

Mortality and Early Growth in England, France, and Sweden

Nils-Petter Lagerlöf*

December 17, 2002

Abstract:

We set up an open-economy, three-country version of the endogenous-mortality model of Lagerlöf (forthcoming in the *International Economic Review*). The model is calibrated to pre-industrial mortality data from England, France and Sweden. Fitting parameters to match observed rates of correlation in mortality rates, the model can also account for: (1) differences in the volatility of mortality rates; and (2) differences in the timing of the industrial revolution.

*Department of Economics, Concordia University, 1455 de Maisonneuve Blvd. W., H3G 1M8 Montreal QC, Canada, E-mail: nippe@alcor.concordia.ca. Earlier papers in this project have benefited from comments from Debasis Bandyopadhyay, Bill Cardak, Alexia Fürnkranz-Prskawetz, Paul Klein, Tomas Kögel, Johan Lagerlöf, Greg LeBlanc, Hans Lundström, Jim McIntosh, Olivier Morand, Rachel Ngai, Mike Sadler, Avi Simhon, and participants at a seminar at the University of Melbourne; the Midwest Macro Meetings 2000 in Iowa; a workshop at the Max-Planck Institute for Demographic Research in Rostock, Germany; the SED Meetings 2000 in Costa Rica; the Econometric Society World Meetings 2000 in Seattle; and a workshop at Harvard University financed by the Swedish Institute for Future Studies. This particular paper owes a lot to comments from Gordon Fisher, Susumu Imai, Toshihiko Mukuyama, Pierre Ross, and two anonymous referees. All remaining errors are mine.

1 Introduction

This paper explains patterns of volatility and correlation in pre-industrial mortality rates in England, Sweden and France, as well as the timing of the industrial revolution across these countries. We use a growth model where the mortality rate is endogenous, but also subject to exogenous shocks. Whereas the distribution of these shocks does not change over time, the way an economy reacts to them does. The central assumptions are the following: The effects of a shock are (1) more severe if population density is high (capturing e.g. that diseases then spread more easily)¹; and (2) less severe if the human capital stock is large (capturing the mortality reducing effects of e.g. medical knowledge). We also allow population and human capital to be connected via a scale effect: productivity in human capital production is higher in more densely populated economies, where ideas spread more easily.²

This theory builds on recent work by Lagerlöf (2003). The basic idea is that an industrial revolution is the outcome of a set of favorable mortality shocks which allow population to expand. This raises human capital productivity and generates a quantity-quality shift in children, which lowers birth rates and spurs faster growth in human capital: an industrial revolution and a demographic transition.

Whereas Lagerlöf (2003) considers only one economy (or, equivalently, several isolated economies), here we allow for several economies which are partly integrated. Thus mortality depends not only on domestic shocks, human capital, and population, but also on that of other countries.³ For each country pair there is a parameter capturing their degree of integration. If this param-

¹This is consistent with the fact that pre-industrial death rates were higher in cities than rural areas (Kunitz 1983). See also Diamond (1999, Ch. 11).

²This is consistent with the results from Glaeser and Maré (2001), who find that densely populated areas (cities) have an advantage in human capital accumulation.

³The idea that diseases and other mortality shocks can spread between countries is very plausible. The Black Death spread from Caffa in the Crimea in 1346 to Scandinavia in 1350 (McNeill 1998, pp. 177-178). It is also likely that England had low transportation costs to France and the Netherlands already in the middle ages (see Clarke 2001, p. 65).

eter is zero for all country pairs, each country is autonomous; if the parameter equals one for all country pairs, they behave as if they were one and the same economy.⁴

We calibrate a three-country version of this model by setting the interaction parameters to roughly fit the simulated correlation in mortality rates to that in data from pre-industrial England, France, and Sweden. In the data, English and French mortality is most closely correlated; Sweden is less correlated with both of them, but slightly more correlated with England than with France. This is not too surprising, considering Sweden's geographical periphery.

After calibrating the model to fit differences in correlation across countries, we find that the model also generates a pattern of volatility in death rates which fits well with data: England's simulated death rate is more stable than that of France, which in turn is more stable than that of Sweden. What drives this result is the shock-spreading effect of integration. If two countries are fully integrated, they function as one economy receiving the average of the two countries' shocks.

However, the most simple version of the model cannot account for observed differences in the timing of the industrial revolution. The reason is that, if all countries are otherwise identical, the country with more volatile death rates should industrialize first, since it faces a higher probability of receiving a set of favorable shocks. Thus, the model seems to suggest that Sweden should industrialize first, and England last. However, we can account for what we see in data by letting England have an exogenous advantage in the production of human capital. This could constitute a feature of English society which is not captured by the model.⁵

Not too surprisingly, this modified setting can replicate England's lead in industrialization. What is less obvious, however, is that the model can now

⁴A more semantic difference compared to Lagerlöf (2003) is that we talk also about other shocks than epidemics, such as wars, revolutions, and bad harvests. In the data, mortality rose e.g. in the turmoil following the French Revolution.

⁵For instance, von Hayek (1960) argues that English common law was superior to French civil law. Also, being geographically close to the Atlantic may have helped Britain by inducing trade and thus the development of growth-enhancing institutions (cf. Acemoglu et al. 2003).

also account for the fact that France imported the industrial revolution earlier than Sweden. Once again, the integration parameter is crucial: France is more closely integrated with England (since we calibrated the model to fit the correlation in mortality), so the take-off in English human capital growth will reduce French mortality rates, thus generating a population expansion, which drives an increase in human-capital productivity, and pushes France onto the sustained growth path. Sweden, being more isolated, cannot import England's low death rate as effectively.

We contribute to an expanding literature on the escape from Malthusian stagnation to modern growth. Our ambition is to use one unified framework to explain many facts. This approach follows e.g. Galor and Weil (1999, 2000), Galor and Moav (2002), and Galor and Mountford (2003).⁶ As in Lagerlöf (2003), our paper differs from these in the stochastic timing of the industrial revolution, the endogeneity of mortality, and the role played by mortality shocks.⁷ The major contribution here, compared to Lagerlöf (2003), lies in the combination of an open-economy setting and a unified framework. This enables us to analyze a potential mechanism through which industrialization diffuses from one economy to others.⁸

The remainder of this paper is organized as follows. Section 2 presents the data. The model is introduced in Section 3, first in the single-economy setting, and then when there are many economies. Section 4 derives the quantitative results, and Section 5 ends with a concluding discussion.

⁶Other contributors to this literature include Jones (2001), Kögel and Prskawetz (2001), Tamura (2002a,b), Hansen and Prescott (2002), and Lucas (2002, Ch. 5) .

⁷Related growth models with endogenous mortality include Jones (2001), Kalemli-Ozcan (2003a,b), Kalemli-Ozcan et al. (2002), and Tamura (2002b). Different from our setting, Kalemli-Ozcan and Tamura analyze how falling mortality reduces the precautionary demand for children.

⁸There is a large literature on why some countries industrialize later than others. In our model the diffusion works via the mortality rate, but we could think of different mechanisms; see e.g. Tamura (1996) and Lucas (2002, Ch. 4). Empirical work by Acemoglu et al. (2001) study the importance of mortality among European settlers for migration and the diffusion of European institutions.

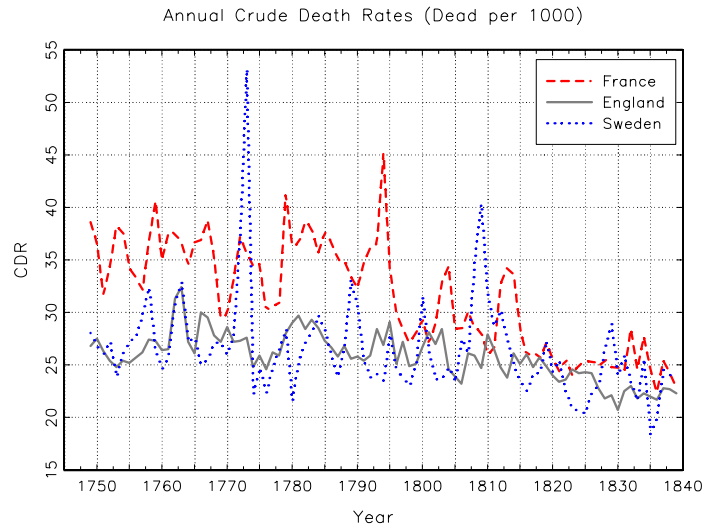


Figure 1: Mortality rates 1749-1839.

2 The Facts

2.1 Mortality rates

Figure 1 shows the mortality rates for England, France, and Sweden in 1749-1839, measured by the Crude Death Rate (CDR), i.e., the total number of deaths per 1000 people.⁹ 1749 is the earliest year for which we have comparable data from all countries. The period after 1839 is not reported in the sources we have available, but is not too interesting here, since we want to look at the Malthusian phase of development which preceded the period in which mortality started to fall. A reasonable definition of the Malthusian phase could be the period up to about 1800; after that both levels and volatility in mortality rates started to decline.

Figure 2 shows the variance in mortality rates over different 25-year periods

⁹The sources are: for England, Wrigley and Shofield (1981, Table A3.3); for France, INED (1977, *Tableau Annexe I*); for Sweden, Statistics Sweden (1999). Fogel (1997) provides an overview of several other studies using this data.

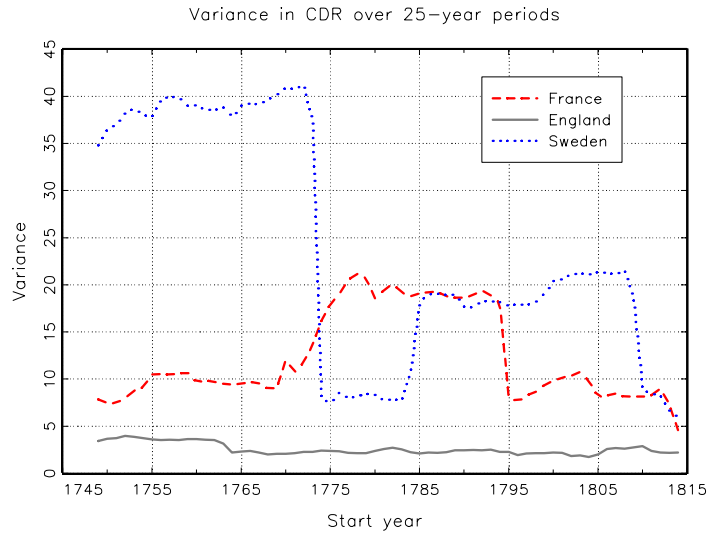


Figure 2: Variance in mortality rates over 25-year periods (without de-trending). The start year refers to the first year of each 25-year period.

1749-1814 (i.e., the value for 1749 refers to the variance over the period 1749 to 1773). Throughout, England had a much lower variance than both France and Sweden. We also note that the variance in Swedish and French mortality rates fluctuate a lot over time. This is driven by a couple of very large mortality peaks. For example, the big drop in Sweden’s variance for periods starting after 1773 was due to the spike in Swedish mortality rates that year (see Figure 1). Put another way: periods starting post 1773 do not include this spike and thus have much lower variance than earlier periods. Similarly, the temporary increase in the variance in French mortality rates in periods starting after 1770 is due to the French Revolution in 1789 and “The Great Terror” under Robespierre, with mortality peaking in 1794.

From Figure 2 it seems that Sweden mostly had more volatile death rates than France. This in particular holds for the Malthusian phase, say before 1800 (i.e., 25-year periods starting before 1776). The same picture emerges if we

<i>Correlation coefficients</i>				
	England	France	Sweden	<i>Variance</i>
England	1	-	-	2.9
France	0.34	1	-	10.4
Sweden	0.18	0.08	1	19.1

Table 1: Correlation and variance in mortality after linear de-trending.

de-trend the series and look at the variance for the whole period. As shown in Table 1, Sweden has the highest variance and England the lowest; France lies in between.

Finally, the correlation between the mortality rates across the three countries is shown in Figure 3. The correlation coefficient is calculated for 25-year periods starting with the year indicated. As seen, the correlation between each pair of the three countries fluctuates a lot over time, and all countries seem to be less correlated with each other around the time of the French Revolution.¹⁰

Again, if we focus on the era up to 1775 the correlation between England and France was clearly the highest, at about 0.5. Sweden was much less correlated with both France and England, which is not surprising considering Sweden's geographical periphery. For most periods, it seems that Sweden was slightly more correlated with England than with France. This also holds if we look at the correlation matrix in Table 1, where the correlation coefficients refer to the whole period, after linear de-trending.

2.2 The timing of the industrial revolution

Figure 4 shows the levels of GDP per capita in England (actually the United Kingdom), France, and Sweden, for about 4 centuries starting 1500. (The 20th century had some unique shocks to GDP growth associated with the wars; here we are focusing on earlier periods.) Incomes per capita started to grow first

¹⁰Curiously, the very correlation coefficients seem to move in tandem, so that the degree of correlation across one pair of countries seems highly correlated with the other pairs.

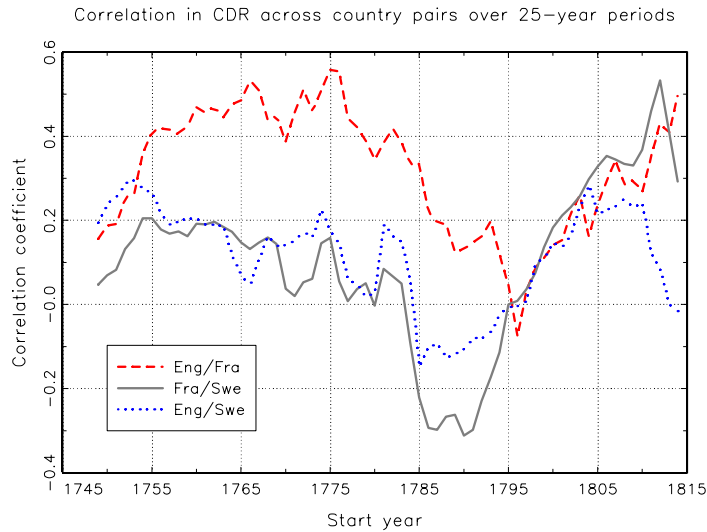


Figure 3: The correlation between mortality rates over 25-year periods. The start year refers to the first year of each 25-year period.

in England. France followed with a slightly shorter lag than Sweden. The timing difference could be about a century, in the sense that it took until 1820 for France and Sweden to reach about the same level of GDP per capita as England had reached by 1700. This amounts to about 4 generations in terms of an overlapping-generations model.

3 The model

3.1 A single economy

Consider first the model set up by Lagerlöf (2003), where there is only one economy (or many isolated economies). Agents live in childhood and as adults. Children consume nothing, so period- t output (Y_t) equals adult consumption (C_t), as given by

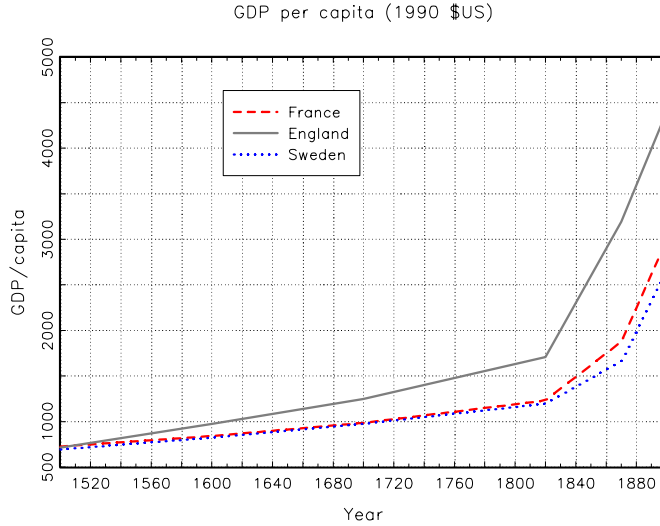


Figure 4: Levels of income per capita. Source: Maddison (2001, Table B-21).

$$Y_t = [1 - (v + h_t)B_t](L + H_t) = C_t, \quad (1)$$

where $L + H_t$ denotes productivity of a unit of time. Nature equips every agent with L units of skills, whereas H_t measures a component resulting from parental investment, referred to as human capital.

B_t denotes the number of children, and $v + h_t$ the time spent on each child, where v is a fixed time cost and h_t denotes education time (which is a control variable to the parent). Each parent has a unit time endowment, so time input in the consumption goods sector is $1 - (v + h_t)B_t$.

Out of the B_t born children, a fraction T_t survive to adult age. Let P_t denote the (adult) population size in period t , which also measures population density since land size is fixed. The survival rate is an increasing function of the ratio of human capital over population (H_t/P_t) and take this simple parametric form:

$$T_t = T(H_t/P_t, \omega_t) = \frac{H_t/P_t}{\omega_t + H_t/P_t}, \quad (2)$$

where ω_t denotes the period- t mortality shock, which is log-normally distributed, and thus always positive, implying that the survival rate lies between 0 and 1:

$$\ln(\omega_t) \sim N(\mu, \sigma^2). \quad (3)$$

Human capital is produced using

$$H_{t+1} = A(P_t) [L + H_t] (\rho v + h_t), \quad (4)$$

where $\rho < 1$ (capturing that education time is more productive than “nursing” time in building human capital). The scale effect in human capital production is captured by $A'(P_t) > 0$. We specify $A(P_t)$ as:

$$A(P_t) = A^* - \tilde{A} + \tilde{A} \left(\frac{P_t}{\eta + P_t} \right) = A^* - \tilde{A} \left(\frac{\eta}{\eta + P_t} \right), \quad (5)$$

where $A^* > \tilde{A}$, and $\eta > 0$. This functional form ensures that increasing population density does not raise human-capital productivity indefinitely, but only up to the level A^* , and that zero population implies positive human-capital productivity (since $A^* - \tilde{A} > 0$).

3.1.1 Preferences

An adult agent active in period t (referred to as agent t) maximizes a utility function given by

$$U_t = \ln(C_t) + \alpha \ln(B_t T_t) + \alpha \delta \ln(L + H_{t+1}) \quad (6)$$

subject to (1) and (4). We assume that $\delta \in (\rho, 1)$ (see below), and that $\alpha > 0$.

The first-order condition for the number of births, B_t , gives:

$$B_t = \left(\frac{\alpha}{1 + \alpha} \right) \frac{1}{v + h_t}. \quad (7)$$

The first-order condition for education time, h_t , gives:

$$h_t = \begin{cases} \frac{1}{1-\delta} \left[v(\delta - \rho) - \frac{L}{A(P_t)(L+H_t)} \right] & \text{if } P_t > \Gamma(H_t) \\ 0 & \text{if } P_t \leq \Gamma(H_t) \end{cases}, \quad (8)$$

where $A(P_t)$ is given in (5), and $\Gamma(H_t) = \eta \left(\frac{\tilde{A}}{A^* - \frac{L}{v(\delta-\rho)(L+H_t)}} - 1 \right)$. The two cases in (8) follow from the non-negativity constraint on h_t . Notably, whether h_t is operative (not constrained to zero), or not, depends on the levels of H_t and P_t .

The important feature of the model is the co-existence of two types of equilibria. First of all, there is a Malthusian steady state, where h_t is constrained to zero and birth rates thus high. Since parents invest little in their children, human capital is low and mortality high. This keeps population stationary in levels, but at the same time highly volatile, since a low human capital stock makes the economy vulnerable to mortality shocks.

There also exists a sustained growth path, where h_t is operative, and human capital and population both exhibit sustained growth, but human capital grows faster. Thus, H_t/P_t approaches infinity, implying that the effect of the mortality shocks becomes negligible, and the survival rate goes to 100%.

An economy can transit from a Malthusian steady state to sustained growth by experiencing a series of sufficiently mild shocks. This leads to lower mortality and rising population growth. Via the scale effect on human capital production this raises human capital productivity and induces a quality-quantity shift at the point in time when the ($h_t \geq 0$)-constraint stops to be binding.

3.2 Many economies

Next we consider several economies, or countries, interacting with each other. The only difference is that the death rate in each country now depends not only

on domestic – but also foreign – shocks and state variables. Let $k_{ij} \in [0, 1]$ measure the degree of “integration” between countries i and j , and let there be N countries, indexed by the set $\{1, 2, \dots, N\}$. Analogous to (2) we now let the death rate for country i in period t be written as

$$T_{i,t} = \frac{H_{i,t} + \sum_{j \neq i}^{N-1} k_{ij} H_{j,t}}{\omega_{i,t} P_{i,t} + \sum_{j \neq i}^{N-1} k_{ij} \omega_{j,t} P_{j,t} + \left\{ H_{i,t} + \sum_{j \neq i}^{N-1} k_{ij} H_{j,t} \right\}}, \quad (9)$$

where $\omega_{j,t}$ is the mortality shock to country j , and $H_{j,t}$ and $P_{j,t}$ now denote human capital and population in country j . These shocks are independent across countries and over time.

Different from the case in (2) mortality now depends on non-domestic variables. First of all, through the interaction parameter k_{ij} , the human capital stock in country j tends to mitigate the effect of a mortality shock in country i . This could capture medical knowledge, plants, or food imported from neighboring countries, or more direct medical assistance.

The interaction effect also implies that mortality shocks in country j raise mortality in country i , and more so if country j has a large population. This could capture the facilitated spread of diseases between regions which are more densely populated. The Black Death resulted from increased interaction across different Eurasian regions, when larger densities of human (and rat) populations facilitated the spread of plague germs. Also, those regions in Europe which were spared from the Black Death were often geographically, or otherwise, isolated. (See McNeill 1998, Ch. 4.)

3.2.1 Implications

Just as in the one-country case, given identical parameters across countries, we have both a growth path on which human capital in all countries grow at an identical sustained rate, and a non-growing stationary state with volatile death rates. When one country’s human capital starts growing it will pull down the death rates of other countries, and thus “export” its population expansion and

industrial revolution.

Integration here amounts to spreading mortality shocks across countries. In the extreme case when all countries are fully integrated the model boils down the one-country setting, but with each country receiving the *average* of all countries' shocks.¹¹ Integration thus amounts to the opposite of a mean-preserving spread. This is consistent with the data discussed earlier: More isolated countries, like Sweden, had more volatile death rates.

Moreover, since the industrial revolution in this model is driven by a series of mild shocks (which expand population and thus raise human capital productivity) a *small* variance in death rates tends to generate *late* industrialization. This may seem counter-intuitive, but recall that shocks here can be both positive and negative, i.e., both reduce and raise mortality. A rise in mortality can reduce population, but population eventually adjusts back to its stationary Malthusian level. A fall in mortality, by contrast, can lead to a population expansion which – through the scale effect in human capital production – may push the economy onto sustained growth for ever. In short, 10 bad shocks followed by 10 good may bring an industrial revolution, whereas 20 average shocks may not. Therefore – *ceteris paribus* – a more isolated country, with more volatile death rates, would tend to industrialize sooner, since a sequence of sufficiently favorable shocks would arrive sooner. In that sense, our model would predict that Sweden should industrialize first, which is clearly not the case.

On the other hand, given that one “leading” country, like England, starts to

¹¹To see this, set all $k_{ij} = 1$, and let initial human capital and population, H_0 and P_0 , be identical across countries. That is, $H_{i,t} + \sum_{j \neq i}^{N-1} k_{ij} H_{j,t} = NH_0$ and similarly for population. The period-0 survival rate in country i , $T_{i,0}$, is then also identical for all countries, and can be written

$$T_0 = \frac{NH_0}{P_0 \sum_{j=1}^N \omega_{j,t} + NH_0} = \frac{H_0/P_0}{\left(\frac{1}{N}\right) \left(\sum_{j=1}^N \omega_{j,t}\right) + H_0/P_0}.$$

Thus, each intergrated economy behaves like an isolated economy receiving the average shock. Note also that since death rates are the same in period 0, so is next period's population and human capital stocks, so that all countries stay identical over time.

industrialize – e.g. due to exogenously given favorable institutions – a country which is more integrated with England will “import” lower death rates, thus generating its own population expansion and industrial revolution. More precisely, if we stack the cards so that England is more likely to industrialize first, we should see France follow with a slightly shorter lag than Sweden. This is consistent with data. In the calibration below we are capturing this by letting England’s productivity in human capital production be higher than that of France and Sweden.

4 Quantitative analysis

The next step is to calibrate and simulate the model. Since every run of the economy has a stochastic outcome, we do a Monte Carlo simulation, i.e., we run the model until the industrial revolution arrives in all countries, and repeat the exercise 10,000 times.

One challenge is to find parameter values which can both ensure the type of multiplicity of growth paths the model serves to generate, and give plausible values for the endogenous growth rates. Most parameter values are chosen as in Lagerlöf (2003) where the growth rate of per-capita income on the balanced growth path is calibrated to 2.6% annually, the population growth rate to 0.5% annually, and the birth rate in the Malthusian Regime (i.e., where $h_t = 0$) to 3% annually. Each period corresponds to 25 years.¹²

We also have some new parameters compared to Lagerlöf (2003), namely the interaction parameters across the three countries – England, France, and Sweden – which we denote k_{EF} , k_{ES} , and k_{FS} (with obvious notation). Then we need to set a lower level of \tilde{A} for England; we choose to set it 5% lower than France and Sweden (i.e., $\tilde{A}^{\text{Eng}} = 0.95 \times \tilde{A}^{\text{Fra/Swe}}$). This means that England has a higher level of human capital productivity, $A(P_t)$, at any (finite) level of

¹²To make the model’s death rate fit with the Crude Death Rate in the data we first calculate the annual mortality rate as $1 - T_{i,t}^{1/25}$, and then multiply by 1000. Similarly, we compute the Crude Birth Rate as $1000 \times \{B_{i,t}^{1/25} - 1\}$.

Parameter	ρ	δ	α	v	L	A^*	η
Value	0.0046	0.4615	0.067	0.03	500	74.2	12
Parameter	$\tilde{A}^{\text{Fra/Swe}}$	\tilde{A}^{Eng}	k_{EF}	k_{ES}	k_{FS}	μ	σ^2
Value	55.7	52.9	0.23	0.04	0.01	-3.9	0.15

Table 2: Parameter values.

population, P_t [see (5)].¹³

Table 2 shows the full list of parameter values.

We have chosen the integration parameters (the k 's) so that the simulated correlation coefficients across country pairs are roughly in line with those in the data for the Malthusian phase, say up to 1775 (see Figure 3 again). The simulated correlation coefficients are shown in Table 3.

It is harder to fit the rates of variance in the model's mortality rate to data, but there are several reasons why this should not be a concern. Firstly, for France and Sweden the variance fluctuates a lot depending on what time period we look at (see Figure 2). Secondly, it is not obvious how one should interpret the annual mortality rate in the data, in terms of the mortality rate in the model, where each period corresponds to 25 years.¹⁴ Thirdly, the variance in English mortality had already started to decline by 1749 and the period shown in Figure 3 need not be representative of England's Malthusian phase.

The simulated rates of variance for France and Sweden are shown Table 3. The success here is in the ranking: Sweden's variance is higher than that of France, which is higher than that of England. This is clearly consistent with data.

Note also that the numbers shown in Table 3 represent the average over

¹³Note that we here let human capital productivity in each country depend only on domestic population, i.e., the scale effect is local.

¹⁴We set σ^2 a bit lower compared to Lagerlöf (2003), with the ambition to fit England's simulated variance closer to that in the data. We could get a better fit by setting σ^2 even lower, at the cost of delaying industrialization and extending the needed computation time.

<i>Correlation coefficients</i>				<i>Variance</i>
	England	France	Sweden	
England	1	-	-	7.93
France	0.48	1	-	8.33
Sweden	0.10	0.04	1	12.28

Table 3: Variance and correlation in mortality rates in the Monte Carlo simulation.

6000 runs, and hide a great deal over variation across runs. Figure 5 shows the histograms over simulated rates variance for the three countries, and Figure 6 shows a similar histogram for the correlation coefficients. As seen they vary a great deal across runs.

One test of the model then comes in terms of differences in timing of the industrial revolution. (We define the date for the industrial revolution as the last period in which $h_t = 0$.) This timing is stochastic. If all countries had the same exogenous parameters (except for k_{EF} , k_{ES} , and k_{FS}), Sweden would industrialize first on average, since its death rate is more volatile, due to its relative isolation (k_{ES} and k_{FS} are low). For the same reason, however, *if* luck brings the industrial revolution first to e.g. England, Sweden would be less able to import it than would France. Here we stack the cards so that England industrializes more often, by lowering its parameter \tilde{A} .

Trivially, this tends to make England industrialize earlier. The test, however, comes from comparing Sweden and France. In our simulations, the industrial revolution on average spreads to France sooner than to Sweden, since France is more closely integrated with England. This in turn reflects that we have calibrated the interaction parameter to fit the higher correlation in mortality rates between England and France.

On average, England’s lead over Sweden is a little more than a century (4.3 generations), and slightly less for France (4.0 generations). Again, these averages hide a great deal of variability across runs. Figure 7 shows the distribution

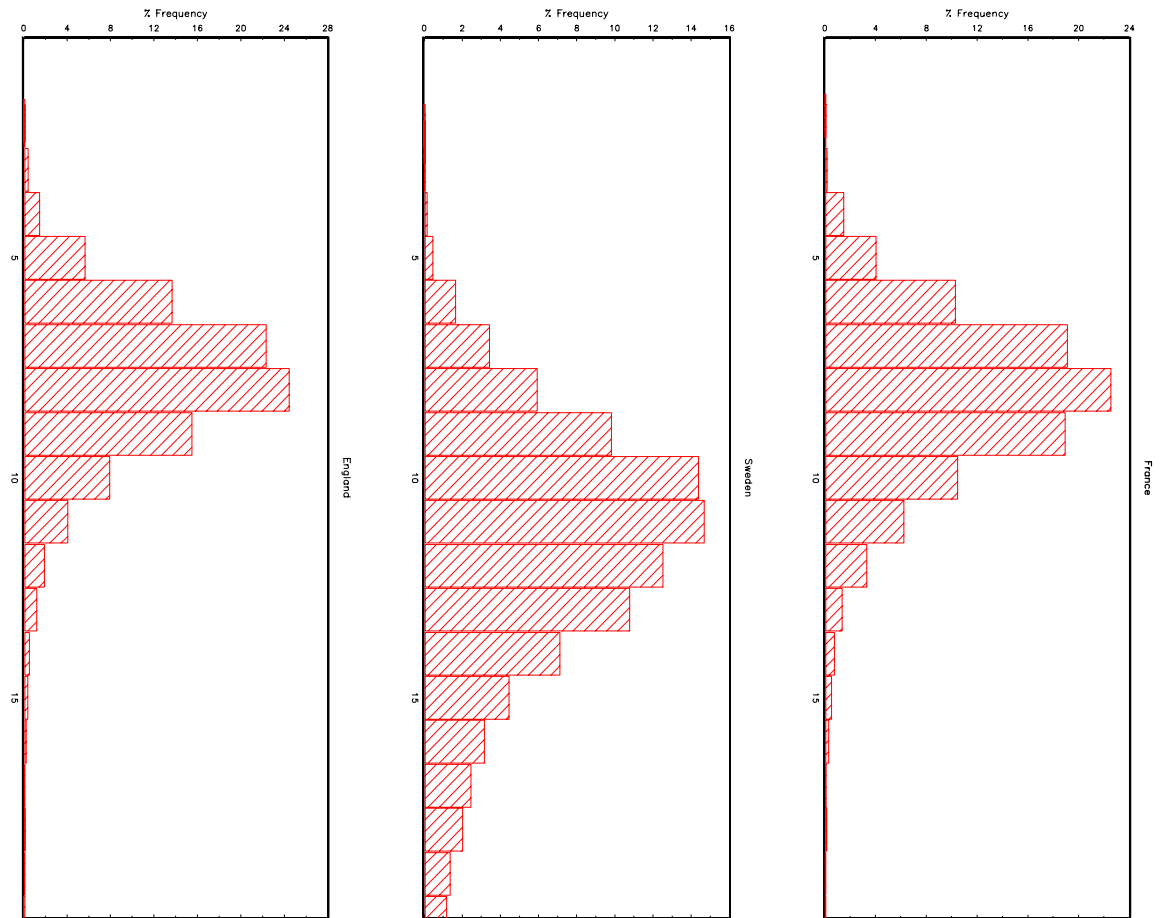


Figure 5: Histogram over rates of variance in the Monte Carlo simulation.

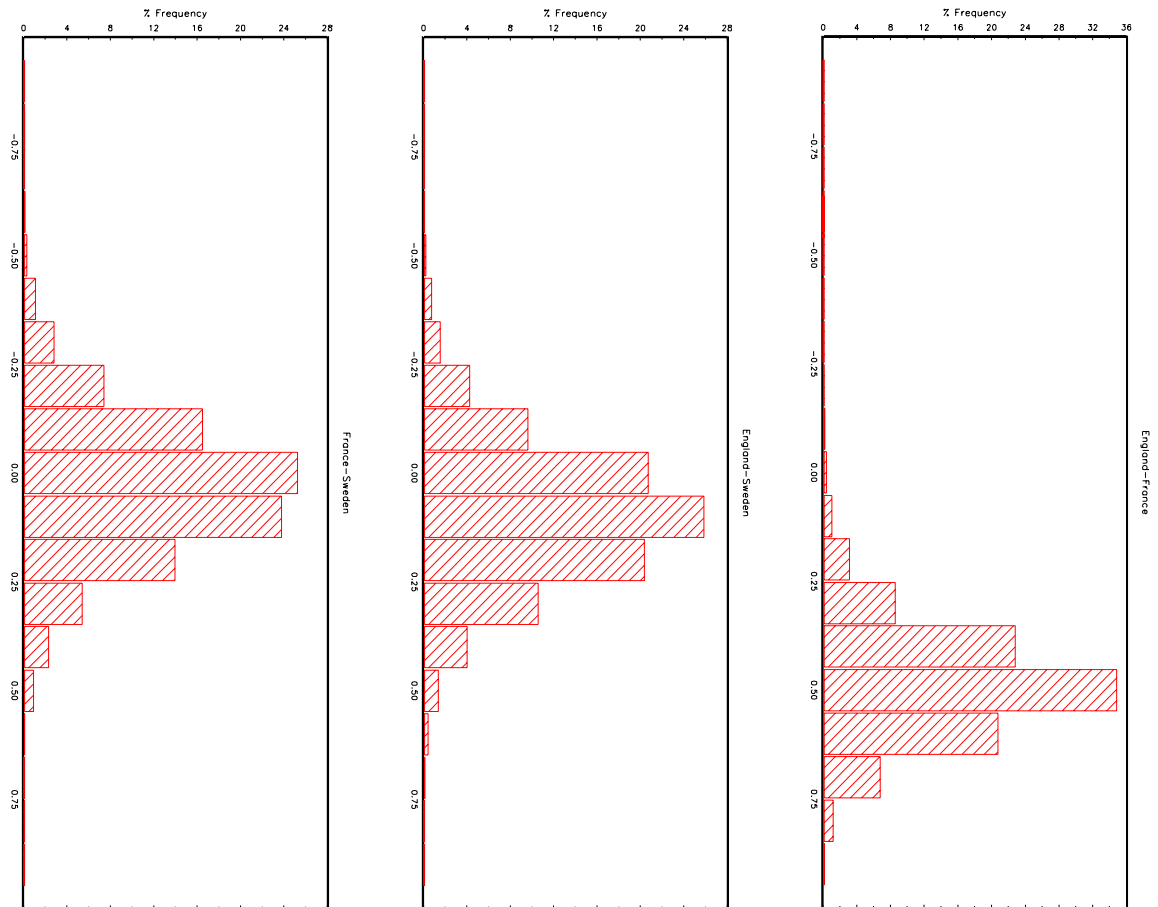


Figure 6: Histogram over rates of correlation in the Monte Carlo simulation.

of the number of generations by which England precedes Sweden and France in its industrialization. As seen, the distributions are twin-peaked. Negative numbers represent runs where Sweden or France, respectively, industrialize before England, and the peak in the negative region stems from the fact that less integrated regions have an inherit advantage in generating an industrial revolution, since they receive more extreme shocks. The larger peak, in the positive region, stems from England's higher human capital productivity.

4.1 One particular path

Figure 8 shows the paths of mortality, fertility, and population growth in the three countries for one particular run. We transform generations into years by letting each period correspond to 25 years and letting the industrial revolution arrive in 1750. The population growth rate rises as mortality declines. As long as education time is constrained to zero the fertility rate (here measured as the Crude Fertility Rate, i.e., the number of births per 1000 people) is unchanged [see (7)]. As population expands, and raises human-capital productivity, education time becomes operative, and births rates start to fall pulling population growth down.

The paths of per-capita income levels [as given by Y_t in (1)] for each country, are shown in Figure 9. In this run (but not all) per-capita income starts growing first in England, and then spreads first to France and later Sweden. This is consistent with the pattern in Figure 4.

5 Conclusions

Throughout human history epidemics, wars, and famines have shaped the growth path of population. Such shocks to mortality are the central theme in the model set up by Lagerlöf (2003), which can endogenously generate a long phase of stagnant population and living standards, followed by an industrial revolution and a demographic transition (the so-called Three Regimes).

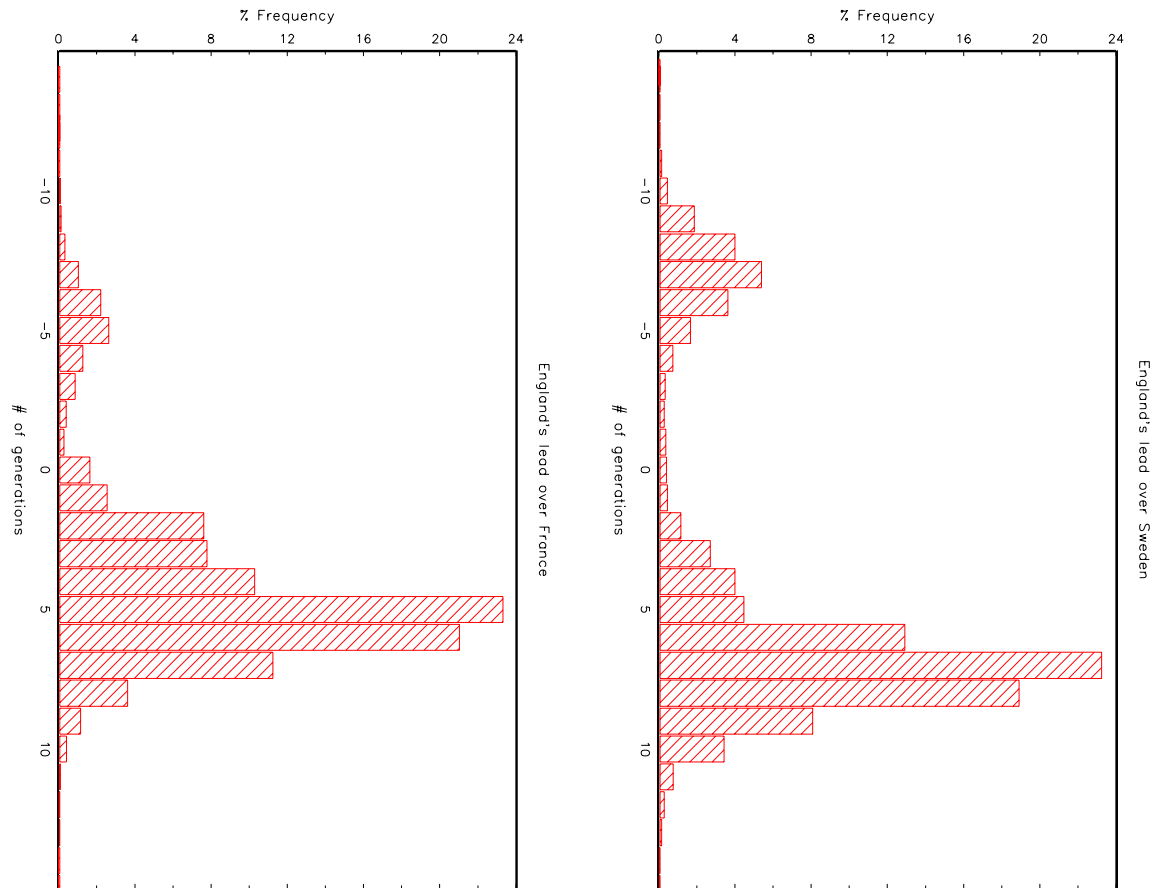


Figure 7: Histogram over gaps in the timing of the industrial revolution in the Monte Carlo simulation. (Negative numbers imply that England industrializes later.)

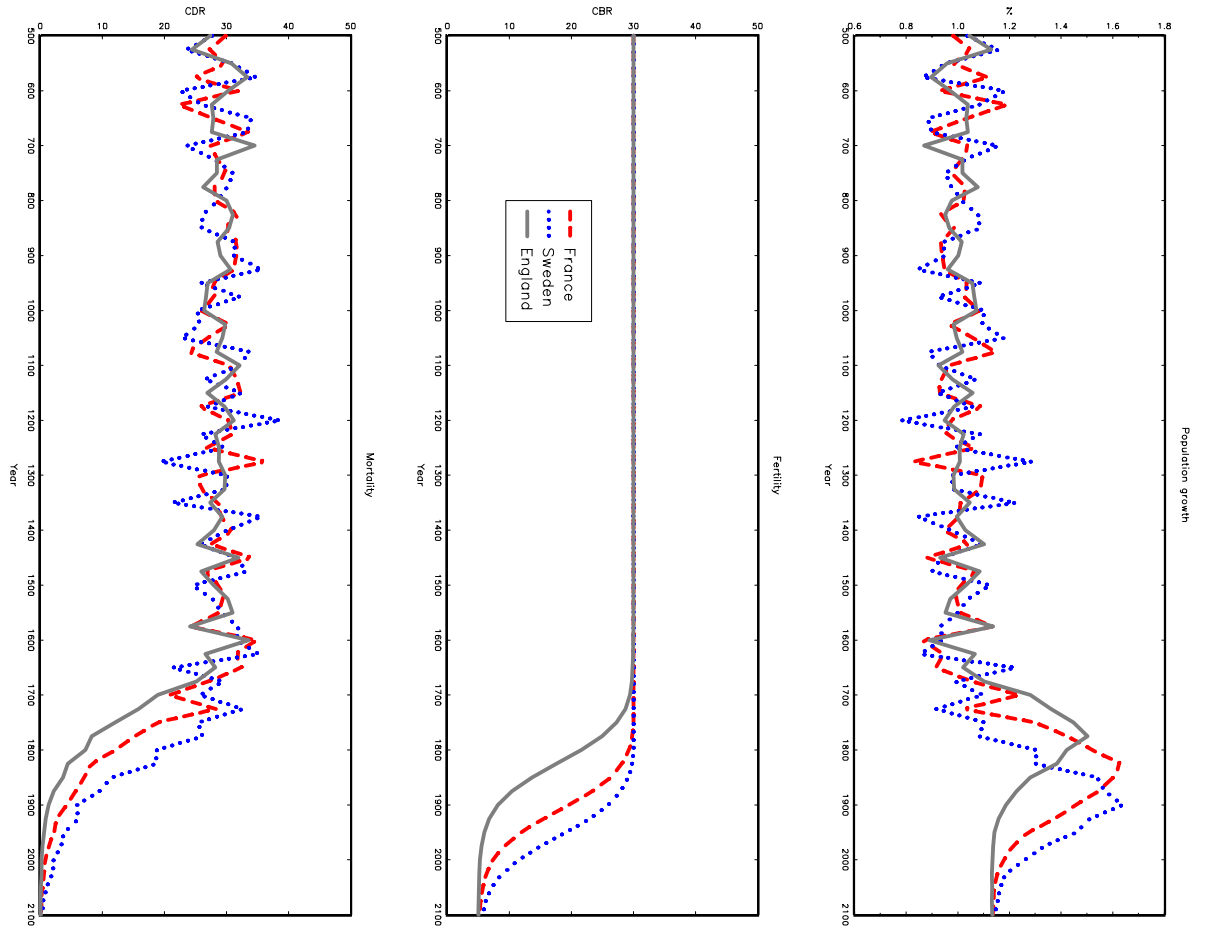


Figure 8: Population growth, birth, and death rates in one run.

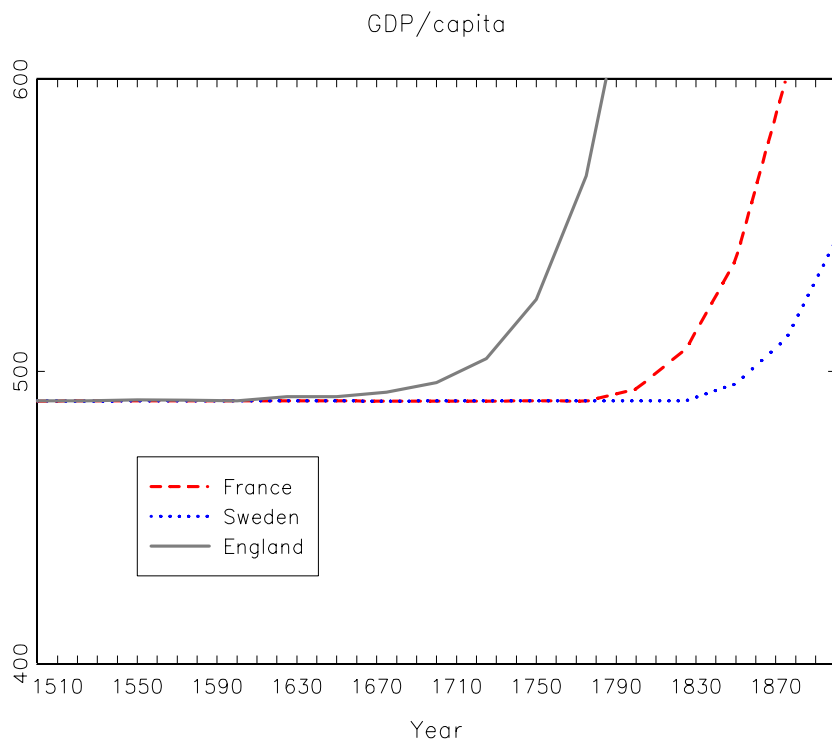


Figure 9: Income per capita, Y_t , in one run.

Here we extend that model to allow for several economies which are partially integrated. A shock to mortality in one economy affects mortality in all others. We calibrate a three-country version of the model to data from pre-industrial England, France, and Sweden, choosing parameter values to make the correlation across countries' mortality rates fit the correlation in annual death rates in the data. We then set exogenous parameters so that England is more likely to industrialize first, capturing some exogenous institutional advantage.

The model is able to replicate the following empirical observations:

(1) England had the least volatile death rate and Sweden the most volatile; France had something in between.

(2) The industrial revolution came to England first and spread to France before it came to Sweden.

The second result is less obvious than it may seem. Of course, England tends to industrialize first since we assume higher human-capital productivity there. The interesting result is that, consistent with data (see Figure 4), the industrial revolution diffuses to France sooner than to Sweden, since France is more closely integrated with England. This in turn reflects that we have calibrated the interaction parameter to fit the correlation in mortality rates between England and France.

Our results also give some insights about per-capita income gaps observed across countries today, and how and why the industrial revolution has diffused from one part of the world to another. In our model, human capital accumulation in the rich part of the world reduces death rates elsewhere. With lower mortality rates and expanding population, poor countries' human capital productivity increases, pushing them onto sustained growth. In recent history, this could capture things like inoculation campaigns in poor countries.

Moreover, in our model mortality shocks which hit when a country is just starting to industrialize can delay the take-off. The AIDS epidemic in many poor countries today could constitute such a shock, potentially delaying their industrialization by a number of generations, i.e., several centuries. Findings by Kalemli-Ozcan (2001) suggest that something akin to this may be happening

right now in Sub-Saharan Africa. She finds that countries which are affected worst by the AIDS epidemic have seen abruptions to their previous falls in fertility and their rising levels of schooling, and more so than countries which are less affected by the AIDS epidemic.

References

- [1] Acemoglu, D., S. Johnson, and J.A. Robinson, 2001, The colonial origins of comparative development: an empirical investigation, *American Economic Review* 91, 1369-1402.
- [2] — — —, 2003, The Rise of Europe: Atlantic trade, institutional change and economic growth, mimeo, MIT Entrepreneurship Center.
- [3] Clarke, G., 2001, The secret history of the industrial revolution, mimeo, University of California – Davis.
- [4] Diamond, J., 1999, *Guns, germs, and steel*, W.W. Norton & Company, New York.
- [5] Fogel, R.W., 1997, New findings on secular trends in nutrition and mortality: some implications for population theory, in: Rosenzweig, M.R., and O. Stark, *Handbook on population and family economics*, Elsevier Science B.V.
- [6] Galor, O., and O. Moav, 2002, Natural selection and the origin of economic growth, *Quarterly Journal of Economics* 117, 1133-1192.
- [7] Galor, O., and A. Mountford, 2003, Why are a third of people Indian or Chinese? Trade, industrialization, and demographic transition, mimeo, Brown University.
- [8] Galor, O., and D. Weil, 1999, From Malthusian stagnation to modern growth, *American Economic Review* 89, 150-154.

- [9] — — —, 2000, Population, technology, and growth: from the Malthusian regime to the demographic transition and beyond, *American Economic Review* 90, 806-828.
- [10] Glaeser, E.L., and D.C. Maré, 2001, Cities and skills, *Journal of Labor Economics* 19, 316-342.
- [11] Hansen, G.D., and E.C. Prescott, 1998, Malthus to Solow, *American Economic Review* 92, 1205-1217.
- [12] INED, 1977, Sixième rapport sur la situation démographique de la France, *Population* 32, 253-338.
- [13] Jones, C., 2001, Was the industrial revolution inevitable? Economic growth over the very long run, *Advances in Macroeconomics* 1, 1-43.
- [14] Kalemli-Ozcan, S., 2001, The effect of mortality on fertility and human capital investment: what do we learn from AIDS?, mimeo, University of Houston.
- [15] — — —, 2003a, Does mortality decline promote economic growth?, Forthcoming in the *Journal of Economic Growth*.
- [16] — — —, 2003b, A stochastic model of mortality, fertility, and human capital investment,” Forthcoming in the *Journal of Development Economics*.
- [17] Kalemli-Ozcan, S., H.E. Ryder and D.N. Weil, 2000, Mortality decline, human capital investment, and economic growth, *Journal of Development Economics* 62, 1-23.
- [18] Kunitz, S.J., 1983, Speculations on the European mortality decline, *Economic History Review* 36, 349-364.
- [19] Kögel, T., and A. Prskawetz, 2001, Agricultural productivity growth and escape from the Malthusian trap, *Journal of Economic Growth* 6, 337-357.

- [20] Lagerlöf, N.P., 2003, From Malthus to modern growth: can epidemics explain the three regimes?, Forthcoming in the *International Economic Review*.
- [21] Lucas, R.E., 2002, *Lectures on economic growth*, Harvard University Press.
- [22] Maddison, A., 2001, *The world economy – a millennial perspective*, Development Centre Studies, OECD.
- [23] McNeil, W.H., 1998, *Plagues and peoples*, Anchor press, Doublebay.
- [24] Statistics Sweden, 1999, *Population development in Sweden in a 250-year perspective*, Demografiska Rapport 1999:2.
- [25] Tamura, R., 1996, From decay to growth: a demographic transition to economic growth, *Journal of Economic Dynamics and Control* 20, 1237-1261.
- [26] — — —, 2002a, Human capital and economic development, *Journal of Economic Dynamics and Control* 27, 207-242.
- [27] — — —, 2002b, Human capital and economic development, mimeo, Clemson University.
- [28] von Hayek, F.A., 1960, *The constitution of liberty*, University of Chicago Press.
- [29] Wrigley, E.A., and R.S. Shofield, 1981, *The population history of England, 1541 – 1871: a reconstruction*, Harvard University Press, Cambridge, Massachusetts.