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Human Capital and Economic Development

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Abstract: This paper develops a general equilibrium model of fertility and human capital investment under uncertainty. Uncertainty exists in the form of a probability that a young adult does not survive to old age. Parents maximize expected utility arising from own consumption, their fertility, and the discounted utility of future generations. There exists a precautionary demand for children. Young adult mortality is negatively related to the average human capital of young adults. Therefore, rising human capital leads to falling mortality, which eventually induces a demographic transition and an acceleration in human capital investment. The model can fit data on world and country populations, per capita incomes, age at entry into the labor force, total fertility rates, life expectancy, conditional life expectancy, and infant mortality.

JEL classification: O0, O57, O10, N10

Key words: fertility, mortality, demographic transition, economic development

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Human Capital and Economic Development

This paper develops a general equilibrium model of fertility and human capital investment choice under uncertainty. Uncertainty exists in the form of a probability that a young adult does not survive to old age. Parents maximize expected utility arising from own consumption, their fertility and the discounted utility of the future generations. Expected utility maximization produces precautionary fertility demand. Fertility depends positively on the probability of an early death, or a young adult death. Additionally since human capital investments are made prior to the realization of survival from young adult to old adult, higher young adult mortality reduces human capital investment in each child. If young adult mortality depends on the average human capital of children, then an endogenous Demographic Transition to an Industrial Revolution can occur. That is an economy transits from a high mortality, high fertility, slow human capital accumulation, slow (if any) economic growth regime to a low mortality, low fertility, rapid human capital accumulation and rapid economic growth. With human capital accumulation, young adult mortality falls. Falling young adult mortality implies lower fertility. Lower fertility lowers the cost of human capital investment, and hence parents increase their human capital investments per child. This leads to a virtuous cycle in which human capital growth leads to lower fertility and more rapid human capital growth. There exists a limit to the cycle, since young adult mortality is bounded below by 0.

The model is calibrated to fit the behavior of world population as well as the population history of the rich region and the poor region, as well as the time series of per capita income, age at entry into the labor force, life expectation, conditonal life expectation at age 20, infant mortality and total fertility rates for the US since 1800. However in addition to fitting these time series, the model delivers time series for 21 other rich countries, and 4 poor regions, Latin America, China, India and the rest of the world, for population, income per capita, age at entry into the labor force, life expectation, conditional life expectation, infant mortality and total fertility rates for the past 200-400 years. The model solution fits all of these data extremely well.

The next section contains the specification of preferences and technologies for output production and human capital production. Section 2 details the behavior of the model under a constant young adult mortality regime. It illustrates the mechanism of the tradeoff between high fertility arising from a precautionary demand for children and slow human capital accumulation. However with falling young adult mortality, the precautionary component of child demand falls and human capital accumulation accelerates. Section 3 produces a model of total factor productivity in output production, which produces measures of the degree of specialization in the economy. Section 4 introduces multiple regions producing in separate markets. It describes the integration of multiple regions into a single market. Section 5 presents the calibrated numerical solution. I calibrate the model to fit world population and the population of the rich countries as well as the US time series on per capita income, age at entry into the labor force, total fertility rates, life expectancy at birth, life expectancy at 20 and infant mortality. I evaluate the model's fit with the historical evidence on the aforementioned variables for 21 other rich countries and 4 poor "countries." Section 6 presents the predictions of the model for the world income distribution from 2000 onward. Section 7 concludes.

1. MODEL

The typical person lives two periods, young and old.[1] A girl passively receives investment in her human capital from her mother. As a woman she chooses her consumption, fertility and human capital investment per child. A mother receives utility from her consumption and the expected utility from the next generation. The expectation arises because there is mortality, and not all children will live to be an adult. Mothers have expected utility concerning surviving children, and expected utility from the continuing dynasty. Therefore preferences are given by:

$$U\left(h_t\right) = E_t\left\{\sum_{i=t}^{\infty} \beta^{i-t}\left\{\alpha \ln \widetilde{c}_t + (1-\alpha)\ln \widetilde{n}_t\right\}\right\}, \tag{1}$$

[1] Reproduction is asexual. I will refer to all individuals as females.

where $\widetilde{c}_t$ is the consumption of a mother in time period t, and $\widetilde{n}_t$ is the number of her surviving children at time t; the mathematical expectation is taken with respect to the information available to the mother at time t. The information available to the mother is the mortality rate of young women, the fraction of girls that will not survive through motherhood, δ_t. The mortality of young women strikes after all human capital investment has been made. Consumption in the future is random because output is produced with land, and with random population, land per person is random.

Mortality is a function of the average human capital in the population. Let $\overline{h}_t$ be the average human capital at time t. The young woman mortality rate is given by:

$$\delta_t = \Delta \exp\left(-\gamma_1 \overline{h}_{t+1}^{\gamma_2} - \gamma_3 \overline{h}_{t+1}^{\gamma_4}\right) \tag{2}$$

where $\gamma_1 > 0$, $\gamma_2 > 0, \gamma_3 > 0$, $\gamma_4 > 0, \Delta > 0$. Notice that in this formulation the young adult mortality function is a function of the average young woman human capital stock. Thus a mother's human capital stock only matters to the extent that it determines the human capital stock of young women. Therefore if average human capital is increasing over time, then the young woman mortality rate is falling over time. Of course if average human capital accumulates without bound, then young woman mortality goes to 0.[2]

A dynastic mother chooses fertility, and a fixed proportion survive to motherhood. I assume that a law of large numbers applies for each dynasty. Let x_t be the number of infants per mother. Thus the number of children surviving to of old age in t+1 is given by:

$$\widetilde{n}_t = x_t \left(1 - \delta_t\right) \tag{3}$$

[2] I assume that the overwhelming incentive for accumulation of human capital arises from its direct effect on production of consumption. If mothers are aware that rising human capital can lower mortality, this would increase the return to human capital accumulation. However this will not affect the time series solution qualitatively. If mortality reductions occur via public investments in health, then as long as the investments were modeled as forgone time spent discovering improved public health rules, and if the productivity in these exercises were proportional to the private productivity gains the qualitative results remain. I thank Kevin Murphy for each of these points. Additionally by modeling the effect on mortality as an external effect, it greatly reduces the numerical complexity of the solution algorithm.

Since the population is made up of identical dynasties, population grows if the number of girls per household surviving into their old age exceeds 1. The law of motion of population is given by:

$$P_{t+1} = P_t x_t \left(1 - \delta_t\right) \tag{4}$$

Assume that an economy is made up of women with identical levels of human capital. Output is produced by combining land per woman with market goods produced via specialization of labor. An adult at t produces output given by:

$$y_t = Z_t \left(\frac{L_t}{P_t}\right)^{\sigma} h_t^{1-\sigma}, \tag{5}$$

where $\frac{L_t}{P_t}$ is the land per person, notice that the amount of land is allowed to vary over time, h_t is the human capital of the typical person in the economy, and as in McDermott (2000) the intermediate market goods produced via specialization is reflected by Z_t, Total Factor Productivity, TFP. To the typical person the level of TFP, Z_t, is taken as given.

A woman chooses how many children to have and how much time is spent educating her children. Each child takes θ units of time to rear. A mother chooses education time, τ_t, per child. Therefore the typical mother faces the following budget constraint:

$$c_t = y_t \left[1 - x_t \left(\theta + \tau_t\right)\right], \tag{6}$$

where x_t is the number of children that survive infancy.[3]

Human capital accumulation across generations is given simply by:

$$h_{t+1} = A \overline{h}_t^{\varepsilon} h_t^{1-\varepsilon} \tau_t^{\rho} \tag{7}$$

where $\rho > 0$, and $\overline{h} = \max\left\{h_{it}\right\}$.

Following Kalemli-Ozcan (2000), I simplify the preferences by using the Delta method, see Appendix A for details. Ignoring terms not including current choice variables, preferences are given by:

$$\max_{x_t, \tau_t} \left\{ \begin{array}{c} \alpha \ln y_t + \alpha \ln \left[1 - x_t \left(\theta + \tau_t\right)\right] + (1-\alpha) \ln x_t + (1-\alpha) \ln \left(1 - \delta_t\right) \\ -\dfrac{(1-\alpha)\,\delta_t}{2x_t\left(1-\delta_t\right)} - \dfrac{\alpha\beta\sigma \ln x_t}{1-\beta} + \dfrac{\alpha\beta\sigma\delta_t}{(1-\beta)2x_t(1-\delta_t)} + \beta\alpha(1-\sigma)\ln h_{t+1} \end{array} \right\} \tag{8}$$

[3] In later sections I will introduce infant mortality. However I will assume that infants impose no rearing time cost, and hence their births are costless.

The first order conditions determining optimal fertility and optimal human capital investment are given by:

$$\frac{\alpha(\theta+\tau_t)}{1-x_t(\theta+\tau_t)} = \frac{1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}}{x_t}+\frac{(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta})\delta_t}{2(1-\delta_t)x_t^2} \tag{9}$$

$$\frac{\alpha x_t\tau_t}{1-x_t(\theta+\tau_t)} = \beta\alpha\rho(1-\sigma)+\frac{\beta\alpha x_{t+1}\tau_{t+1}(1-\varepsilon)}{1-x_{t+1}(\theta+\tau_{t+1})} \tag{10}$$

Notice that from (9) the first order condition for fertility depends on the mortality rate of young women, δ_t. The introduction of expected utility produces the precautionary demand for children, otherwise the Euler condition would contain only the first term of the right hand side of (9). Although the introduction of young woman mortality and expected utility introduces a precautionary demand for children, it has no direct effect on the demand for human capital investment. This is clear from (10), which is independent of the mortality rate of young adults, δ_t. However since δ_t affects fertility, x_t, it will have an indirect effect on desired human capital investment.

The model is solved numerically in order to characterize the long run history of the economy. The numerical solution is easy to implement. If there is human capital accumulation, then from (2) the young adult mortality rate converges to 0. Along the balanced path with human capital accumulation and 0 young adult mortality, long run fertility and human capital investment rate are:

$$x = \frac{\left[1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right]\left[1-\beta(1-\varepsilon)\right]-\alpha\beta\rho(1-\sigma)}{\left[1-\frac{\alpha\beta\sigma}{1-\beta}\right]\left[1-\beta(1-\varepsilon)\right]\theta} \tag{11}$$

$$\tau = \frac{\alpha\beta\rho(1-\sigma)\theta}{\left[1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right]\left[1-\beta(1-\varepsilon)\right]-\alpha\beta(1-\sigma)\rho} \tag{12}$$

2. EFFECTS OF YOUNG ADULT MORTALITY

In this section I illustrate the mechanism by which human capital accumulation induces a Demographic Transition to an Industrial Revolution. Recall that (x_t, τ_t) are determined by (9) and (10), which in turn depend on δ_t and (x_{t+1}, τ_{t+1}). One way to see the effects of changing young adult mortality on fertility and human capital investments is to compare two steady state regimes, one with higher young adult mortality than the other. I show below that the higher young adult mortality regime implies higher fertility, arising from the greater precautionary demand for children, and lower rates of human capital investments.[4] Simplifying the two Euler equations in this case produces:

$$x(\theta+\tau) = \frac{[(1-\alpha)(1-\beta)-\alpha\beta\sigma]\,\tau}{\alpha\beta\rho(1-\sigma)}\left[x+\frac{\delta}{2(1-\delta)}\right] \tag{13}$$

$$\frac{\alpha[1-\beta(1-\varepsilon)]x\tau}{1-x(\theta+\tau)} = \alpha\beta\rho(1-\sigma) \tag{14}$$

I show in Appendix C that:

$$\frac{\partial x}{\partial \delta} > 0 \tag{15}$$

$$\frac{\partial \tau}{\partial \delta} < 0 \tag{16}$$

The results indicate that fertility is greater and human capital investment time is lower in the high young woman mortality regime relative to the low young woman mortality regime. These two results illustrate the quantity-quality tradeoff between fertility and human capital investment. High young woman mortality raises the price of human capital investment relative to the number of children. If preferences were logarithmic and depended on the expected number of surviving children, $x(1-\delta)$, then fertility and human capital investment time would be independent of δ. Thus the assumption of expected utility is one way to generate a Demographic Transition to an Industrial Revolution via reductions in young woman mortality.

Since δ is a decreasing function of the average human capital stock, rising human capital levels reduces young woman mortality. This in turn reduces the demand for children and raises the demand for human capital investment. This positive reinforcement leads to more rapid human capital accumulation and still lower fertility. This continues until young woman mortality becomes negligible. At this point fertility and human capital investment are given by their stationary values in (11) and (12), respectively.

[4] The only way for the higher young adult mortality regime to be in steady state is for the productivity of human capital investments to be higher than in the lower young adult mortality regime, ceteris paribus.

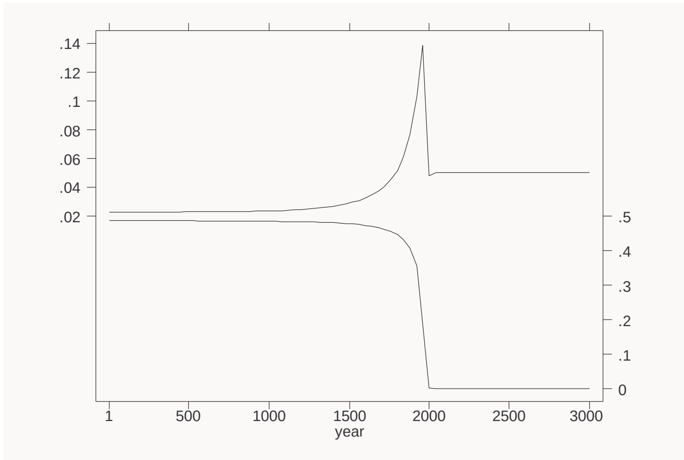

FIG. 1. Time series of population growth rates (top) and young adult mortality (bottom)

Does the model produce rising population growth associated with falling young adult mortality? The gross rate of population growth is given by:

$$x_t (1 - \delta_t) \tag{17}$$

Therefore the change in the population growth rate is given by:

$$\frac{\partial x_t}{\partial \delta_t} (1 - \delta_t) - x_t \tag{18}$$

Falling mortality has two offsetting effects, first by decreasing the precautionary demand for children the rate of growth of population is falling, $\frac{\partial x_t}{\partial \delta_t} > 0$, and the second effect is that more children will survive to adulthood. First examine the effects of mortality reductions when an economy is initially at a stationary young woman mortality regime. Appendix D shows that falling young woman mortality leads to increases in population growth rates. Unfortunately this analysis does not hold for the transition dynamics precisely because the rate of young mortality is falling rapidly over this period. Figure one shows the time series of the generational population growth rate for the numerical solution.

Figure 1 indicates that the generational growth rate of population accelerates and exceeds the long run growth rate of population during the Demographic Transition.

3. PRODUCTION TECHNOLOGY

In this section I describe the Total Factor Productivity term in (5). As in Tamura (2001) the model assumes an agglomeration economy in market participation, limited by the coordination costs of specialization. This technology produces more rapid transition dynamics in income growth than models without specialization gains. I assume that per capita production of the final output depends on the land per person and on the provision of intermediate goods. These intermediate goods can be produced by any woman, but there exists an agglomeration economy in specialization. However intermediate good specialization amongst individuals is costly to coordinate. Ignoring time subscripts, the reduced form for the aggregate production technology is:

$$Y = ZL^{\sigma}\left[\frac{P}{N}\left\{\sum_{i=1}^{N} h_i^{\frac{1}{\omega}}\right\}^{\omega} q\left(\overline{h}\right)^{N}\right]^{1-\sigma} \tag{19}$$

where P is the population of the economy; N is the optimal market size, and hence, $\frac{P}{N}$ is the number of markets in the economy; the term in curly brackets represents the gains from specialization because $\omega > 1$, and $q\left(\overline{h}\right) < 1$ is the coordination costs of organizing specialiation of intermediate goods, which depends on the average level of human capital in the market.[5] Coordinating costs are falling in the average level of human capital in the market and rising in the number of participants in the market.

As in Tamura (2001), the optimal market size is a simple function of the average human capital in the market. Clearly the optimal market size does not depend on the amount of land in the economy. Assume that all individuals in the economy are identical in human capital, $h_i = \overline{h}$. Per capita output becomes:

$$y = Z\left(\frac{L}{P}\right)^{\sigma}\left\{N^{\omega-1}\overline{h}q\left(\overline{h}\right)^{N}\right\}^{1-\sigma} \tag{20}$$

Assume that production is organized to maximize per capita output in each period.

[5] Similar to Kremer (1993) and Tamura (2001) the coordination costs of specialization is represented by the term q^N, where $q = \frac{\exp\left(\lambda_1\left[\lambda_2\overline{h}+\lambda_3\right]^{\lambda_4}\right)}{\lambda_5+\exp\left(\lambda_1\left[\lambda_2\overline{h}+\lambda_3\right]^{\lambda_4}\right)}$, $\lambda_i > 0$, $i = 1, 2, 3, 4, 5$.

The size of the market that maximizes per capita output is given by:

$$N = -\frac{(\omega - 1)}{\ln q\left(\overline{h}\right)} \tag{21}$$

Therefore as average human capital rises, the optimal coalition grows. How does this translate into TFP, Z? As long as the optimal market size is less than the population, $N < P$, it is easy to show the value of Z. It is important to notice that while there is an agglomeration economy in the number of people in a coalition, there is constant returns to scale in human capital of all the individuals in the market production of intermediate goods. Thus if individuals in the market are paid the marginal product of their human capital, then output is exactly exhausted. Assume there is a Lebesgue measure N workers in the market. Further assume that each individual is a set of measure 0 within the market, and within type. The wage per unit of human capital for a worker of type s, which the worker takes as exogenous, is:

$$w_s = \left\{ \sum_{i=1}^{N} h_i^{\frac{1}{\omega}} \right\}^{\omega - 1} q\left(\overline{h}\right)^N h_s^{\frac{1}{\omega} - 1} \tag{22}$$

where N is given by (21). If $N < P$, then Z can be written as:

$$\begin{aligned} Z &= \left[\left\{ \sum_{i=1}^{N} h_i^{\frac{1}{\omega}} \right\}^{\omega - 1} h_s^{\frac{1}{\omega} - 1} e^{1-\omega} \right]^{1-\sigma} \\ &= \left[N^{\omega - 1} e^{1-\omega} \right]^{1-\sigma} \end{aligned} \tag{23}$$

where the second line arises when all individuals are identical. When individuals in an economy are identical, per capita output can be written as:

$$y = \left[N^{\omega - 1} e^{1-\omega} \right]^{1-\sigma} \left(\frac{L}{P} \right)^{\sigma} h^{1-\sigma} \tag{24}$$

Observe that as human capital accumulates, the optimal market size grows. Thus there will be TFP growth arising from the increasing extent of the market.

4. RICH AND POOR REGIONS

Before presenting the numerical solution, I extend the model to include two regions: rich and poor. The advantage of introducing two regions is the ability to track the behavior of income inequality in the world, as well as the differential speed of demographic transitions. In particular, the earlier arrival of the Demographic Transition and Industrial Revolution in the rich region and the delayed diffusion of the Demographic Transition and Industrial Revolution in the poor region will produce large increases in income inequality. There is a shortening in the length of an individual country's Demographic Transition and a more rapid transitional growth phase for late developers compared to early developers. For example the Demographic Transition took 250 years to occur in Northern and Western Europe, and less than 50 years to occur in South Korea and Singapore. Similarly per capita income growth rates in excess of 5 percent per year for over several decades occurred in Japan, South Korea, Singapore and Taiwan. Per capita income growth rates in excess of 7 percent per year over the past 10 years has occurred in China.

Within the rich region there are 22 countries, and within the poor region there are 4 "countries."[6] All residents within a "country" are endowed with identical levels of human capital, but "countries" can differ in their initial human capital. Broadly speaking, the rich countries are the high human capital countries and the poor countries are the low human capital countries. I assume that land is equally distributed to all individuals in the world. Throughout most of human history the typical market size is smaller than the population of the country. However as human capital accumulates, eventually the optimal market size in a country exceeds the population of the country. When this occurs there exists an incentive to integrate markets across county borders.

I allow for two cross country spillovers, but these do not effect the choices of fertility and human capital investment time except for their effects on young woman mortality. The first spillover exists in the accumulation technology. Due to knowledge spillovers across borders, I assume, as in Tamura (1991), the following human capital accumulation technology for a resident in country i:

$$h_{it+1} = A\overline{\overline{h}}_t^{\varepsilon} h_{it}^{1-\varepsilon} \tau_{it}^{\rho} \tag{25}$$

where $\overline{\overline{h}}_t = \max\{h_{it}\}$ is the maximum human capital in the world. The second spillover

[6] See Appendix E for a list of the countries used in the solution.

exists in the young woman mortality risk, and it takes the following form:

$$\delta_{it} = \left[\Delta \exp\left(-\gamma_1 \overline{h}_{it+1}^{\gamma_2} - \gamma_3 \overline{h}_{it+1}^{\gamma_4}\right)\right]^{1-\nu} \overline{\overline{\delta}}_t^{\nu} \tag{26}$$

where $\overline{h}_{it}$ is average human capital in country i at time t, and $\overline{\overline{\delta}}_t = \min\{\delta_{it}\}$ is the minimum young adult mortality in the world, $1 > \nu > 0$. Notice that the spillovers are symmetric, they affect all residents the same no matter which country they reside in. Residents in poor countries gain more from the spillovers than residents in rich countries and this is the mechanism for human capital convergence and a more rapid demographic transition.

As human capital in a country grows eventually the optimal market size grows more rapidly than population. With accumulation the optimal market size in the rich region will exceed the population of any individual country in the rich region and eventually the total population of the rich region. At this point partial or full economic integration with the poor region may occur. In the numerical solution presented below, the rich region becomes a single market incorporating all of the 22 individual countries, and eventually integrates each of the four poor "countries." The highest human capital "country" in the poor region will integrate first, and the lowest human capital "country" will be the last to integrate. This occurs because the benefits of an additional person are increasing in their human capital and the costs, dilution of the average human capital, are decreasing in human capital.

I present the calculus determining the integration of any country with an amalgam that I call the rich region. Each region is characterized by its population and the human capital of residents in the region. Aggregate integrated production between the P^{rich} rich individuals with h^{rich} human capital and $N \leq P^{poor}$ poor individuals with h^{poor} human capital is:

$$Y^{int} = L^{\sigma}\left[\left\{P^{rich}\left(h^{rich}\right)^{\frac{1}{\omega}} + N\left(h^{poor}\right)^{\frac{1}{\omega}}\right\}^{\omega} q\left(\overline{h}\right)^{P^{rich}+N}\right]^{1-\sigma} \tag{27}$$

where $\overline{h} = \left(h^{rich}\right)^{\frac{P^{rich}}{N+P^{rich}}}\left(h^{poor}\right)^{\frac{N}{N+P^{rich}}}$. Since each individual is a set of measure 0, all individuals act competitively and act as if they have no effect on the wage rate of others. However in the integration issue, coordinated action on the part of the high human capital individuals is necessary in order to determine the number of poor individuals to integrate. Therefore I assume that high human capital individuals cooperate to choose the number of poor individuals to integrate. High human capital individuals tradeoff gains from greater specialization, $\omega > 1$ the curly bracket term in (27), versus greater costs of coordination, lower $\overline{h}$ and greater numbers, $N + P^{rich}$. Each high human capital individual has income that is proportional to

$$\left[\left\{P^{rich}\left(h^{rich}\right)^{\frac{1}{\omega}} + N\left(h^{poor}\right)^{\frac{1}{\omega}}\right\}^{\omega-1} q\left(\overline{h}\right)^{P^{rich}+N}\right]^{1-\sigma} \tag{28}$$

Thus I assume that each high human capital individual chooses the number of poor individuals to integrate with as long as it maximizes (28). Each high human capital individual votes on the number of poor individuals to integrate with, and because each high human capital individual has income that is proportional to (28) the vote will be unanimous.[7]

5. NUMERICAL SOLUTION

In this section I present the results of a numerical solution to the model. Parameters are chosen in order to fit the population history of the world from 25,000 BC to 2000 AD, the population history of the rich world from 1 AD to 2000 AD, and the history of income per capita, age at entry into the labor force, total fertility rates, life expectancy at birth, life expectancy at 20 and infant mortality for the US. I present the typical Demographic Transition of total fertility rates and child deaths. The evidence on the fit of the model to the US experience on the aforementioned variables is contained in Appendix F.

I chose human capital and population for year 2000 for the rich countries to match year 2000 per capita incomes and populations, and year 2200 human capital for the poor regions in order to match 2000 per capita incomes and populations.[8] Assume that the

[7] In this case the TFP term for a resident of the rich region becomes:

$$\left[\left\{P^{rich}\left(h^{rich}\right)^{\frac{1}{\omega}} + M\left(h^{poor}\right)^{\frac{1}{\omega}}\right\}^{\omega-1}\left(h^{rich}\right)^{\frac{1}{\omega}-1} q\left(\overline{h}\right)^{P^{rich}+M}\right]^{1-\sigma} \tag{29}$$

[8] In the solutions a period is 40 years, so that year 2200 represents 5 generations since year 2000.

human capital stock for 2000 is such that the young mortality rate, δ_{2000}, is very close to 0 in the rich countries and δ_{2200} is 0 in the poor "countries." Assume that human capital growth is such that in 2040, $\delta_{2040} = 0$, and thus the human capital investment rate will attain its long run value given by (12). With these assumptions, for the rich countries, $(x_{2040}, \tau_{2040}) = (x, \tau)$. Notice that (9) and (10) are two first order difference equations in (x_t, τ_t) and (x_{t+1}, τ_{t+1}). We can now solve for (x_{2000}, τ_{2000}) recursively. Given solutions for (x_{2000}, τ_{2000}) and values for P_{2000} and h_{2000}, P_{1960} and h_{1960} can be calculated. The iteration continues until time hits 25,000 B.C.

In order to fit the world population and rich region population time series, I used a technique developed by Jones(2000), which is to assume the existence of 0 mean random young adult mortality rate shocks. Let φ_t be the generation t young adult mortality rate shock, then the law of motion of population and human capital are given by:

$$P_t = \frac{P_{t+1}}{x_t\,(1 - \delta_t - \varphi_t)} \tag{30}$$

$$h_t = \left\{ \frac{h_{t+1}}{A\bar{h}_t^{\varepsilon}\tau_t^{\rho}} \right\}^{\frac{1}{1-\varepsilon}} \tag{31}$$

I chose the following parameters of preferences: $\alpha = .44605137$, $\beta = .52$. For the parameters of the young adult mortality function I chose: $\Delta = .55$, $\gamma_1 = .04$, $\gamma_2 = .01$, $\gamma_3 = \frac{1}{95}$, $\gamma_4 = 2.20$. For child rearing I assume that $\theta = .106$. For output production, I assume that the share of output produced via land per person is given by $\sigma = .10,$ and the gains from specialization parameter varies over time, but for most of human history, $\omega = 1.00025$.[9] Finally for production of human capital, the parameters are given by $A = 5.561793185$, $\rho = 1.0186386$. In the human capital accumulation technology the parameter $\varepsilon = .10$. Finally the spillover in the young adult mortality function is given by $\nu = .0001$ if average human capital in the country is less than or equal to 2.25, and $\nu = .15$

[9] Actually ω is a time varying parameter. Prior to 1640, $\omega = 1.00025$, and after 2000 $\omega = 1.27$. The values for 1640, 1680, 1720, 1760, 1800, 1840, 1880, 1920, 1960 and 2000 are 1.0015, 1.005, 1.015, 1.05, 1.145, 1.2170, 1.2700, 1.2853, 1.2853, 1.2853 respectively. Therefore, as in Jones (2000) the model indicates that there was a rise in the return to human capital coinciding with the increased protection of private property in the West.

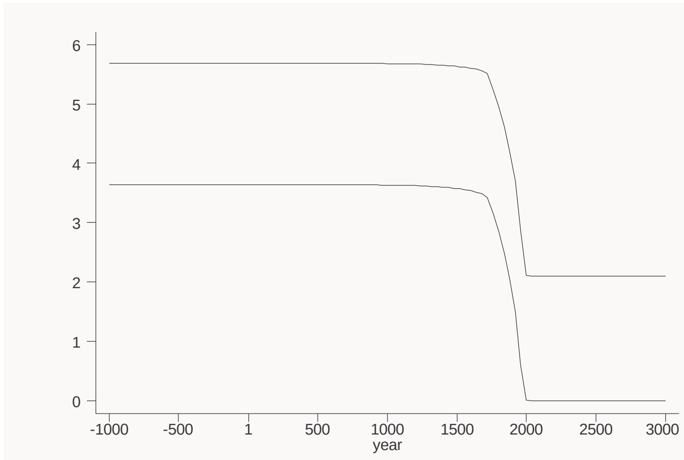

FIG. 2. Total Fertility Rate and Total Young Deaths

if average human capital in the poor region is greater than 2.25.[10]

Figure 2 contains the evidence on the Demographic Transition. Total fertility rates are close to 6 throughout most of human history, 25,000 B.C. until the 15th century A.D. Total deaths are close to 4 children per mother over this same period.[11]

Figures 3 and 4 contain the simulated world population and the actual world population over time; figure 3 presents the evidence from 25,000 BC to 1 AD, and figure 4 the evidence from 1AD to 2000. Actual values are presented by the labels, pop and Δ, and the simulated values are connected by the line. In the solution the young adult mortality shocks were chosen in order to fit the model to the population values labeled by pop. The actual data represented by Δ were not used, but serve as a test of the fit of the model.

In figure 4 the simulated world population contains two distinct boom bust cycles, whereas the actual world population contains a much smoother series. This exaggeration arises because the young adult mortality shocks that I used in the solution were attempting to match many fewer values of world population than actual data exist.

[10] The solution algorithm is presented in the Appendix E.

[11] These deaths include infant mortality that I have yet to specify. Infant mortality is included in order to match life expectation, life expectation at age 20 and infant mortality itself.

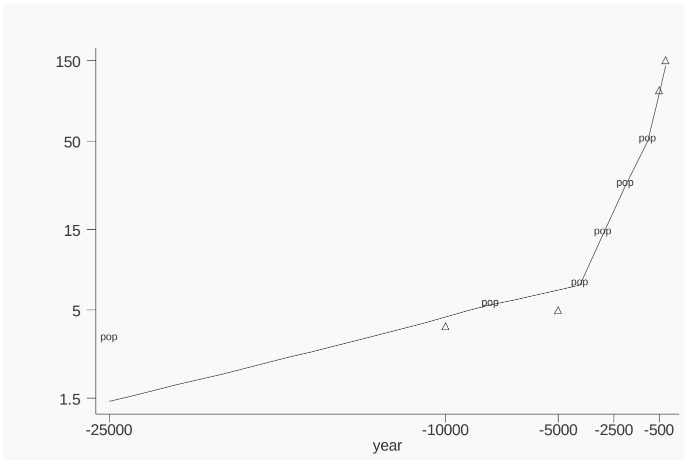

FIG. 3. World population solution (connected), actual (labeled) in millions

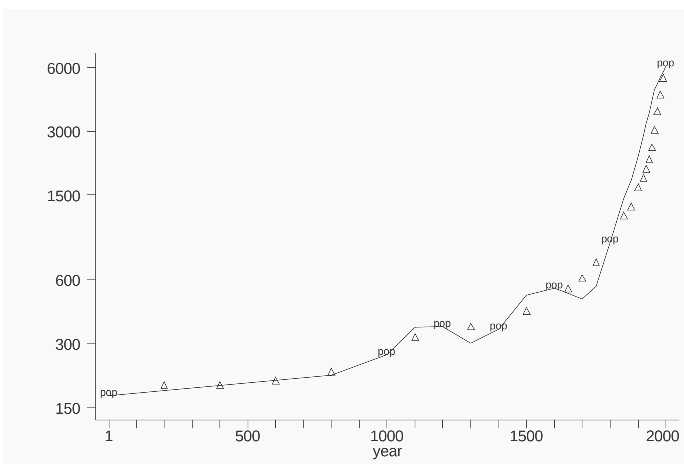

FIG. 4. World population solution (connected) & actual (labeled), in millions

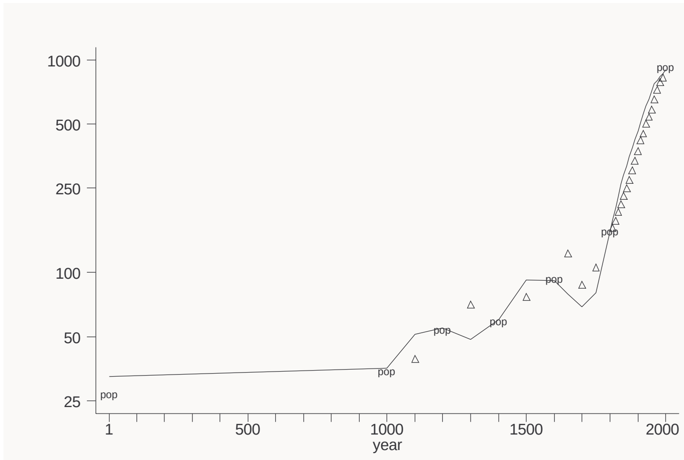

FIG. 5. Rich population solution (connected) & actual (labeled) in millions

Figure 5 contains the rich world population solution and the actual population values. Data on individual countries comes from McEvedy and Jones (1978). In the figure, the connected plot is the model solution, and the labeled values are the historical values. As with the world population series, the observations labeled with triangles were not used to fit the solution. Observe that there are two more pronounced population cycles in the rich region relative to the world population series.

Figure 6 contains the time series evidence of the market size in the rich economy. The final linear portion of the figure from 2080 A.D. onward shows that the market is the entire world population. Market size is 5 from the start of the agricultural revolution, say 8000 BC. By 1500 AD, market size has increased by sixty percent to 8. Market size grows rapidly from 1600 to 1700, increasing from 9 to over 400. By 1800 market size grows to 12,500.[12]

Figure 7 contains the per capita income of the rich region. Per capita income is 264 dollars in 1 A.D. and remains roughly stationary until growth begins in the 17th century.[13]

[12] The average size of cities serves as a useful proxy for market size. Bairoch (1988) presents evidence on the average size of cities. In 1800 the average sizes of European cities, conditional on being at least 2000, 5000 and 20000, are 7800, 16,700 and 54,900. The first two are quite similar to the model solution.

[13] All income values are in 1999 dollars.

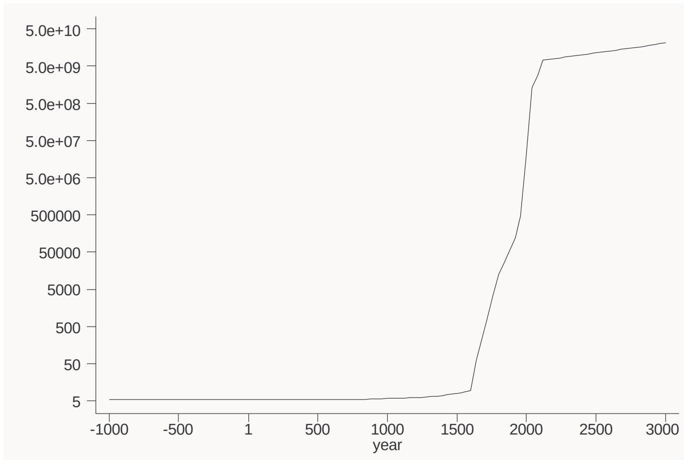

FIG. 6. Time series of market size in rich region

From 1600 to 1800, per capita income grows to 850 dollars. The Industrial Revolution begins in earnest in 1800, with smooth per capita income growth of around 1.7 percent per year.

6. EMPIRICAL EVALUATION OF THE MODEL

In this section, I present empirical evidence supporting the model. The model has two predictions about the behavior of human capital investment and fertility. Human capital investment should be negatively related to young adult mortality, and essentially independent of infant mortality.[14] Fertility should be positively related to infant mortality as well as young adult mortality. The empirical evidence supports the model on each of these predictions. In addition, the calibrated model produces time series for 22 rich countries and 4 poor "countries." In the second subsection, I report the results of regressions in

[14] The model predicts that infant mortality should have no effect on human capital investment. This assumes that infant mortality imposes no costs on parents. However a full term pregnancy that results in an infant that does not survive to age 1 reduces a woman's reproductive capacity by between 9 months and 1 year. Since reproductive capacity is finite, lasting roughly 30 to 35 years, infant mortality is not costless.

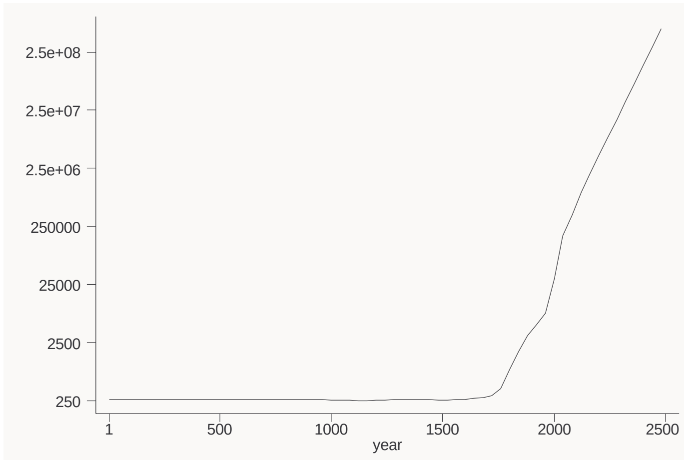

Fig. 7. Time series of per capita income in rich region

which these time series are compared with the actual time series for these groups.

6a. Empirical test of model predictions

In this subsection I examine the actual behavior of human capital investment and fertility to infant mortality and young adult mortality. While I have used female gender in reference to individuals, it is most likely that for much of development that young adult male mortality is more closely related to the model than young adult female mortality. Scarce investment resources would tend to be specialized on males, who are more likely to work than females. Total fertility rates, conditional mortality rates come from Keyfitz and Flieger (1968, 1990) and Preston, Keyfitz and Schoen (1972). Human capital data come from Baier, Dwyer and Tamura (2001) and is measured in years of schooling. In Table 1 I report the results of regressing the average years of schoooling in the adult population against various measures of male mortality. I constructed various measures of young adult mortality from the conditional mortality data. The model suggests that the probability of not surviving to reach age 15 or so would be a reasonable measure of young adult mortality.[15]

[15] The US average age of entry into the labor force in 1870 was 13, see *1993 Annual Report of the Federal Reserve Bank of Dallas.*

Table 1: Regressions of years of schooling on mortality rates

(standard error), significant at the *10 percent, **5 percent and ***1 percent

variable	years of schooling one decade hence	years of schooling one decade hence
	OLS	Fixed Effects
years of schooling	0.9608***	0.9927***
	(0.0161)	(0.0212)
male probability of death between 10 and 15	-156.52***	-197.52***
	(32.36)	(34.21)
male infant mortality	-2.321*	-4.338**
	(1.281)	(1.693)
male probability of death between 1 and 5	2.111	-1.714
	(3.408)	(3.536)
male probability of death between 5 and 10	36.900*	92.417***
	(19.220)	(19.84)
constant	1.898***	1.768***
	(0.115)	(0.155)
$\overline{R}^2$	.9331	.9283
N	535	535

The key feature from the two regressions is that human capital in the next period is negatively related to the probability that a child dies between the ages of 10 and 15. The results are similar for both OLS and Fixed Effects regressions. A reduction in the male probability of dying between 10 and 15 from .5 percent to .4 percent increases years of schooling 10 years from now by .16 years.[16] However a 20 percent reduction in infant mortality, evaluated at the mean infant mortality rate, raises years of schooling 10 years from now by only .03 years.[17] Thus while not insignificant, as the baseline model predicts,

[16] The mean male probability of death between the ages of 10 and 15 is .0049758 in the data. It ranges from a high of .0285 and a low of .00058.

[17] Mean male infant mortality is .063, with a range of .0055 to .56.

reductions in male infant mortality is only 20 percent as large in magnitude as a similar relative magnitude reduction in male probability of death between the ages of 10 and 15. The fixed effects regressions are similar to the OLS regressions.

The results, for fertility in Table 2, are weaker. Observe that years of schooling of parents have the expected negative effect on total fertility rates. Higher young adult male mortality, proxied as above, by the probability that a boy dies between the ages of 10 and 15, increases total fertility rates. At the mean increase in this death risk from .005 to .006 produces an increase in the total fertility rate of over one half a child. This occurs in the OLS regression, but not in the Fixed Effects regression. Higher male infant mortality lowers total fertility rates in the OLS case, but not in the Fixed Effects case. Higher male mortality rates in youth, death between 1 and 5 and death between 5 and 10, lower total fertility rates in the OLS case, but not in the Fixed Effects case. The results are different for female mortality. Young adult female mortality, proxied by the mortality of females between the ages of 10 and 15 are negatively related to total fertility rates, although only signficantly so in the OLS case. Female infant mortality and female mortality between the ages of 1 and 5 are positively related to total fertility rates, but female mortality between 5 and 10 are insignificantly related to total fertility rates.

Table 2: Regressions of total fertility rates on mortality rates

(standard error), significant at the *10 percent, **5 percent and ***1 percent

variable	total fertility rates OLS	total fertility rates Fixed Effects
years of schooling	-.2383***	-.2018***
	(.0224)	(.0198)
male probability of death between	519.87***	25.78
10 and 15	(79.32)	(57.63)
male infant mortality	-14.07***	0.477
	(2.935)	(2.205)
male probability of death between	-116.93***	-17.19
1 and 5	(18.96)	(15.51)
male probability of death between	-93.13	24.86
5 and 10	(66.55)	(47.59)
female probability of death between	-369.18***	-43.25
10 and 15	(56.40)	(41.74)
female infant mortality	5.632**	-2.239
	(2.77)	(1.815)
female probabilty of death between	149.57***	37.03**
1 and 5	(18.34)	(15.65)
female probability of death between	16.235	-41.43
5 and 10	(58.84)	(42.83)
constant	3.967***	4.052***
	(0.176)	(0.158)
$\overline{R}^2$	.5363	.5384
N	535	535

6b. Regressions of actual values on numerical solutions

Once the model was calibrated to fit the US time series, I examined the fit of the solution to the actual experience of the 22 rich countries, and the 4 poor "countries." In this section I present the results from regressions of the actual values for population, income per capita, age at departure from schooling, life expectancy at birth, life expectancy at 20, total fertility rates and infant mortality rates on their counterpart solutions. In order to evaluate the model's ability to simultaneously fit all of these variables, I created a synthetic variable. For each variable, I calculated the model's solution value for each year of available data. I then normalized both the actual value and the solution value by dividing by the mean of the solution series. I then stacked these observations into a single synthetic time series of normalized actual values and normalized solution values. By normalizing each series by the solution mean, I give an observation on any variable equal weight to any other randomly chosen observation. Thus population and per capita incomes that are measured in millions and dollars get no additional weight relative to infant mortality, total fertility rates because of their size. Tables 3 and 4 contain the results of regressions for the world, the rich and the poor. Table 4 contains the results from regressions that allow the population series to have a different intercept and a different slope because the model does not account for immigration. If the model explained the data perfectly, then the regressions should produce a slope coefficient on the solution of one and a zero intercept.

Table 3: Goodness of fit regressions

(standard error), significant at the *10 percent, **5 percent and ***1 percent

	all with US	rich with US	poor	all without US	rich without US
solution	0.7752***	0.8568***	0.8570***	0.7726***	0.9868***
	(0.0054)	(0.0073)	(0.0362)	(0.0054)	(0.0082)
constant	0.1680***	0.1103***	0.0352	0.1662***	-0.0059
	(0.0094)	(0.0099)	(0.0412)	(0.0095)	(0.0095)
$\overline{R}^2$	.8778	.8374	.6765	.8810	.8514
N	2912	2644	268	2777	2509

The first column of Table 3 shows that the model explains a large amount of the variation in the data. However the slope coefficient is .78, and it is significantly different from one. Table 3 also indicates that the rich and poor regions behave similarly.[18] Since the data are from a panel, I also ran Fixed Effects regressions for all countries, the rich countries and the poor countries. Nothing changes in any of the three cases, and are not reported here. The final two columns of Table 3 rerun the first two regressions, but deleting all US observations. In the penultimate column, nothing changes. However notice that in the final column, deleting the US observations changes the results greatly. The slope coefficient moves from .86 to .99, which is not significantly different from 1. Further observe that the constant term is insignificantly different from 0 both economically and statistically. This suggests that perhaps the model fails by not taking into account migration from the European countries to the US over the 400 year period between 1600 and 2000.

As mentioned above, the model does not account for immigration from one country to another. The model systematically overpredicts the United States population, as well as Canada and Australia. The overprediction for the US is 43.4 million, 4.9 million for Canada and 3.1 million for Australia. McEvedy and Jones (1978) estimate that 42 million Europeans emigrated to the United States over this period, and 4 million to Canada. Thus Table 4 contains the results for the world, and the rich and poor regions separately with population and population interacted with the solution.

Table 4: Goodness of fit regressions

(standard error), significant at the *10 percent, **5 percent and ***1 percent

[18] In the rich and poor regressions, I normalized the values by the means of each respective groups.

	all with the US	rich with the US	poor	all without the US	rich without the US
solution	1.0259***	1.0213***	1.0343***	1.0195***	1.0151***
	(0.0138)	(0.0121)	(0.0575)	(0.0143)	(0.0106)
constant	-0.0384**	-0.0319**	-0.0919	-0.0394**	-0.0336***
	(0.0159)	(0.0140)	(0.0611)	(.0165)	(0.0122)
$\overline{R}^2$	.8971	.8553	.7177	.8985	.8525
N	2912	2644	268	2777	2509
controls	pop.	pop.	pop.	pop.	pop.

The first three columns contain the results for the world, the rich and the poor regions. Observe that controlling for the population effects, all three regressions indicate a slope of 1.[19] The slope coefficients for the rich and poor regions are similar as before. Notice that the constant term for the world and for the rich group has been reduced by a factor of four. Deleting the US observations and rerunning the regressions does not change the results for either the entire sample or for the rich countries. The Fixed Effects regressions produce similar results and hence are not reported here.

7. RICH AND POOR AND THE FUTURE

Having demonstrated that the model can fit the actual behavior of the rich and poor, in this section I present the time series from the model solution for the rich and poor regions from the past into the future. This is an out of sample prediction from the model as to the evolution of the world distribution of per capita income and the other 6 variables. This is an extension of Lucas (2000). As in Prichett (1997) there is divergence between the rich and poor as the rich region countries undergo their demographic transition to economic growth. However with spillovers from human capital, the poor region will undergo their own demographic transition and an even more accelerated transitional growth phase. This

[19] In each of the first three regressions, the coefficient on the solution is never statistically different from 1 at the 5 percent level. The p values for the world, rich and the poor are .0610, .0798 and .5509, respectively.

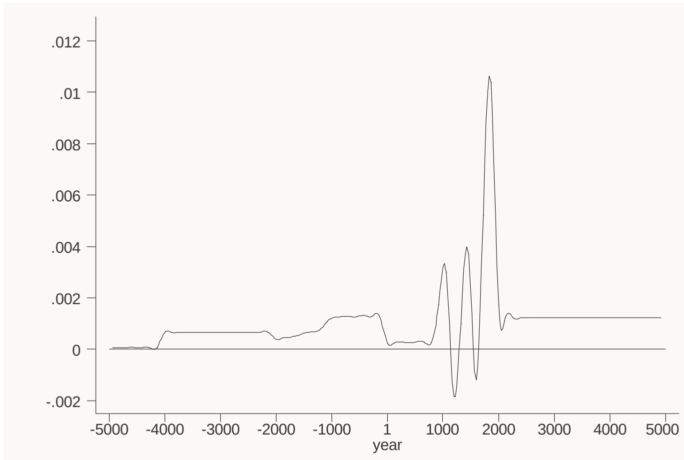

FIG. 8. Time series of annualized world population growth rates

section presents the time series evidence for world population growth, world per capita income growth, world total factor productivity growth, income, and income inequality.

I present the results through graphs. Figure 8 illustrates the demographic transition in the world. The first hump in the growth rate of population is the completed demographic transition in the rich region. The second, much larger hump, represents the demographic transition that is ongoing in the poor countries today. However the falling in the total fertility rates in the non rich world, indicate the falling population growth rates from 2000 onward. The peak population growth rate in the world occurred over the 1960-2000 period.[20]

Figure 9 details the change in average world per capita income as well as the change in world total factor productivity. These graphs detail the industrial revolution in the rich region, and predicts the consequences of the diffusion of the industrial revolution to the poor. As mirrored in the population growth rates, per capita income growth rates as well as technological progress have two humps. The first is the industrial revolution in the rich region and the second is the industrial revolution in the poor region. The model predicts

[20]The negative growth rate for the 2000-2040 period is an artifact of the smoothing process in the graph, it is not real.

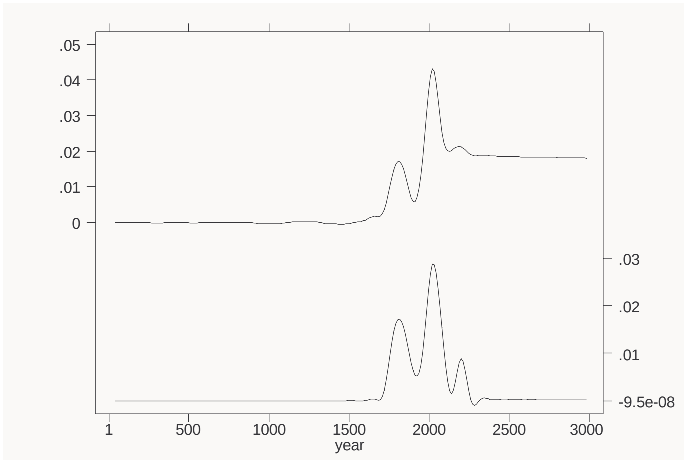

FIG. 9. Time series of annualized world per capita income growth rates (top) and annualized world technological progress (bottom)

that the industrial revolution diffuses into the poor region over the 2000-2040 period.

Figures 10 and11 detail the explosive change in the income distribution between the rich and the poor, and the predicted convergence starting from 2040. These are represented by two separate graphs, the first presents mean per capita income by region, the second illustrates the increase in life expectancy by region.

It is evident that the explosive increase in inequality between the rich and the poor occurred with the initial industrial revolution in the rich region. Relative per capita incomes reach a maximum gap between rich and poor in the 2000-2040 period, where average rich per capita income is 9 times larger than average poor per capita income. Despite the rising relative income gap from 1800-2040, there is great heterogeneity amongst the "countries" in the poor group. Suppose one identifies 1880 as the date of the US industrial revolution, and income of roughly 3500 dollars. Then using this income figure as the threshold value for any country to attain to signify the industrial revolution, the poor have quite different start dates. The model has Latin America industialization right after World War II in 1946. For China the model indicates a start date of 1989. India's industrial revolution begins in 2011, and the rest of the world in 2014. Thus it takes about a generation from

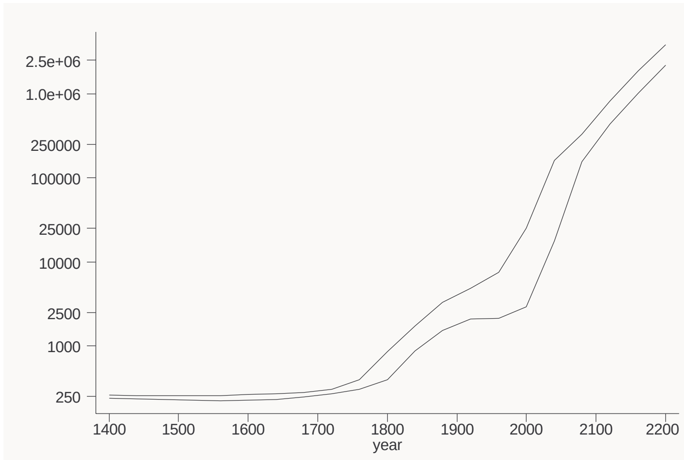

FIG. 10. Time series of per capita income for rich (top) and poor (bottom)

the onset of industrialization in China, India and the rest of the world to begin to close the relative income gap. However the explosive growth of income inequality does not imply any differences in policies, but rather could be merely an indication of slight differences in initial conditions.

Figure 11 contains the change in life expectancy over the past millenia. Again there was a creation of a gap between rich and poor from 1720 to 2000 as the result of the earlier demographic transition in the rich region. However by 2080 this gap is completely eliminated.

8. CONCLUSION

The paper presents a simple general equilibrium model of human capital investment and fertility. When young adult mortality is a function of the average human capital of the young adults in the population, human capital accumulation can produce a Demographic Transition. The model assumes that individual maximize expected discounted dynastic utility. Although preferences are logarithmic, expected utility maximization produces a precautionary demand for children. Therefore in high young adult mortality environments fertility will be high and thus human capital investments will be low. If human capital accu-

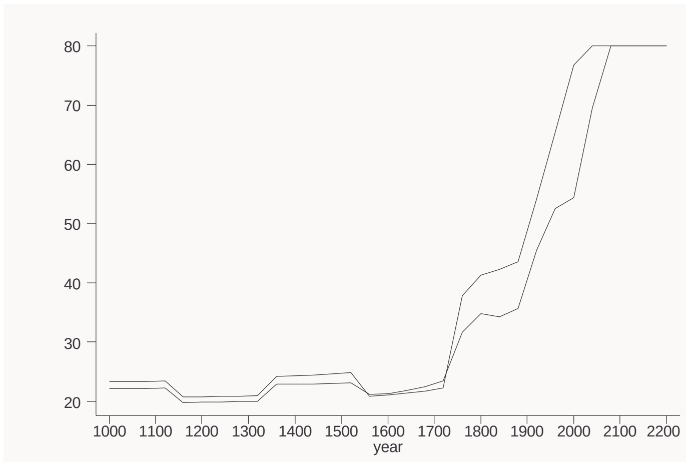

FIG. 11. Time series of life expectancy at birth for rich (top) and poor (bottom)

mulates, eventually young adult mortality falls. With falling young adult mortality comes falling fertility. Falling fertility lowers the cost of human capital investments, and hence the rate of human capital accumulation accelerates. This in turn induces a Demographic Transition to an Industrial Revolution.

The model's prediction that human capital investment should be negatively related to young adult mortality, but independent of infant mortality is strongly confirmed in the data. The model's prediction that total fertility rates should be positively related to infant mortality and young adult mortality is weakly supported. While higher young adult mortality does raise the total fertility rate, the effects of infant mortality are not well identified.

The model was calibrated to fit the world population experience from 25,000 B.C. to 2000 A.D. The unexpected young adult mortality shocks were chosen in order to fit both the population histories for the rich and poor regions, as well as multiple time series for the US. With these choices, the model was able to fit the behavior of 21 other rich countries, and 4 poor regions. This behavior includes total fertility rates, infant mortality rates, life expectancy at birth, conditional life expectancy, age at entry into the labor force and income. The measure of the fit was presented in two different ways, via the Theil inequality coefficient as well as the regression results. In both cases the model does surprisingly well in capturing the disparate behavior of these 26 different time series.

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A. PREFERENCES: DERIVATION OF APPROXIMATION OF EXPECTED UTILITY FUNCTION

The Delta method is the expectation of the utility function that has been expanded in a Taylor series approximation around the mean of the distribution. In this paper, as in Kalemli-Ozcan, I use a third degree approximation. Thus:

$$\begin{aligned} \ln \widetilde{n}_t &= \ln x_t(1-\delta_t) + \frac{(\widetilde{n}_t - x_t(1-\delta_t))}{x_t(1-\delta_t)} - \frac{(\widetilde{n}_t - x_t(1-\delta_t))^2}{2!\,[x_t(1-\delta_t)]^2} \\ &\quad + \frac{2(\widetilde{n}_t - x_t(1-\delta_t))^3}{3!\,[x_t(1-\delta_t)]^2} + \cdots \end{aligned} \tag{32}$$

Taking the expectation implies:

$$\begin{aligned} E\{\ln \widetilde{n}_t\} &= \ln x_t(1-\delta_t) + E\left\{\frac{(\widetilde{n}_t - x_t(1-\delta_t))}{x_t(1-\delta_t)}\right\} - E\left\{\frac{(\widetilde{n}_t - x_t(1-\delta_t))^2}{2!\,[x_t(1-\delta_t)]^2}\right\} \\ &\quad + E\left\{\frac{2(\widetilde{n}_t - x_t(1-\delta_t))^3}{3!\,[x_t(1-\delta_t)]^2}\right\} + \cdots \end{aligned} \tag{33}$$

$$E\{\ln \widetilde{n}_t\} = \ln x_t(1-\delta_t) + 0 - \frac{x_t\delta_t(1-\delta_t)}{2\,[x_t(1-\delta_t)]^2} + 0 + \cdots \tag{34}$$

the second and fourth terms are 0 because they are an odd moments of a symmetric function, the third term depends on the variance of the distribution. Thus as an approximation of the expected utility function term:

$$(1-\alpha)\,E\left\{\ln \widetilde{n}_t\right\} = (1-\alpha)\left[\ln x_t(1-\delta_t) - \frac{\delta_t}{2x_t\,(1-\delta_t)}\right]. \tag{35}$$

Now observe that the current consumption term depends on the number of people in the economy. Therefore the expectation of utility from future consumption depends on the number of people in the economy in the future. From equation 5 observe that output at time t depends on the land per person at time t, $\frac{L_t}{\widetilde{P}_t}$. An adult at time t, is endowed with land in the amount of $\frac{L_t}{P_t}$. He or she cares about the consumption of his or her children and their progeny. Therefore his or her preferences include the future terms:

$$E_t\left\{\sum_{i=t+1}^{\infty} -\beta^{i-t}\alpha\sigma \ln \widetilde{P}_i\right\} = -\frac{\alpha\beta\sigma\ln P_t}{1-\beta} - E_t\left\{\sum_{i=t+1}^{\infty}\beta^{i-t}\alpha\sigma\sum_{j=t}^{i-1}\ln\widetilde{n}_j\,(1-\delta_j)\right\} \tag{36}$$

Focusing only on the terms that contain x_t, the preferences of an adult become:

$$-\frac{\alpha\beta\sigma\ln x_t}{1-\beta} + \frac{\alpha\beta\sigma}{(1-\beta)2x_t^2(1-\delta_t)} \tag{37}$$

B. SOLUTION ALGORITHM FOR TRANSITION DYNAMICS

In this Appendix I present the solution algorithm for the numerical solution. The first order conditions for optimal fertility and human capital investments are repeated below

$$\frac{\alpha(\theta+\tau_t)}{1-x_t\,(\theta+\tau_t)} = \frac{1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}}{x_t} + \frac{(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta})\delta_t}{2(1-\delta_t)x_t^2} \tag{38}$$

$$\frac{x_t\tau_t}{1-x_t\,(\theta+\tau_t)} = \beta\rho(1-\sigma) + \frac{\beta x_{t+1}\tau_{t+1}\,(1-\varepsilon)}{1-x_{t+1}\,(\theta+\tau_{t+1})} \tag{39}$$

Define the variable M_{t+1}as

$$M_{t+1} = \frac{\beta x_{t+1}\tau_{t+1}\,(1-\varepsilon)}{1-x_{t+1}\,(\theta+\tau_{t+1})} \tag{40}$$

Taking the ratio of the two Euler equations produces

$$\frac{\alpha\,(\theta+\tau_t)}{\tau_t} = \frac{\left[1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right]\left\{1+\frac{\delta_t}{2(1-\delta_t)x_t}\right\}}{\beta\rho(1-\sigma)+M_{t+1}} \tag{41}$$

Solving for the rate of human capital investment as a function of fertility and young adult mortality produces

$$\tau_t = \frac{[\beta\rho(1-\sigma) + M_{t+1}]\,\alpha\theta}{\left[1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right]\left\{1+\frac{\delta_t}{2(1-\delta_t)x_t}\right\} - \alpha\left[\beta\rho(1-\sigma)+M_{t+1}\right]} \tag{42}$$

Replacing this back into the second Euler equation and simplifying produces the following quadratic equation

$$a_t x_t^2 + b_t x_t + c_t = 0 \tag{43}$$

$$a_t = \frac{1-\frac{\alpha\beta\sigma}{1-\beta}}{1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}}\theta \tag{44}$$

$$b_t = \frac{\delta_t\theta}{2(1-\delta_t)} + \frac{\alpha\beta(1-\sigma)\rho + \alpha M_{t+1}}{1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}} - 1 \tag{45}$$

$$c_t = -\frac{\delta_t}{2(1-\delta_t)} \tag{46}$$

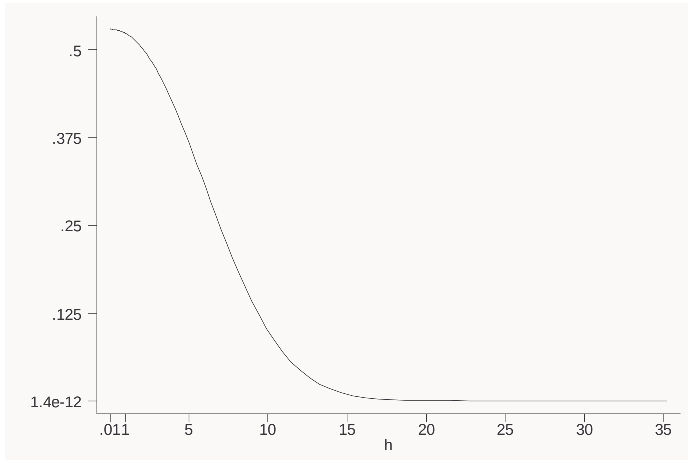
Since young adult mortality, δ_t, is a function of average human capital of generation t+1, all the coefficients are known for known values of (x_{t+1}, τ_{t+1}). As a quadratic equation, it is clear that there are two roots to (43), however only one is positive. Once (x_t, τ_t) are determined from (43) and (42), it is simple to use (30) and (31) to determine period t population and human capital. Continuing in this recursive manner produces the time series on population and human capital.

C. YOUNG ADULT MORTALITY & INFANT MORTALITY

In this Appendix I present the parametric form of both the young adult mortality function and the infant mortality function. The young adult mortality function is given by:

$$\delta_t = .55\exp\left(-\frac{\overline{h}_{t+1}^{.01}}{25} - \frac{\overline{h}_{t+1}^{2.2}}{95}\right) \tag{47}$$

This is graphed below



Young adult mortality as a function of average young adult human capital
The infant survivor function is given by:

$$m = \max\left\{ .70, \frac{\exp\left(\left[\frac{h}{1.2}\right]^{1.23}\right)}{\max\left\{10, .005N^{.58}\right\} + \exp\left(\left[\frac{h}{1.2}\right]^{1.23}\right)} \right\} \tag{48}$$

where N is the coalition size. Infant survival probability depends positively on the average human capital of the parent and negatively on the size of the coalition. This negative relationship with respect to coalition size proxies for the effects of urban life. It was not until the early 20th century that cities in the world were able to maintain their populations through natural population growth instead of net migration.[21] A graph of the survivor function is:

In order to see the effects of mortality on fertility and human capital investment, assume that there is a stationary young adult mortality rate of δ. Stationary fertility and stationary human capital investment rate are given by

$$x(\theta + \tau) = \frac{\left(1 - \alpha - \frac{\alpha\beta\sigma}{1-\beta}\right)(1 - \beta[1 - \varepsilon])\tau}{\beta\alpha\rho(1 - \sigma)} \left[x + \frac{\delta}{2(1 - \delta)}\right] \tag{49}$$

$$\frac{(1 - \beta[1 - \varepsilon])x\tau}{1 - x(\theta + \tau)} = \beta\rho(1 - \sigma) \tag{50}$$

[21] See Diamond (1999).

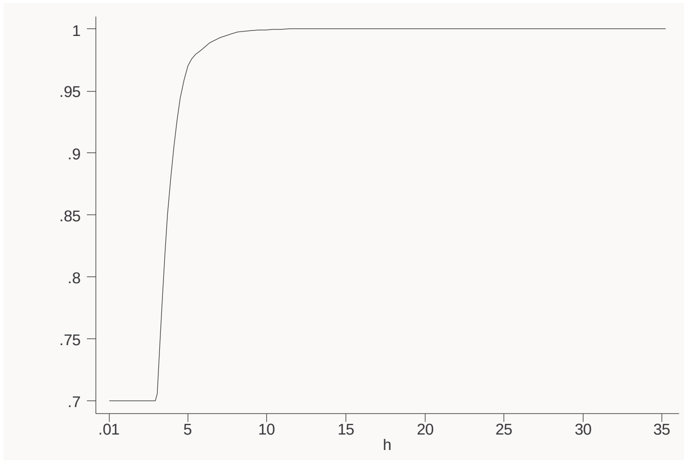


FIG. 12. Infant survival rates as a function of average parental human capital

Differentiating with respect to δ produces the following:

$$\frac{\partial\tau}{\partial\delta} = -\left[\frac{1-\beta\,[1-\varepsilon]+\beta\,(1-\sigma)\,\rho\,(\theta+\tau)}{x\,(1-\beta\,[1-\varepsilon]+\beta\,(1-\sigma)\,\rho)}\right]\frac{\partial x}{\partial\delta} \tag{51}$$

$$\frac{\partial x}{\partial\delta}W = \frac{\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\tau}{2\beta\alpha\rho(1-\sigma)(1-\delta)^2} > 0 \tag{52}$$

$$W = \left[\begin{array}{c} x\theta\left(\frac{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho(\theta+\tau)}{x(1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho)}\right)+ \\ \frac{\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\delta\tau}{\beta\alpha\rho(1-\sigma)2x(1-\delta)} \end{array}\right] > 0 \tag{53}$$

The first equation shows that the effect of young mortality on human capital investment is opposite in sign to the effect on fertility. The second equation clearly shows that higher young adult mortality produces higher fertility. Thus higher young adult mortality lowers human capital investment.

Finally the conditional life expecation function is presented below:

$$clife = 80\frac{\exp\left(\left(\frac{h}{2.05}\right)^{1.26}\right)}{2.25+\exp\left(\left(\frac{h}{2.05}\right)^{1.26}\right)} \tag{54}$$

This is graphed below:

The Theil inequality coefficient for this time series is .014. The bulk of this trivial error comes from bias, 67 percent. Mismatched variances account for 19 percent and

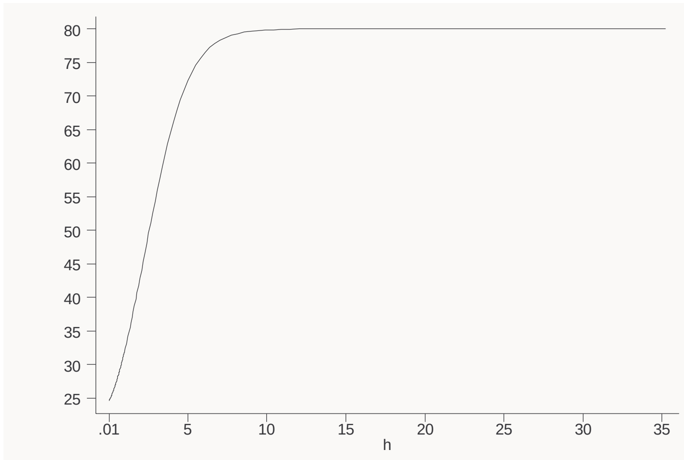


FIG. 13. Conditional life expectation

unsystematic error accounts for 13 percent.

D. FERTILITY UNDER CONSTANT MORTALITY

In the range where mortality is essentially constant, fertility is the positive solution to the following quadratic equation:

$$a_{ss}x_{ss}^2 + b_{ss}x_{ss} + c_{ss} \tag{55}$$

$$a_{ss} = \left(1 - \frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\,\theta \tag{56}$$

$$b_{ss} = \alpha\beta(1-\sigma)\rho - \left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\left(1-\frac{\theta\delta}{2(1-\delta)}\right) \tag{57}$$

$$c_{ss} = -\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\frac{\delta}{2(1-\delta)} \tag{58}$$

If there is an increase in the population growth rate over the range where mortality is roughly constant then:

$$\frac{\partial x_t}{\partial \delta_t}(1-\delta_t) - x_t < 0 \tag{59}$$

Replacing for $\frac{\partial x_t}{\partial \delta_t}$ from the previous appendix, rearranging and simplifying produces the following:

$$\frac{\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\tau}{2\alpha\beta(1-\sigma)\rho} < \left(\frac{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho(\theta+\tau)}{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho}\right)\theta x \tag{60}$$

Replacing for τ from the steady state mortality Euler equation and simplifying produces the following quadratic equation:

$$\begin{aligned}
0 &< a_\delta x_\delta^2 + b_\delta x_\delta + c_\delta && (61)\\
a_\delta &= \left(1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho\theta\left[\frac{1-\beta[1-\varepsilon]}{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho}\right]\right)\theta && (62)\\
b_\delta &= \frac{\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])\theta}{2\alpha} + \frac{\beta^2(1-\sigma)^2\rho^2\theta}{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho} && (63)\\
c_\delta &= -\frac{\left(1-\alpha-\frac{\alpha\beta\sigma}{1-\beta}\right)(1-\beta[1-\varepsilon])}{2\alpha} && (64)
\end{aligned}$$

Comparing the quadratic equation for steady state fertility with the quadratic equation in fertility for the change in the growth rate of population will suffice to show that falling young adult mortality increases population growth over the range where young adult mortality is roughly constant. It is clear that $0 < a_{ss} < a_\delta$. It is also clear that $c_{ss} < c_\delta < 0$ if $\frac{\delta}{1-\delta} > \frac{1}{\alpha}$, which in the simulations holds over this range in young adult mortality. Comparing the coefficients on the linear term, $b_{ss} < b_\delta$ if $\theta\delta < 2(1-\delta)$ and $\alpha < \frac{\beta(1-\sigma)\rho\theta}{1-\beta[1-\varepsilon]+\beta(1-\sigma)\rho}$. These are sufficient conditions under which evaluation of (64) will be positive. Hence the population growth rate is increasing as young mortality rates fall.

E. THEIL INEQUALITY COEFFICIENT AND ITS COMPONENTS

In this Appendix I present the evidence of the goodness of fit of the solution for the US time series. Unlike the standard calibration exercises, this solution attempts to actually match the time series values for these variables. I present the evidence on the goodness of fit of the model solution to the US time series in two ways. First I present the graphs of the model solution and the actual US values for each series. In Table F1 of Appendix F I present report the Theil inequality coefficient, essentially $1-R^2$, and its components (bias, variance and covariance) to provide analytical meat to the figures.[22] For all US time series the Theil inequality coefficients are below .20. The bias ranges from 0 to over 90 percent of the root mean square error and the variance ranges from 6 percent to 70 percent. The covariance term, representing the unsystematic portion of error, ranges from 2.5 percent to 60 percent.This Appendix presents the basic measure of fit of the simulated series with the actual time series. It also provides diagnostics on the share of the error that arises from three components, mean, variance and covariance. All of this comes from Pindyck and Rubinfeld (1997).

The Theil inequality coefficient is a normalization of the root mean square error between a simulated series, $Y^s = \{Y^s_{it}\}$, and an actual series, $Y^a = \{Y^a_{it}\}$. It is given by:

$$\frac{\left\{\sum_i \sum_t (Y^s_{it} - Y^a_{it})^2\right\}^{\frac{1}{2}}}{\left\{\sum_i \sum_t (Y^s_{it})^2\right\}^{\frac{1}{2}} + \left\{\sum_i \sum_t (Y^a_{it})^2\right\}^{\frac{1}{2}}} \tag{65}$$

A bit of algebra can generate the share of the root mean square error that arises from mismatched means, variances and an unsystematics term, covariance.

$$U^M = \frac{\left\{\overline{Y}^s - \overline{Y}^a\right\}^2}{\frac{1}{N}\sum_i \sum_t (Y^s_{it} - Y^a_{it})^2} \tag{66}$$

$$U^V = \frac{\left\{\sigma_s - \sigma_a\right\}^2}{\frac{1}{N}\sum_i \sum_t (Y^s_{it} - Y^a_{it})^2} \tag{67}$$

$$U^C = \frac{2\left(1-\rho\right)\sigma_s \sigma_a}{\frac{1}{N}\sum_i \sum_t (Y^s_{it} - Y^a_{it})^2} \tag{68}$$

where N is the total number of observations, $\overline{Y}^i$ is the mean of the i series, σ_i is the standard deviation of the i series, where i = s or i = a, and ρ is the correlation coefficient between

[22] The solution produces a Theil inequality coefficient of .19 for world population. About 5 percent of the root mean square error arises from mismatched means; 45 percent of the root mean square error arises from differences in variances of the two series. Half of the root mean square error is unsystematic. For rich population, capturing the behavior of the 22 different countries' population, the Theil inequality coefficient is .17. The main reason for the failure is the lack of migration in the model. The model solution, without immigration produces a predicted population for the US in 1800 of 49 million compared to an actual population of 5 million.! Perhaps too good to be true, total immigration to the United States from 1500 to 1975 was 42 million, which almost completely accounts for this discrepancy.

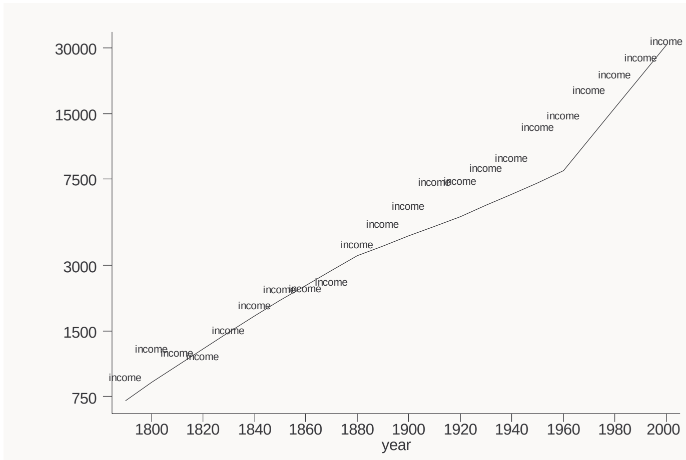


FIG. 14. US per capita income solution & actual (labeled)

the actual and the simulated series.

Figure 8 contains the actual per capita income of the US from 1790 to 2000, by decade, as well as the solution income. The actual income is labeled, and the solution income is connected.[23] The model fits the US history well, although it underpredicts per capita income in the 20th century.

Figure 9 contains the information for age of entry into the labor force for the US.[24]

The model predicts age at entry into the labor force is given by $40\,(\theta + \tau)$. However it is well know that there is human capital accumulation from learning by doing and on the job training. I calculated the schooling equivalent of this human capital and added it to the years of schooling data.[25] Again the actual US values are labeled and the solutions are

[23] The income data for the US comes from Baier, Dwyer and Tamura (2001).

[24] This data comes from Baier, Dwyer and Tamura (2001). To calculate age of entry into the labor force, I took the average years of schooling added 6 and added a years of schooling equivalent to human capital acquired via work experience.

[25] I calculated the average age of the population not enrolled in school and less than 65. I subtracted the measure of years of schooling to produce potential experience, X. To create a years of schooling equivalent, E, I used the following formula: E = $(.04X\text{-}.0075X^2)/.134$. The parameters chosen for this conversion are taken from labor economics wage regressions pioneered by Jacob Mincer (1962). I use the value of .134

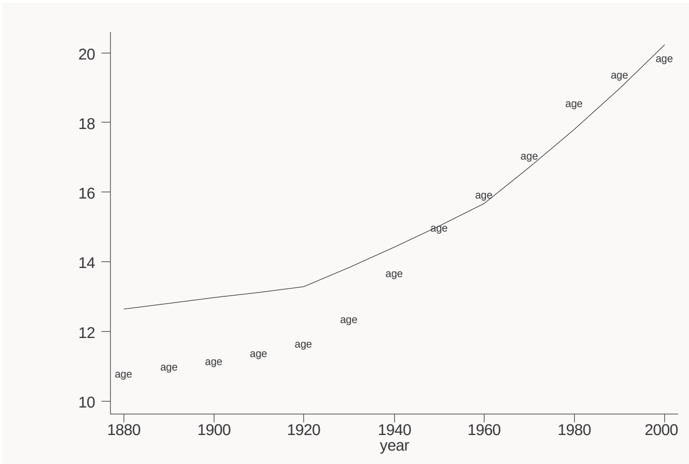


FIG. 15. US age at entry into the labor force solution & actual (labeled)

connected.

Life expectation is calculated from the infant survival rate, m_t, young adult mortality rate, δ_t, the conditional life expectancy of old adults, $clife_t$, and the unexpected young adult mortality rate, φ_t. I assume that infant mortality is costless in that infants that die do not impose any time costs on parents. I assume that infant survival is a positive function of the average human capital of parents, $\overline{h}_t$, and negatively related to the size of the market, N_t, representing the effect of urban density.[26] Thus for the richest country the infant survial rate, $\overline{m}_t$, is given by:

$$\overline{m}_t = \max\left\{ .70, \frac{\exp\left(\left[\frac{\overline{h}_t}{1.2}\right]^{1.23}\right)}{\max\left\{10, .005N_t^{.58}\right\} + \exp\left(\left[\frac{\overline{h}_t}{1.2}\right]^{1.23}\right)} \right\} \tag{69}$$

For all other countries I assume that there is a spillover from the highest human capital country. Advances in sanitation, nutrition and health practices in the highest

return per year of schoooling in order to calculate the schooling equivalent.

[26] See Diamond (1999) p. 205 for evidence that urban living was more hazardous than rural life. See also McNeil (1998) for a discussion of the change of fatal infectious diseases into fatal infant and childhood diseases.

human capital country diffuse to all other countries. Let i denote the country subscript, then infant survival rate in country i is given by:

$$m_{it} = \overline{m}_t^{.55} \max \left\{ .70, \frac{\exp\left(\left[\frac{\overline{h}_{it}}{1.2}\right]^{1.23}\right)}{\max\left\{10, .005N_{it}^{.58}\right\} + \exp\left(\left[\frac{\overline{h}_{it}}{1.2}\right]^{1.23}\right)} \right\}^{.45} \tag{70}$$

I assume that each life period is 40 years, and that the young adults who pass away before attaining old age die after $40\,(\theta + \tau)$ years. Conditional life expectation in the richest country, $\overline{clife}_t$, is given by:

$$\overline{clife}_t = 80 \frac{\exp\left(\left[\frac{\overline{h}_t}{2.05}\right]^{1.26}\right)}{2.25 + \exp\left(\left[\frac{\overline{h}_t}{2.05}\right]^{1.26}\right)} \tag{71}$$

For all other countries, I assume that there is a spillover in best practices in sanitation, nutrition and medical care from the richest country. Let i denote the country subscript, then conditonal life expectation in country i is given by:

$$clife_{it} = \overline{clife}_t^{.5} \left[80 \frac{\exp\left(\left[\frac{\overline{h}_{it}}{2.05}\right]^{1.26}\right)}{2.25 + \exp\left(\left[\frac{\overline{h}_{it}}{2.05}\right]^{1.26}\right)} \right]^{.5} \tag{72}$$

Life expectation is therefore given by:

$$\text{life exp ectation}_{it} = \left\{40\,(\theta + \tau_{it})\,(\delta_{it} + \varphi_t) + clife_{it}\,(1 - \delta_{it} - \varphi_t)\right\} m_{it} \tag{73}$$

Figure 10 contains the information of life expectation in the US from 1850 to 2000, labeled, and the solution values, connected.[27]

Figure 11 presents the evidence on conditional life expectation in the US. The model gives the life expectation conditioned on surviving life through education. The actual data is the life expectation at age 20. I graph the solution and the actual values (labeled).

[27] Life expectation data comes from Weil (2000), *Time Almanac 1999.*

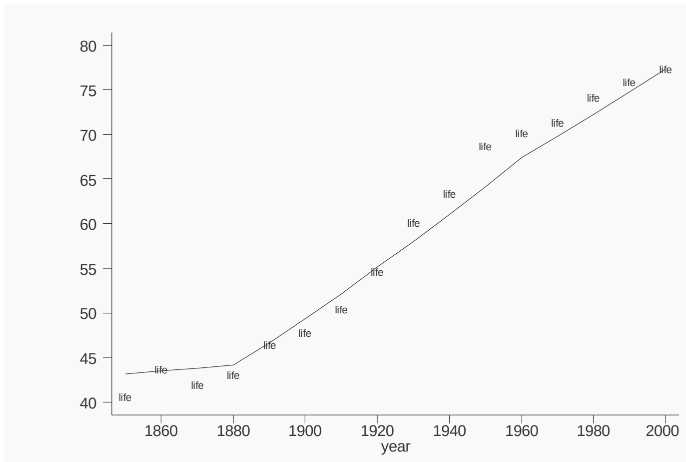


Fig. 16. US life expectation at birth solution & actual (labeled)

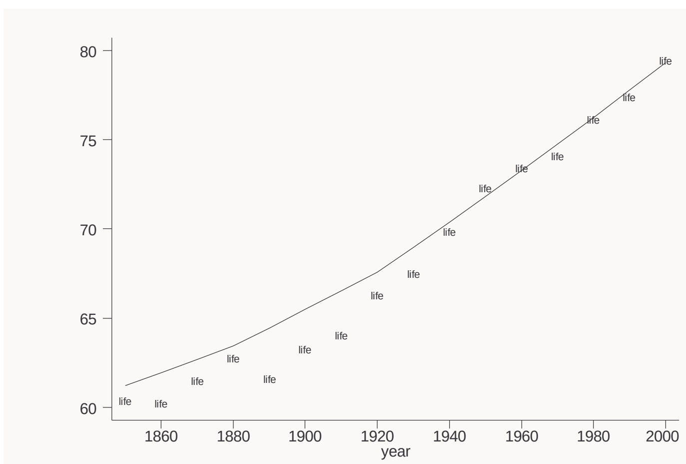


Fig. 17. US conditional life expectation at 20 solution & actual (labeled)

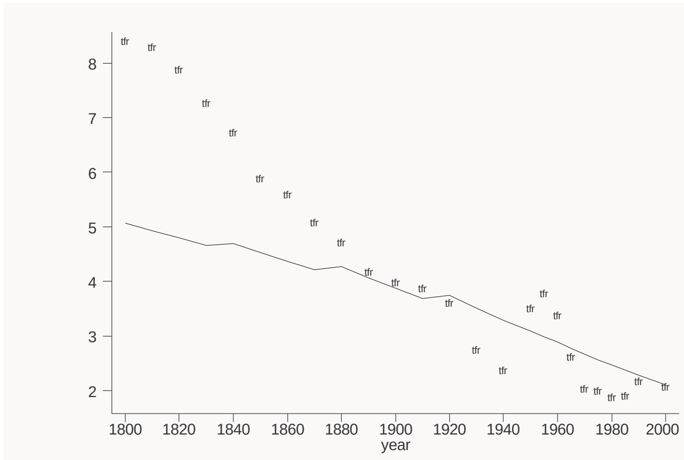


FIG. 18. US total fertility rates solution & actual (labeled)

Figure 12 contains the information on Total Fertility Rates, TFR, for the U.S. from 1800 to 2000, labeled, and the solution values, connected.[28] Since reproduction is asexual in the model, and there is costless infant mortality, Total Fertility Rates in the model are given by:

$$tfr_t = 2\frac{x_t}{m_t} \tag{74}$$

While the solution fits fairly well, it is below the extremely high fertility rates from 1800-1890, and it clearly misses the cyclical pattern from 1930-1990, which includes the small cohort from the Depression era, the Baby Boom, and the Baby Bust.

Figure 13 presents the US infant mortality rate solution and actual values. Observe that there exists an increase in infant mortality from 1850 to 1870. It remains at this higher rate until about 1900. Until significant improvements in public sanitation measures in cities, and the assimilation of rural migrants into cities through their adoption of urban living rules, e.g. disposal of human waste, disposal of garbage, etc., infant mortality rises with rising urban concentrations. This is consistent with the observation of Diamond (1998) that it was not until the 20th century that cities were able to sustain their population without an

[28]Total fertility rates come from *Historical Statistics of the United States: Colonial Times to 1970*, Keyfitz and Flieger (1990) and various editions of the *Statistical Abstract of the United States*.

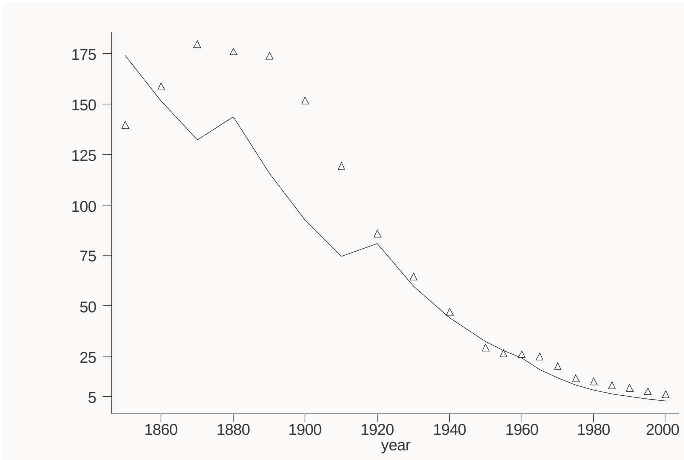


Fig. 19. US infant mortality rates per 1000 live births solution & actual (labeled)

influx of rural migrants. Notice that while the infant mortality rate rose over this period, total fertility rates continued to fall throughout this period and life expectation held roughly constant over the 1850-1880 period. This would be consistent with the model only if the young adult mortality rate fell over this period.

Table F1 contains the Theil Inequality Coefficients and their components for the US time series.

Table F1: Goodness of Fit of Solution for US

variable	Theil inequality coefficient	bias	variance	covariance	N
income per capita	.1325	.3877	.1521	.4602	22
labor force entry age	.0966	.9119	.0630	.0251	13
life expectation	.0164	.0002	.4717	.5281	16
conditional life expectation	.0112	.6213	.1771	.2016	16
TFR	.1671	.1682	.6936	.1383	25
infant mortality	.1453	.1964	.1952	.6084	25

G. COUNTRIES IN RICH AND POOR REGIONS

Rich group: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea (South), Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

Poor group: Argentina, Brazil, Chile, Mexico (Group I), China (Group II), India (Group III) and Rest of World (Group IV).

The data used for the paper come from a variety of sources. Most of the population, income per capita, age at labor force entry come from Baier, Dwyer and Tamura (2001), hereafter abbreviated BDT. Earlier per capita income comes from Maddision, Mn. To convert his values of per capita income into comparable values from BDT, I used 6 overlapping years to construct the geometric mean conversion rate. Early population comes from McKevedy and Jones (1978), MJ. Historical life expectation comes from Kalemli-Ozcan, K-O, and Keyfitz and Flieger (1968,1990), KF1 and KF2 and Mitchell (1998), M. Recent life expectation comes from Human Development Reports, HDR. Conditional life expectation comes from KF1, KF2 and Preston, et al. All are calculated as life expectation at reaching the age of 40 $(\theta + \tau)$, where I typically interpolated between the ages of 10, 15 and 20. Total fertility rates for 1950-1990, at the quinquennial frequency, come from Keyfitz and Flieger (1990), KF2. The 2000 figure comes from *Human Development Report 2000*. Earlier total fertility rates come from Keyfitz and Flieger (1968), KF1, Wrigley and Schofield, WR, and calculated from population statistics from Mitchell (1998), M.[29]

Australia:

Population (1600, 1800, 1840-2000): The first two observations are from MJ. Values over the 1840-2000, at the decadal frequency, are from BDT.

Per capita income (1820, 1850-2000): Values for 1820, 1850 and 1870 are from Mn. All values from 1880 onward, at the decadal frequency, are from BDT.

Age at labor force entry (1880-2000): All values except 2010, at the decadal frequency, are from BDT.

Life expectation (1900-2000): All even year values except 2000, at the decadal frequency, are from K-O. In addition 1955 and 1965 are from KF1, and 1975 and 1985 values are from KF2. The 2000 value comes from *HDR 2000*.

Conditional life expectation (1911, 1921, 1933, 1950-1985): The 1911, 1921, 1933, 1950, 1960 and 1965 values are from KF1. The 1970-1985 values, at the quinqennial frequency, are from KF2.

Total fertility rates (1870, 1900-1930,1950-2000): The 1870, 1900 and 1930 values are from M. The 1910 and 1920 values are calculated from KF1. The 1950-1990 values, at the quinquennial frequency, are from KF2. The 2000 figure is from *HDR 2000*.

[29] When using Mitchell's historical data, I use the following transformation to generate total fertility rates: I took the birthrate, b_t, from the specified date, averaging over three years when the rate varies, and multiplied by the population of the country at that date, P_t. I then divided this value by the total female population aged 15-44, and multiplied by 30. Thus:

$$tfr_{it} = \frac{30 * b_{it} P_{it}}{\sum_{j=15}^{44} f_{ijt}} \tag{75}$$

where f_{ijt} is the female population in country i at time t aged j. A similar method is used to calculate the total fertility rate using KF1.

Infant mortality rates (1870-1900, 1911, 1921, 1933, 1950-2000): The 1870-1900 data are at the decadal frequency, and they are from M (1998). The 1911, 1921 and 1933 values are from KF1. The 1950-1985 values are quinquennial and are from KF2. The 1990, 1995 and 2000 values are from various WDR and HDR.

Austria:

Population (1600, 1800, 1810-2000): The first two values are from MJ, and the rest, at the decadal frequency, are from BDT.

Per capita income (1820, 1850, 1870-2000): Values for 1820, 1850 and 1870 are from Mn. All values from 1880-2000, at the decadal frequency, are from BDT.

Age at labor force entry (1880-2000): All values 1880-2000 at the decadal frequency from BDT.

Life expectation (1950-2000): All even year values, except for 2000, are from K-O. The 2000 value is from *HDR 2000*. In addition 1955, 1965, 1975 and 1985 are from KF2.

Conditional life expectation (1950-1985): All values are at the quinquennial frequency. The 1950-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1870-2000): All values 1870-1950 at the decadal frequency. The 1950-1990 values are at the quinquennial frequency. The 1870-1940 values are from M. The 1950-1990 values are from KF2. The 2000 value is from *HDR 2000*.

Infant mortality rates (1810-1940,1950-2000): The 1810-1940 values are at the decadal frequency and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values are from various WDR and HDR.

Belgium:

Population (1600, 1720, 1760, 1800-2000): The first three values are from MJ. The 1800-1840 values, at the decadal frequency are from M. The final figures, at the decadal frequency are from BDT.

Per capita income (1820, 1850, 1870-2000): Values for 1820, 1850, 1870-1920 (decadal frequency) are from Mn. All values from 1930-2000, at the decadal frequency, are from BDT.

Age at labor force entry (1880-2000): All values are at the decadal frequency. The

1880-2000 figures are from BDT.

Life expectation (1880-2000): All even year values except for 2000, at the decadal frequency, from K-O. The 2000 figure is from *HDR 2000*. In addition 1955, 1965, 1975 and 1985 values are from KF2.

Conditional life expectation (1900-1985): The 1900-1960 values are at the decadal, and are from KF1. The 1970-1985 values, at the quinqennial frequency, are from KF2.

Total fertility rates (1850-2000): All values from 1850-1950 are at the decadal frequency. Values for 1850-1940 from M. The 1950-1990 values, at the quinquennial frequency, are from KF2. The 2000 figure comes from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840-1940 values, at decadal frequency, are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Canada:

Population (1600, 1800, 1810-2000): All figures are at the decadal frequency. The 1600 and 1800 figures come from MJ. The 1810-1840 figures come from MJ. The 1850-2000 values come from BDT.

Per capita income (1820, 1850, 1870-2000): The 1820 and 1850 values are from Mn. All figures, 1870-2000, are at the decadal frequency. All values come from BDT.

Age at labor force entry (1880-2000): The figures are at the decadal frequency. All values except for 2010 are from BDT.

Life expectation (1920-2000): All even year figures are at the decadal frequency. The 1920-1990 figures are from K-O. The 2000 figure is from *HDR 2000*. The 1965, 1975 and 1985 values are from KF2.

Conditional life expectation (1930-1990): The 1930-1960 values are at the decadal. The 1930-1965 values are from KF1. The 1970-1985 values, at the quinqennial frequency, are from KF2. The 1990 value comes from the internet site of Statistics Canada.

Total fertility rates (1920-2000): The figures from 1920-1950 are at the decadal frequency. They are calculated from M. The 1950-1990 figures are at the quinquennial frequency are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1900-2000): The 1900, 1910 and 1920 values are from M. The 1930 and 1940 values are from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Denmark:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870-2000): The 1820 and 1850 values are from Mn. All figures, 1870-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1840-2000): All figures are at the decadal frequency. The 1840-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The 1950, 1960 and 1965 values come from KF1. The 1970-1985 values, at the quinquennial frequency come from KF2.

Total fertility rates (1840-2000): The 1840-1940 figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840-1940 values are at the decadal frequency and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Finland:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870-2000): The 1820, 1850 and 1870 figures are from Mn. All figures, 1880-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The

1880-2000 figures are from BDT.

Life expectation (1890-2000): All figures are at the decadal frequency. The 1890-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1760-1985): The 1760-1960 values are at the decadal frequency. The 1965-1985 values are at the quinquennial frequency. All values are from Kannisto, Nieminen and Turpeinen (1999).

Total fertility rates (1800, 1830, 1850-2000): The 1800, 1830 and 1850-1940 (at the decadal frequency) are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1870-2000): The 1870-1920 values, at the decadal frequency and the 1940 value are from M. The 1930 value is from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

France:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870-2000): The values for 1820, 1850, 1870-1890 (decadal) are from Mn. All figures, 1900-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1820-2000): All even year figures are at the decadal frequency. The 1890-1990 figures are from K-O. The 1885, 1895, 1905, 1925, 1935, 1945 values are from KF1. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1850-1985): The 1850-1960 values are at the decadal frequency, and are from KF1. The 1970-1985 values, at the quinquennial frequency, are from KF2.

Total fertility rates (1840-2000): The 1840-1940 figures, at the decadal frequency, are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1830-2000): The 1830-1940 values, at the decadal frequency, are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Germany:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870-2000): The 1820, 1850 and 1870 figures are from Mn. All figures, 1880-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1950-2000): All even year figures are at the decadal frequency. The 1950-1990 figures are from K-O. The 1965, 1975 and 1985 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1960-1985): All values are at the quinquennial frequency. The 1960 and 1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1850-2000): The 1850-1940 figures, at the decadal frequency, are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Greece:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1910-2000): All figures are at the decadal frequency, and all are from BDT.

Age at labor force entry (1950-2000): All figures are at the decadal frequency. The 1950-2000 figures are from BDT.

Life expectation (1930, 1950-2000): All even year figures after 1930 are at the decadal frequency. The 1930, 1950-1990 figures are from K-O. The 1965, 1975 and 1985 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The 1950 and 1960 values are from KF1. The 1970-1985 values, at the quinquennial frequency, are from KF2.

Infant mortality rates (1920-2000): The 1920, 1930 and 1940 values are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Total fertility rates (1950-2000): The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Ireland:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1870-2000): The values for 1820, 1870-1940 (decadal) are from Mn. All figures, 1950-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1930-2000): All figures are at the decadal frequency. The 1950-2000 figures are from BDT.

Life expectation (1900-2000): All even year figures are at the decadal frequency. The 1900-1990 figures are from K-O. The 1965, 1975 and 1985 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1925-1985): The 1925-1945 values at the decadal frequency are from KF1. The 1950-1985 values, except for the missing 1965 value, are at the quinquennial frequency. The 1950-1960 values are from KF1, and the 1965-1985 values are from KF2.

Total fertility rates (1950-2000): The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1870-2000): The 1870-1920 values are at the decadal frequency, and are from M. The 1925-1945 values, at the decadal frequency, are from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Italy:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1860–2000): The 1820 value comes from Mn. All figures, 1860-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1880-2000): All even year figures are at the decadal frequency. The 1880-1990 figures are from K-O. The 1955, 1965, 1975 and 1985 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1930-1985): The 1930, 1935, 1950, 1960 and 1965 values are from KF1. The 1970-1985 values, at the quinquennial frequency are from KF2.

Total fertility rates (1850, 1875, 1900-2000): The even years from 1900 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1935 value is calculated from KF1. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1870-2000): The 1870-1920 values are at the decadal frequency, and are from M. The 1930 and 1935 values are from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Japan:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1870, 1890-2000): The 1820, 1870 and 1890 values are from Mn. All figures, 1900-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1900-2000): All figures are at the decadal frequency. The

1900-2000 figures are from BDT.

Life expectation (1900-2000): All even year figures are at the decadal frequency. The 1880-1990 figures are from K-O. The 1955, 1965 and 1975 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1940-2000): The 1940, 1950, 1955, 1960, 1965 values are from KF1. The 1970, 1980 values are from KF2. The 2000 figure is from the internet.

Total fertility rates (1880-2000): From 1880 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1920-2000): The 1920 and 1930 values are from M. The 1940 value is from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Korea:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1900-2000): The 1900-1930 figures, at the decadal frequency, are from Mn. All figures, 1940-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1940-2000): All figures are at the decadal frequency, and all are from BDT.

Life expectation (1950-2000): The even year values (decadal) prior to 1990 are from KF2. The 1985 value also comes from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation values are unavailable for Korea.

Total fertility rates (1950-2000): The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1950-2000): The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Netherlands:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870-2000): The 1820, 1850, 1870-1890 (decadal) values are from Mn. All figures, 1900-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1820-2000): All figures are at the decadal frequency. The 1820-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1900-1985): All values are at the quinquennial frequency. The 1900-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1850, 1875, 1900-2000): The 1900-1990 values are quinquennial. The 1850, 1875, 1900, 1910, 1925 and 1940 values are calculated from M. The 1905, 1915, 1920, 1930, 1935 and 1945 values are calculated from KF1. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840-1890 values are at the decadal frequency, and are from M. The 1900-2000 values are all at the quinquennial frequency. The 1900-1945 values are from KF1. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

New Zealand:

Population (1850-2000): All figures are at the decadal frequency and are from M.

Per capita income (1870-2000): The 1870 value comes from Mn. All figures, 1880-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1890-2000): All figures are at the decadal frequency. The 1890-2000 figures are from BDT.

Life expectation (1880-2000): All figures are at the decadal frequency. The 1820-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The values are at the quinquennial frequency. The 1950-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1910-2000): From 1910 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1860-2000): The 1860-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Norway:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1860, 1870-2000): The 1820, 1850 and 1870 values come from Mn. All figures, 1860 and 1880-2000, at the decadal frequency, are from BDT.

Age at labor force entry (1890-2000): All figures are at the decadal frequency. The 1890-2000 figures are from BDT.

Life expectation (1880-2000): From 1900 all figures are at the decadal frequency. The 1880-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The values are at the quinquennial frequency. The 1950-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1860-2000): From 1860 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Portugal:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1850, 1870, 1890-2000): The 1850, 1870 and 1890-1940 (decadal) values are from Mn. All figures, 1950-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1890-2000): All figures are at the decadal frequency. The 1890-2000 figures are from BDT.

Life expectation (1920-2000): All figures are at the decadal frequency. The 1920-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The values are at the quinquennial frequency. The 1950-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1890-2000): From 1890 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1910-2000): The 1910, 1920, 1930 and 1940 values are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Spain:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850, 1870, 1890-2000): The 1820, 1850, 1870, 1890 and 1900 values are from Mn. All figures, 1910-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1910-2000): All figures are at the decadal frequency. The 1910-2000 figures are from BDT.

Life expectation (1900-2000): All figures are at the decadal frequency. The 1920-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): The 1950, 1960 and 1965 values are from KF1. The 1970-1985 values, at the quinquennial frequency, are from KF2.

Total fertility rates (1860-2000): From 1860 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF2. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1860-2000): The 1860-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Sweden:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820, 1850-2000): The 1820 and 1850 values come from Mn. All figures, 1860-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1780-2000): All figures 1780-1990 are at the quinquennial frequency. The 1780-1960 figures are from KF1. The 1965-1990 values are from KF2. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1780-1985): All values are at the quinquennial frequency. The 1780-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1750-2000): The 1750, 1760 and 1770 values are at the decadal frequency, and are from M. The values from 1780-1990 are at the quinquennial frequency. The values for the years 1780-1795, and the odd years 1905-1945 are calculated from KF1. The even years from 1800 to 1940 are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1780-2000): All values are at the quinquennial frequency. The 1780-1945 values are from KF1. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Switzerland:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1870, 1890-2000): The 1870, 1890 and 1900 values come from Mn. All figures, 1910-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1890-2000): All figures are at the decadal frequency. The 1890-2000 figures are from BDT.

Life expectation (1930-2000): All figures are at the decadal frequency. The 1930-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1950-1985): All figures are at the quinquennial frequency. The 1950-1965 values are from KF1. The 1970-1985 values are from KF2.

Total fertility rates (1870-2000): From 1870 to 1940 the figures are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF. The 2000 figure is from *HDR 2000*.

Infant mortality rates (1870-2000): The 1870-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

United Kingdom:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1820-2000): The 1820 value comes from Mn. All figures, 1830-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1890-2000): All figures are at the decadal frequency. The 1890-2000 figures are from BDT.

Life expectation (1850-2000): All figures are at the decadal frequency. The 1930-1990 figures are from K-O. The 2000 figure is from *HDR 2000*.

Conditional life expectation (1860-2000): The 1860-1940 values are at the decadal frequency. The 1945-1985 values are at the quinquennial frequency. The 1860-1965 values are from KF1. The 1970-1985 values are from KF2. The 2000 figure comes from the internet.

Total fertility rates (1600-2000): The 1600, 1640, 1680, 1720, 1760, 1800 1830 values are from WS. The values from 1840-1940 are at the decadal frequency, and are calculated from M. The 1950-1990 values are at the quinquennial frequency, and are from KF. The

2000 figure is from *HDR 2000*.

Infant mortality rates (1840-2000): The 1840 and 1850 values are from M. The 1860-1940 values are at the decadal frequency. The 1860-1940 values are from KF1. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

USA:

Population (1600, 1800, 1810-2000): The first two figures are from MJ. The rest, at the decadal frequency, are from M.

Per capita income (1790-2000): All figures are at the decadal frequency, and all are from BDT.

Age at labor force entry (1880-2000): All figures are at the decadal frequency. The 1880-2000 figures are from BDT.

Life expectation (1850-2000): All figures are at the decadal frequency, and are from various issues of the *Statistical Abstract of the United States* and *Historical Statistics of the United States: Colonial Times to 1970*.

Conditional life expectation (1850-2000): All figures are at the decadal frequency. The 1850-1970 values from from the *Historical Statistics of the United States: Colonial Times to 1970*. The 1980, 1990 and 2000 values come from various issues of the *Statistical Abstract of the United States*.

Total fertility rates (1840-2000): All figures are at the decadal frequency, and are from various issues of the *Statistical Abstract of the United States* and *Historical Statistics of the United States: Colonial Times to 1970*.

Infant mortality rates (1850-2000): The 1850-1950 values are at the decadal frequency. The 1950-2000 values are at the quinquennial frequency. The 1850-1970 values are from *Historical Statistics of the United States: Colonial Times to 1970*. The 1980, 1985, 1990, 1995 and 2000 values come from various issues of *The Statistical Abstract of the United States*.

Latin America (Argentina, Brazil, Chile, Mexico):

Population (1600, 1800, 1840, 1880, 1900-2000): The first two figures are from MJ.

The figures from 1840 to 2000 are from M. The values from 1900-2000 are at the decadal frequency.

Per capita income (1870, 1890-2000): The 1870, 1890 and 1900 values come from Mn. All figures, 1910-2000, are at the decadal frequency, and all are from BDT. These are population weighted averages.

Age at labor force entry (1920-2000): All figures are at the decadal frequency, and all are from BDT. These are population weighted averages.

Life expectation (1950-2000): The 1950-1990 figures are at the decadal frequency, and all are from KF. The 2000 figure comes from *HDR 2000*. These are population weighted averages.

Conditional life expectation (1955-1970): All values are at the quinquennial frequency. The 1955 value is for Mexico, from KF1. The 1960 and 1965 values are from KF1. They are the weighted averages of Argentina, Chile and Mexico (1960) and Chile and Mexico (1965). The 1970 value is the weighted average of Argentina, Chile and Mexico and comes from KF2.

Total fertility rates (1950-2000): The 1950-1990 figures are at the decadal frequency, and all are from KF. The 2000 figure is from *HDR 2000*. These are population weighted averages.

Infant mortality rates (1900-2000): The 1900-1940 values are at the decadal frequency. The 1900 value is a weighted average of Chile and Mexico and comes from M. The 1910-1940 values, at the decadal frequency, are weighted averages of Argentina, Chile and Mexico, and come from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR;* these are population weighted averages.

China:

Population (1400, 1600, 1800-2000): All figures from 1800-1920 are at the 40 year periodicity. All values from 1400-1920 are from MJ. The 1930-2000 values are at the decadal frequency from Kremer.

Per capita income (1820, 1870, 1890-2000): The 1820, 1870, 1890-1910 and 1940 values come from Mn. All figures, 1930, 1950-2000 (decadal), and all are from BDT.

Age at labor force entry (1930-2000): All figures are at the decadal frequency, and all are from BDT.

Life expectation (1930-2000): The 1930-1990 figures are at the decadal frequency, and all are from K-O. The 2000 figure comes from *HDR 2000*.

Conditional life expectation (1950, 1980): The first value comes from KF1, and the latter value comes from KF2.

Total fertility rates (1950-2000): The 1950-1990 figures are at the decadal frequency, and all are from KF. The 2000 figure comes from *HDR 2000*.

Infant mortality rates (1950-2000): The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

India:

Population (1400, 1600, 1640, 1680, 1760-2000): All figures from 1760-1920 are at the 40 year periodicity. All values from 1400-1920 are from MJ. The 1930-2000 values are at the decadal frequency from Kremer.

Per capita income (1820, 1850, 1870, 1890, 1900-2000): The 1820, 1850, 1870, 1890 and 1940 values are from Mn. All figures, 1900-1930 and 1950-2000, are at the decadal frequency, and all are from BDT.

Age at labor force entry (1920-2000): All figures are at the decadal frequency, except for the missing value in 1940, and all are from BDT.

Life expectation (1900-2000): The 1900-1990 figures are at the decadal frequency, and all are from K-O. The 2000 figure comes from *HDR 2000*.

Conditional life expectation (1960): The value comes from KF1.

Total fertility rates (1950-2000): All figures are at the decadal frequency, and are from KF. The 2000 figure comes from *HDR 2000*.

Infant mortality rates (1910-2000): The 1910-1940 values are at the decadal frequency, and are from M. The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*.

Rest of World:

Population (1600, 1800, 1900-2000): The first two figures are from MJ. The remaining figures are at the decadal frequency and are from the subtraction of all previous country and region values from world population figures in Kremer.

Per capita income (1980, 1990, 2000): The three values are taken from various WDR, evaluated at PPP, and do not include China and India.

Age at labor force entry (1910-2000): All figures are at the decadal frequency, and all are from BDT. They are constructed from the population weighted averages of age for each country in the world except for the rich 22, Latin America, China and India.

Life expectation (1950-2000): All figures are at the decadal frequency. All except 2000 are from KF. The 2000 value comes from *WDR 2000/2001*.

Total fertility rates (1970-2000): All figures are at the decadal frequency. All are from *WDR 2000/2001*.

Infant mortality rates (1950-2000): The 1950-2000 values are at the quinquennial frequency. The 1950-1985 values are from KF2. The 1990, 1995 and 2000 values come from various issues of *WDR* and *HDR*. These are values for the rest of the world without the rich countries, Latin America, China and India.

Age at labor force entry (1960-2000): All figures are at the decadal frequency, and are taken from *WDR 2000/2001*. They are from enrollment rates in the rest of the world relative to China, India, Latin America.

H. YOUNG ADULT MORTALITY SHOCKS

The following four graphs present the values of the young adult mortality shocks, φ, relative to the deterministic portion of the mortality function, in each region.

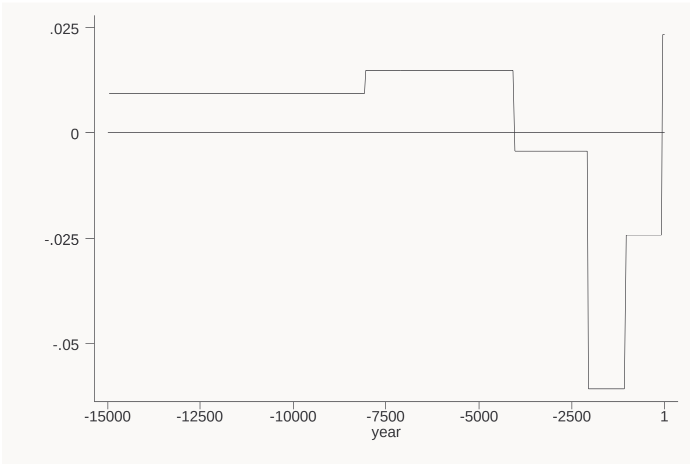


Fig. 20. B.C. Relative mortality shocks: rich region

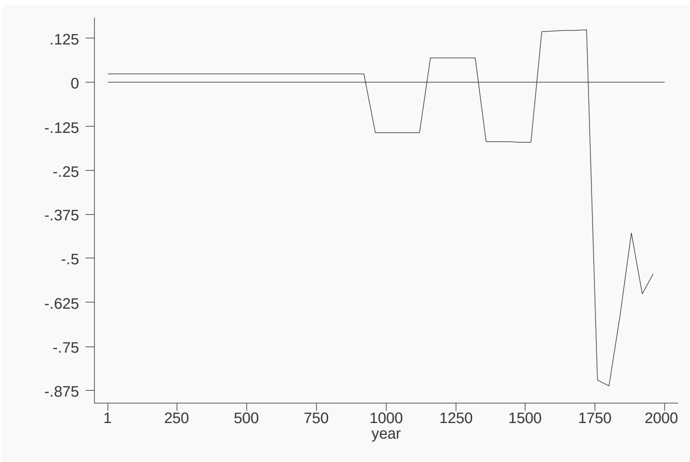


Fig. 21. A.D. Relative mortality shocks: rich region

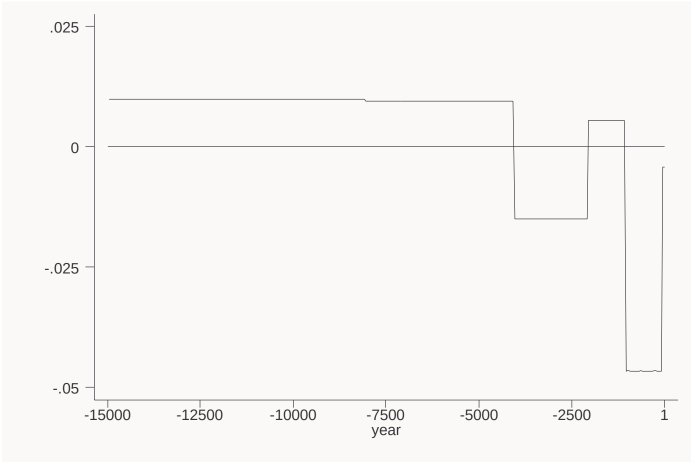


Fig. 22. B.C. Relative mortality shocks: poor region

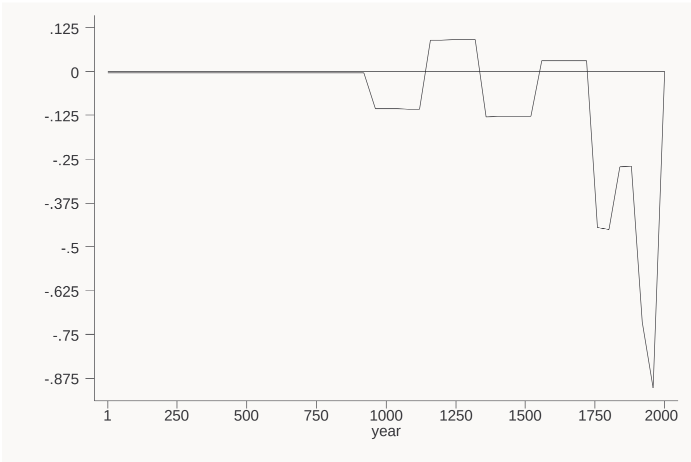


Fig. 23. A.D. Relative mortality shocks: poor region