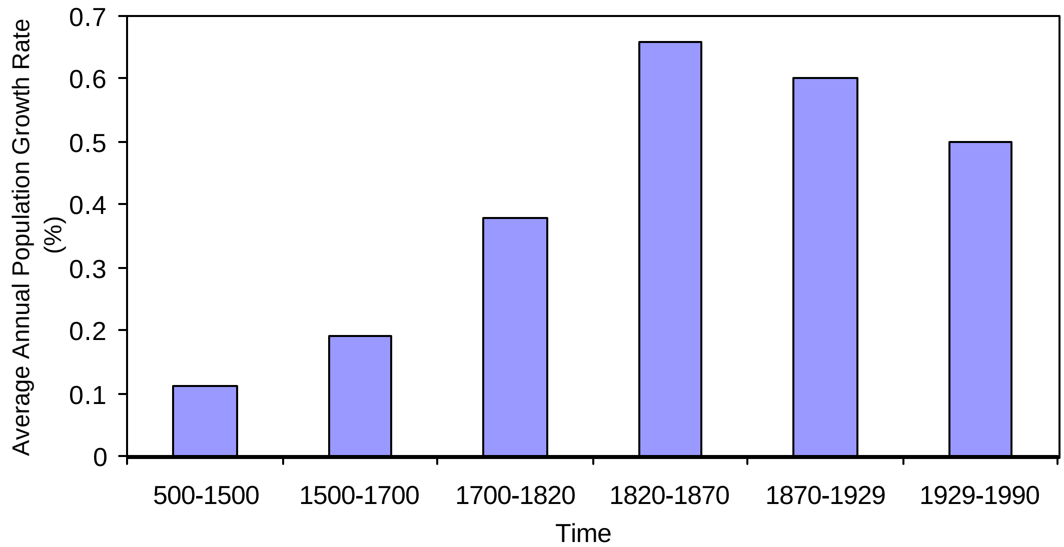


Figure 2: Fertility and Mortality

Note: The LDC data is from United Nations (1999). Total fertility rate for developed countries is from Livi-Bacci (1997). The probability of dying is defined as probability of a newborn dying before age 1 and is from Keyfitz (1968).

Population Growth in Western Europe



Population Growth in LDCs

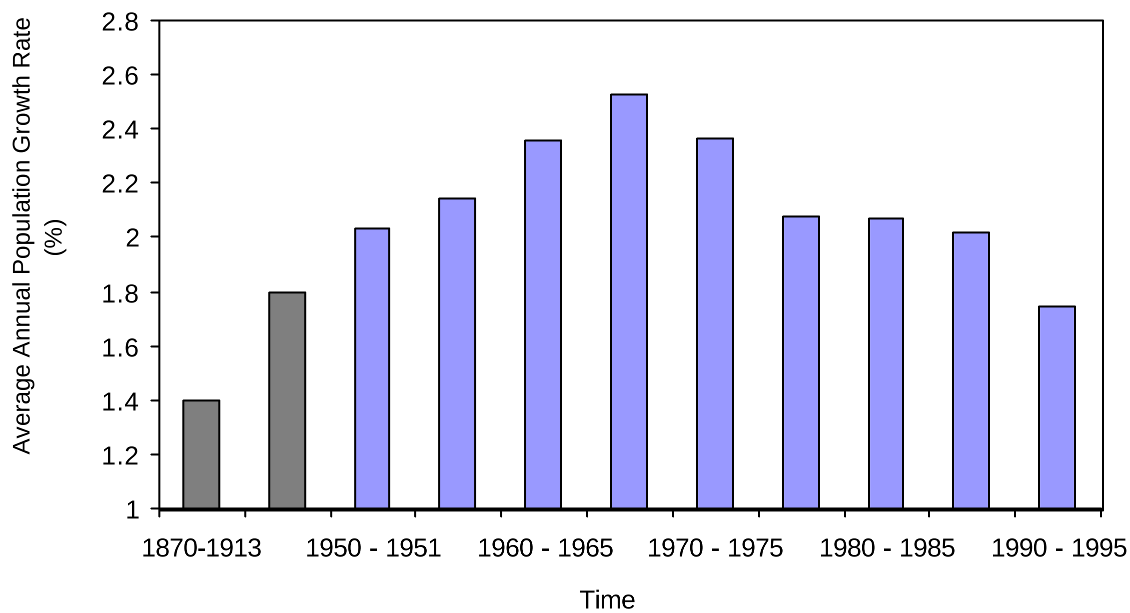


Figure 3: Population Growth

Notes: The countries of Western Europe are Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and UK. This data is from Maddison (1995). The LDCs are all countries of Africa, Latin America and Asia, excluding Japan. This data is from United Nations (1999). The first two observations, marked differently, are from Maddison.

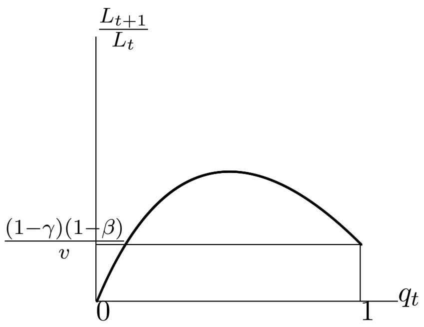


Figure 4a: Population Growth and Survival Probability

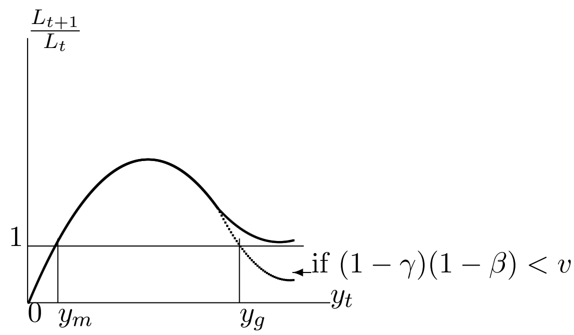


Figure 4b: Population Growth and Income per Capita

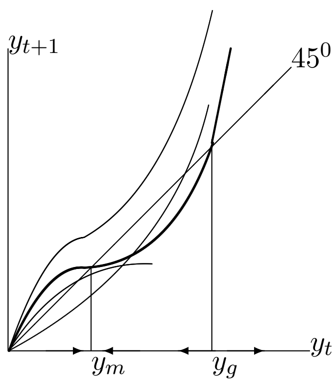


Figure 4c: Evolution of Income per Capita-Various Paths

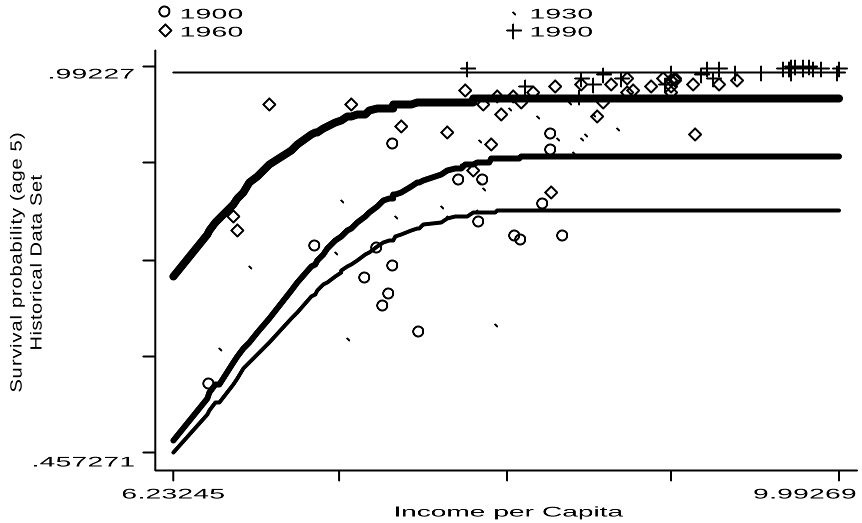


Figure 5a: Survival Probability (age 5) vs. Income

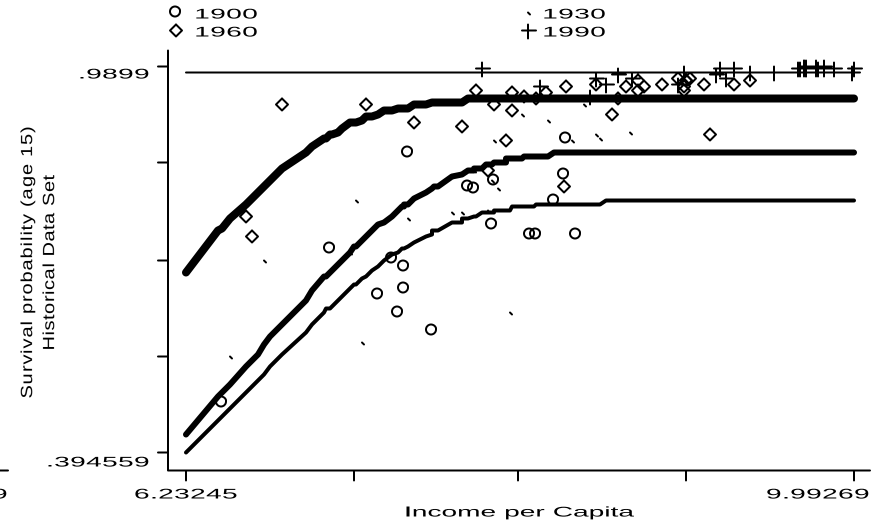


Figure 5b: Survival Probability (age 15) vs. Income

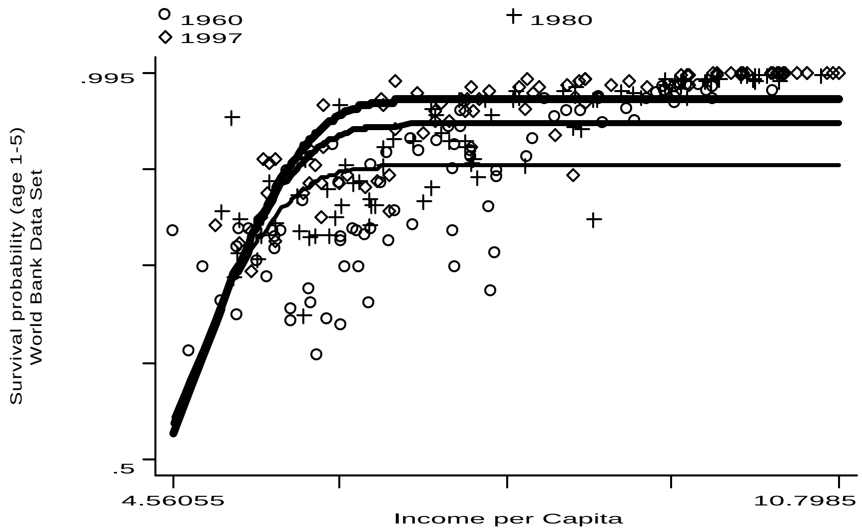


Figure 5c: Survival Probability (age 1-5) vs. Income

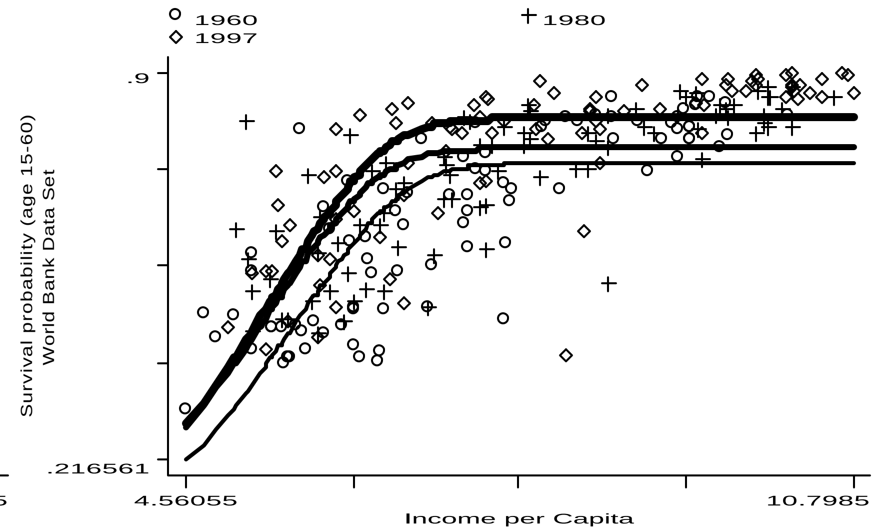


Figure 5d: Survival Probability (age 15-60) vs. Income

Figure 6a: Population Growth vs. Income per Capita
Historical Data Set (Age 5)

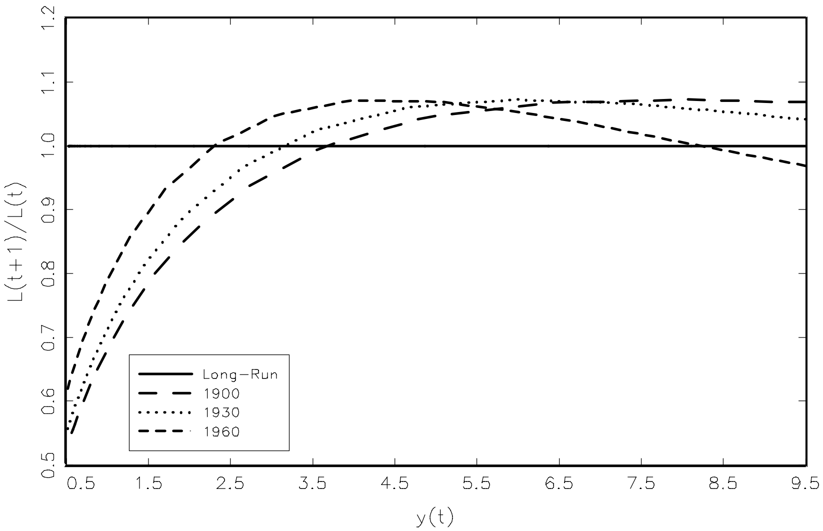


Figure 6b: The Evolution of Income per Capita
Historical Data Set (Age 5)

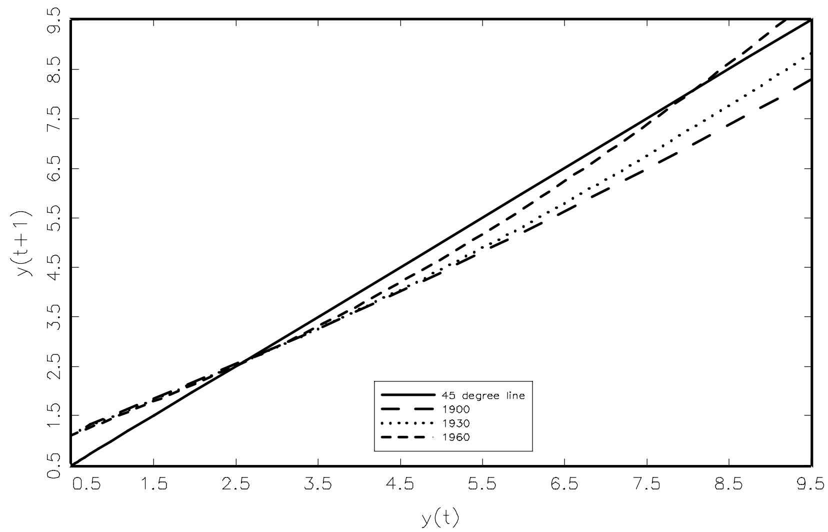


Figure 6c: Population Growth vs. Income per Capita
World Bank Data Set (Age 15)

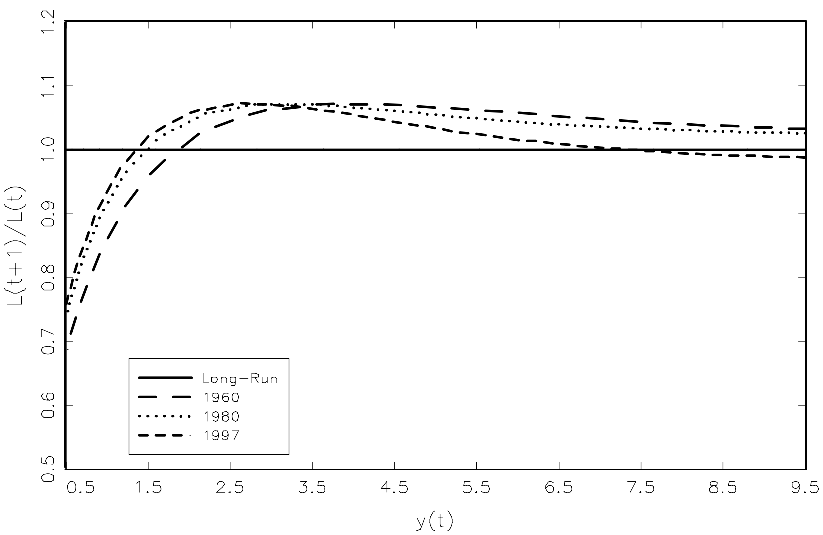


Figure 6d: The Evolution of Income per Capita
World Bank Data Set (Age 15)