Swedish economic growth and education since 1800

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Abstract. The contribution of this paper is twofold. First, it builds and makes use of long-run data from Sweden on formal education that have never been used to date. Second, it provides a quantitative application of recent theoretical work on the link between demographic changes and economic growth through their effect on education. It concludes that changes in longevity may account for as much as 20% of the observed rise in education over the period from 1800–2000 via a horizon effect, but have little impact on income growth over the period. On the contrary, changes in population density and composition are central, mainly thanks to their effect on productivity. Most income growth over this period would not have materialized if demographic variables had stayed constant since 1800. JEL classification: J10, O41, I20, N33

Croissance économique et éducation en Suède depuis 1800. Ce mémoire construit et fait usage des données à long terme sur l'éducation formelle en Suède qui n'ont jamais été utilisées et fait usage d'applications de travaux théoriques récents sur les liens entre changements démographiques et croissance économique par le truchement de l'effet sur l'éducation. On conclut que les changements dans la longévité peuvent expliquer jusqu'à 20% de l'accroissement observé en éducation entre 1800 et 2000 à cause de l'effet d'horizon, mais que cela a peu d'effet sur la croissance du revenu au cours de la période. D'autre part, les changements dans la densité et la composition de la population ont une importance centrale, surtout à cause de leur effet sur la productivité. Le gros de la croissance dans le revenu ne se serait pas matérialisé si les variables démographiques étaient demeurées constantes depuis 1800.

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1. Introduction

The transition from stagnation to growth has been the subject of intensive research in the growth literature in recent years. Galor and Weil (2000) propose a unified theory of economic growth in which the inherent Malthusian interaction between technology and population accelerated the pace of technological progress through rising population density and ultimately brought about an industrial demand for human capital. Human capital formation and thus further technological progress triggered a demographic transition, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita.

Boucekkine, de la Croix, and Licandro (2002) argue that this picture should be completed to account for the specific effect of mortality on the incentive to accumulate human capital. They show in Boucekkine, de la Croix, and Licandro (2003) that the very first acceleration of growth can be related to early drops in adult mortality. In a recent paper, Boucekkine, de la Croix, and Peeters (2007) develop a quantitative theory that argues that the effect of population density on human capital formation prior to the Industrial Revolution was a major force in the process of industrialization. They provide foundations for the effect of population density on human capital formation in the transition from stagnation to growth. The increase in population density made the establishment of schools profitable, stimulating human capital formation (and thereby technological progress) and economic growth.

In this paper, these mechanisms relating income growth to demographic change are confronted with empirical data by calibrating an endogenous growth model on Swedish long-term time series of mortality, education, age structure, and per capita income. In our model, demographic variables are exogenous and influence income growth rates through human capital accumulation and productivity. In a first step, we use long-term data to calibrate the model so as to reproduce the take-off process and the rise in growth rates from stagnation prior to the 18th century to 2% growth in the 20th century. The main mechanisms at work are (a) rises in life expectancy that increase the incentive to get an education, which in turn has permanent effects on growth through a human capital externality and (b) the fact that there is a scale effect from the active population on total factor productivity and growth. In a second step we run different counter-factual scenarios to quantify the effect of demographic change on growth and education. We do not expect demographic changes to explain the whole pattern of development, but we use the model to measure the changes we need in the other variables to convincingly reproduce the growth of Sweden over 250 years. The conclusion is that demographic change does indeed play a significant role for long-run income growth. Total factor productivity is the most important intermediate factor between demography and income per capita. However, a full understanding of the growth process, especially the one leading to increasing levels of education, will require mechanisms in addition to those we have used in this paper.

The paper is organized as follows. Section 1 presents the Swedish demographic transition from 1750 to 2000 and new data on education of this period. Section 2 details the theoretical model, its main theoretical implications, its calibration to data, and its simulation under alternative demographic scenarios. Section 3 concludes.

2. Long-term trends in Sweden

In this section, we describe the main characteristics of long-term growth in Sweden, for both demographic variables and income growth. We also pay special attention to education, since it may be part of the link between the two. For this purpose we will construct long-run data on the average length of education, which have never been used to date. Finally, we argue that the process leading Sweden to sustained income growth through its demographic transition can be generalized to other countries as well.

2.1. Population

As early as 1749, Sweden established a public agency responsible for producing population statistics. These statistics were based on population records kept by the parish ministry of the Swedish Lutheran church. Thanks to this effort we have access to detailed and high-quality data on how mortality and fertility changed over two and a half centuries.

The demographic transition in Sweden follows the standard pattern. Adult life expectancy starts to increase around 1825, while a clear downward trend in Swedish fertility did not materialize until the last quarter of the nineteenth century. That is, at a time when mortality had been declining for almost a century.

The long-term trend in mortality and fertility has led to a total transformation of the Swedish age structure (Malmberg and Sommestad 2000). This is illustrated in figure 1, where the population has been divided into five 20-year age brackets: 0–19, 20–39, 40–59, 60–79, and 80+. Declining mortality and fertility lead to a change in the age structure from a population dominated by children and young adults to a population where all 20-year age brackets except the oldest have about the same size.

2.2. Income

Historical estimates of GDP per capita in Sweden are available from several sources. In this paper we use the series provided by Maddison (2003). Up to the 1820s we have stagnation in per capita income, but there is an increasing growth trend, and after 1850 average growth rates start to exceed the 1% level. After a crisis in the 1870s, the growth takeoff gains strength again, rising above the 2% level in the early twentieth century. Apart from temporary setbacks connected to the world wars and later oil crises, the long-run averages have remained around these levels ever since.

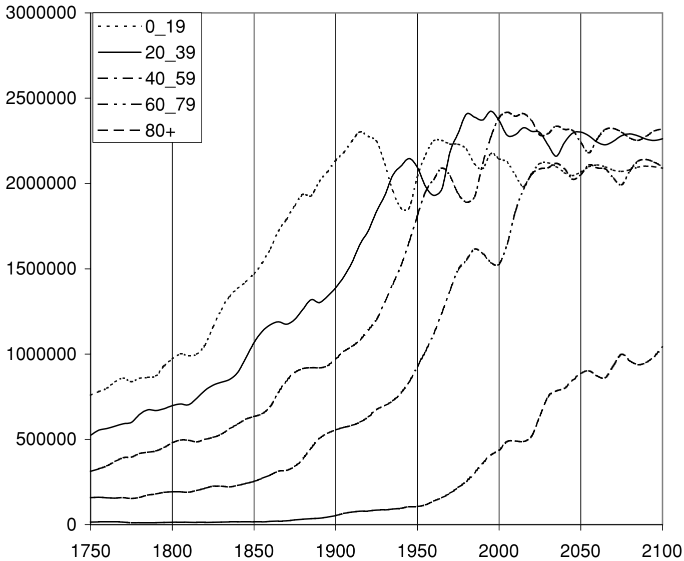

FIGURE 1 Changing age structure

2.3. Education

Constructing long time series for education is made difficult by the successive reforms of the Swedish educational systems. The solution chosen here was to take the current system as a starting point and assign earlier educational programs to the categories in use today. Ever since the 1970s Swedish education has been divided into three levels: extended primary education, upper secondary education, and tertiary education. Extended primary education comprises grades 1–9, that is, primary and lower secondary education. Upper secondary school includes both theoretical and vocational programs. For the post-1870 period, data on educational enrolment are available in the official Swedish statistics. Pre-1870 data are based on calculations made by Sjöstrand (1961) and Aquilonius and Fredriksson (1941). Detailed sources are provided in appendix B.

As can be seen in figure 2, the expansion of Swedish education has been a four-step process. The first step was an expansion of primary and lower secondary education that took place from the mid-nineteenth century to the early twentieth century. The second step was the expansion of upper secondary education. This expansion accelerated after the First World War and continued up to about 1980. The third step was the post-1940 expansion of extended primary education. Part of this expansion was due to an increase in cohort size following a baby boom in the 1940s, but the extension of compulsory education from six to nine years was also an important factor. The fourth step has been the expansion of tertiary education after 1950. This expansion was particularly rapid in the 1960s and the 1990s.

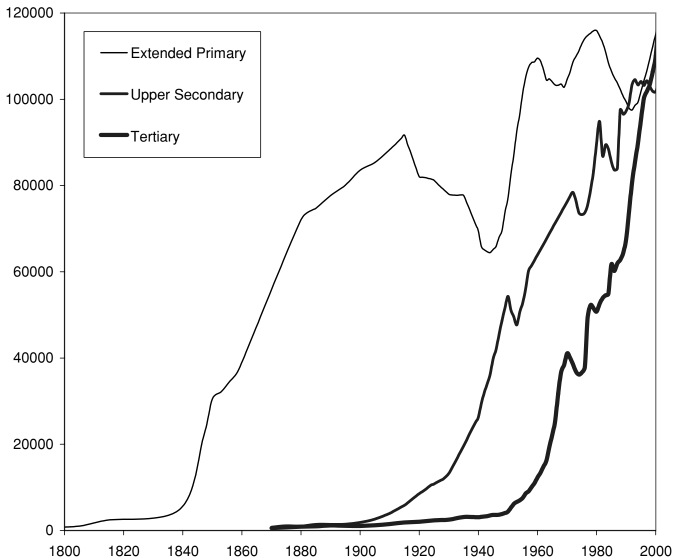

FIGURE 2 Enrolment history

In table 1, we present data on the mean length of education per birth cohort. For cohorts born before 1930, these figures are obtained by adding the yearly, age-specific enrolment rates that result from dividing the number of enrolled pupils per grade with the mean cohort size in the relevant age bracket. For cohorts born between 1930 and 1976, the mean length of education is as observed in 2004 in the Statistics Sweden (2005) Swedish Register of Education. The figures for cohorts born after 1976 are based on the assumption that growth in the observed mean length of education will continue until it reaches 13 years for the cohort born in 1980 and then remains constant.

3. The endogenous growth model

We will now describe the model we use to quantify the effect of demographic change on income growth, its calibration, and the various counterfactual experiments we ran.

3.1. The model

3.1.1. Demographic structure

Time is continuous and at each point in time there is a continuum of generations indexed by the date at which they were born. Each individual has an uncertain lifetime. The unconditional probability for an individual belonging to the cohort t of reaching age $a \in [0, M(t)]$, is given by the survival law

TABLE 1
Years of education

Year	Mean length of education for birth cohort	Mean length of education of those aged 25
1820	0.53	0.26
1870	5.57	4.22
1913	5.72	5.64
1950	10.81	7.17
1980	13	11.88

$$m(a, t) = \frac{\alpha(t) - e^{\beta(t)a}}{\alpha(t) - 1}, \tag{1}$$

with both functions $\alpha(t) > 1$ and $\beta(t) > 0$ being continuous. This two-parameter function is much more realistic than the usual one-parameter function used, for example, in Kalemli-Özcan, Ryder, and Weil (2000); like the actual survival laws, it is concave, reflecting the fact that the death probability increases with age. It also makes it possible to define a maximum age $\mathrm{M}(t)$ that an individual can reach as

$$\mathrm{M}(t) = \frac{\log(\alpha(t))}{\beta(t)}. \tag{2}$$

If we assume that the initial size of a newborn cohort is $N(t)$, its size at time $z > t$ is

$$N(t)\, m(z - t, t), \ \text{ for } z \in [t, t + \mathrm{M}(t)]. \tag{3}$$

The mortality processes $\alpha(t)$, $\beta(t)$ and the process for births $N(t)$ are considered exogenous in the model in conformity with the purpose of forecasting, as noted in the introduction. For given $(\alpha(t), \beta(t), N(t))$ we can easily compute life expectancy at all ages, as well as sizes of any population group. The unconditional life expectancy is

$$\Lambda(t) = \frac{\alpha(t)\log(\alpha(t))}{(\alpha(t) - 1)\beta(t)} - \frac{1}{\beta(t)}. \tag{4}$$

An increase in life expectancy can arise either through a decrease in $\beta(t)$ or an increase in $\alpha(t)$. These two shifts do not lead to the same changes in the survival probabilities. When $\alpha(t)$ increases, the improvement in life expectancy relies more on reducing death rates for young and middle-aged agents. When $\beta(t)$ decreases, the old agents benefit the most from the drop in death rates, which has an important effect on the maximum age.

The size of total population at time t is given by

$$P(t) = \int_{t-\bar{\mathrm{M}}(t)}^{t} N(z)\, m(t-z, z)\,\mathrm{d}z, \tag{5}$$

where $\bar{\mathrm{M}}(t)$ is the age of the oldest cohort still alive at time t; that is, $\bar{\mathrm{M}}(t) = \mathrm{M}(t - \bar{\mathrm{M}}(t))$.

3.1.2. The households' problem

An individual born at time t, $\forall t \geqslant 0$ has the following expected utility:

$$\int_{t}^{t+\mathrm{M}(t)} c(t, z)\, m(z-t, t)\, e^{-\theta(z-t)}\,\mathrm{d}z, \tag{6}$$

where $c(t, z)$ is consumption of a generation t member at time z. The pure time preference parameter is θ.

There is a unique material good, the price of which is normalized to 1, which can be used for consumption. Every working household produces a quantity of good $y(t)$ using human capital $h(t)$ according to the following simple technology: $y(t) = h(t)$. Households' human capital depends on the time spent on education, $\mathrm{T}(t)$, on the average human capital, $\bar{H}(t)$, of the society at birth, and on the state of technology at birth, $A(t)$:

$$h(t) = A(t)\bar{H}(t)\mathrm{T}(t)^{\eta(t)}, \tag{7}$$

In equation (7) we make two specific assumptions. First, with $\bar{H}(t)$ we introduce the typical externality that positively relates the future quality of the agent to the cultural ambience of the society (through, for instance, the quality of the school). This formulation amounts to linking the externality to the output per capita, which is another way of reflecting the general quality of a society. Second, the variable $\eta(t) \in]0, 1[$ is the elasticity of income to years of schooling. This variable can change over time, depending on exogenous factors. Technology $A(t)$ is also time varying. We presuppose that it is only their value at time t that matters for the cohort born at time t, which reflects that it is the education technology at the start of studies that determines its outcome. A more general formulation including the change in $A(t)$ and $\eta(t)$ during the schooling period would not particularly alter the results.

The intertemporal budget constraint of the agent born at t is

$$\int_{t}^{t+\mathrm{M}(t)} c(t, z) R(t, z)\,\mathrm{d}z = \int_{t+\mathrm{T}(t)}^{t+F(t)} h(t) R(t, z)\,\mathrm{d}z. \tag{8}$$

We assume the existence of complete annuity markets. This assumption is equivalent to one with no annuity markets, but with a redistribution of the wealth of the deaths to the persons of the same generation. $R(t, z)$ is the contingent price paid by a member of generation t to receive one unit of the physical good at time z in the case where he is still alive. By definition, $R(t, t) = 1$. The left-hand side is the actual cost of contingent life-cycle consumptions. The right-hand side is the actual value of contingent earnings.

The individual enters the labour market at age $\mathrm{T}(t)$ with human capital $h(t)$ and produces $h(t)$ per unit of time. $F(t)$ is the age until which individuals can work. It can be interpreted either as the age above which the worker is no longer able to work or as a mandatory retirement age.

The problem of the representative individual of generation t is to select a consumption contingent plan and the duration of his or her education to maximize the expected utility, subject to the intertemporal budget constraint and given the per capita human capital and the sequence of contingent wages and contingent prices. The corresponding first-order necessary conditions for a maximum are

$$m(z - t, t)\, e^{-\theta(z-t)} - \lambda(t) R(t, z) = 0 \tag{9}$$

$$\eta(t)\mathrm{T}(t)^{\eta(t)-1} \int_{t+\mathrm{T}(t)}^{t+F(t)} R(t, z)\, \mathrm{d}z - \mathrm{T}(t)^{\eta(t)}\; R(t, t + \mathrm{T}(t)) = 0, \tag{10}$$

where $\lambda(t)$ is the Lagrangian multiplier associated with the intertemporal budget constraint. Since $R(t, t) = 1$ and $m(0, t) = 1$, we obtain from equation (9) $\lambda(t) = 1$. Using this in (7), we may rewrite contingent prices as

$$R(t, z) = m(z - t, t)\, e^{-\theta(z-t)}. \tag{11}$$

Equation (11) reflects that, with linear utility, contingent prices are just equal to the discount factor in utility, which includes the survival probabilities.

The first-order necessary condition for schooling time is (10). The first term is the marginal gain of increasing the time spent at school and the second is the marginal cost, that is, the loss in income if entry on the job market is delayed.

From (10) and (11) the solution for $\mathrm{T}(t)$ should satisfy

$$\mathrm{T}(t)\, m(\mathrm{T}(t), t)\, e^{-\theta \mathrm{T}(t)} = \eta(t) \int_{\mathrm{T}(t)}^{F(t)} m(a, t)\, e^{-\theta a}\, \mathrm{d}a, \tag{12}$$

where the right-hand side represents the discounted flow of income per unit of human capital. Notice that optimal schooling does not depend on productivity $A(t)$, because $A(t)$ symmetrically affects opportunity costs and benefits.

3.1.3. Aggregate human capital

The productive aggregate stock of human capital is computed from the human capital of all generations currently at work:

$$Y(t) = H(t) = \int_{t-\bar{F}(t)}^{t-\bar{\mathrm{T}}(t)} e^{n(z)z}\, m(t-z, z) h(z)\,\mathrm{d}z, \tag{13}$$

where $t - \bar{\mathrm{T}}(t)$ is the last generation that entered the job market at t and $t - F(t)$ is the oldest generation still working at t. Then, $\bar{\mathrm{T}}(t) = \mathrm{T}(t - \bar{\mathrm{T}}(t))$, and $\bar{F}(t) = F(t - \bar{F}(t))$. Accordingly, the size of the active population is

$$P^A(t) = \int_{t-\bar{F}(t)}^{t-\bar{\mathrm{T}}(t)} N(z)\, m(t-z, z)\,\mathrm{d}z. \tag{14}$$

The average human capital at the root of the externality (7) is obtained by dividing the aggregate human capital by the size of the population given in (5):

$$\bar{H}(t) = \frac{H(t)}{P(t)}. \tag{15}$$

The dynamics of human capital accumulation can be obtained by combining (7) with (13) and (15). To evaluate $H(t)$, for $t \geqslant 0$, we need to know initial conditions for $H(t)$, for $t \in [-\bar{\mathrm{M}}(0), 0[$.

3.2. Some theoretical results

As reflected in equation (13), total output is obtained from aggregating generation-specific production. This implies that the composition of population matters. For example, when the workforce is aging, there is more demographic weight put on old human capital, which was acquired some time ago with old education technology negatively influencing average output. This property is similar to the one of vintage capital models. In Boucekkine, de la Croix, and Licandro (2002) some interesting properties of the theoretical model have been derived. Let us provide the intuition for three of them.

PROPERTY 1. *A rise in life expectancy* Λ *(either via an increase in* α *or a drop in* β*) increases the optimal length of schooling.*

A key property of the model is that a decrease in the death rates or, equivalently, an increase in life expectancy induces individuals to study more. This prediction is consistent with the joint observation of a large increase in both life expectancy and years of schooling during the last 150 years.

PROPERTY 2. *When demographic variables are constant through time, income grows at a constant rate.*

There is thus a balanced growth path. The value of the long-run growth rate is a function of various factors, such as the efficiency of education A and the elasticity η. Notice also that the income of an individual does not grow over time; growth in the economy is linked to the appearance of new generations. Hence, the objective function of an individual is always finite.

PROPERTY 3. *A rise in life expectancy Λ has a positive effect on economic growth for low levels of life expectancy and a negative effect on economic growth for high levels of life expectancy.*

Intuitively, the total effect of an increase in life expectancy results from combining three factors: (a) agents die on average later, thus the depreciation rate of aggregate human capital decreases; (b) agents tend to study more because the expected flow of future wages has risen, and the human capital per capita increases; (c) the economy consists more of old agents who did their schooling a long time ago. The first two effects have a positive influence on the growth rate, but the third effect has a negative influence. Notice that the last two effects are still effective even if there is a fixed retirement age (which does not change with life expectancy) or if we had assumed that human capital becomes fully depreciated after a given age. This is due to the fact that a rise in life expectancy reduces the probability of dying during the activity period. Notice that this property holds whether life expectancy increases via a rise in α, or via a drop in β.

3.3. Calibration

We calibrate the demographic processes of the model on the population data presented in section 1. In order to focus on adult mortality, we disregard the huge fluctuations affecting infant mortality in the seventeenth, eighteenth, and early nineteenth centuries. Accordingly, we will consider that the birthdate in our model corresponds to age 10 in the data. One decision variable is affected by this time shift: the schooling time, $\mathrm{T}(t)$. If the birthdate is 10, one can legitimately argue that the true schooling time is not T, but $\mathrm{T}(t) + T_0$, where T_0 is the time spent at school before 10. In our empirical assessment, we take into account this crucial aspect and replace $\mathrm{T}(t)$ with $\mathrm{T}(t) + T_0$ in the model. More precisely, we set $T_0 = 4$, which means that the representative individual has already cumulated four years of education at birth, and replace $\mathrm{T}(t)$ by $\mathrm{T}(t) + 4$ in equation (7) (not in equation (8), where $\mathrm{T}(t)$ determines the length of a working life).

To calibrate the model, the exogenous processes $\alpha(t)$, $\beta(t)$, and $N(t)$ should be made explicit. We assume that all these processes follow a polynomial function of time. Polynomials of order 3 are sufficient to capture the main trends in the data. For the survival function processes $\alpha(t)$ and $\beta(t)$, the parameters of the polynomial are chosen by minimizing the distance (measured as the square of the deviation) between the model's life expectancies at ages 10 to 80 with their empirical counterparts. The parameters of the process for $N(t)$ are chosen so that the distance between the share of the age groups 10–15, 15–30, 30–50, 50–65, and 65+ in total population $P(t)$ and the observed levels is minimized. Notice that changes in $N(t)$ reflect mostly change in birth rates but also to some extent capture migration patterns. Appendix A details the results obtained. In particular figures A1 and A2 in the appendix show that the 13 time series (8 life expectancies and 5 age groups) are replicated quite well using only 3 functions, $\alpha(t)$, $\beta(t)$ and $N(t)$, in turn characterized by 12 parameters (4 per function).

For the risk-free interest rate, we choose 2% per year, which sets $\theta = 0.02$. The total discount rate, including mortality, would then be around 4% on average over life for a life expectancy equal to 50.[1] The effective retirement age $F(t)$ is set constant to 53 (that is, age 63). This number is in accordance with the estimate of the effective retirement age made by Blondal and Scarpetta (1997) in the recent past. Since we do not have more information on its historical value, we keep it constant through time.

Once we have calibrated the demographic processes and chosen the discount rate, we need to determine the process for $\eta(t)$, the elasticity of income to schooling. A value for the elasticity of income to schooling of around 0.5–0.6 is generally drawn from the estimations of the wage equations (see the discussion in de la Croix and Doepke 2003). This value, however, is correct only for the recent years; at least for the very low averages we observe in the nineteenth century we would expect that the income elasticity of average schooling should have increased. Given that we have constructed data corresponding to the average schooling duration $\mathrm{T}(t)$, we can use equation (12) to compute the $\eta(t)$ that is necessary to match the observed length of schooling. This amounts to solving equation (12) for $\eta(t)$ after having replaced $\mathrm{T}(t)$ by the observations. Once we have computed a series for $\eta(t)$, we smooth it by estimating a polynomial of order 3 in time, to eliminate the short/medium-run variations we are not interested in. In table 2 some values of $\eta(t)$ are reported.

The fact that we need such an increase in the return to schooling to capture the rise in educational attainment indicates that the latter cannot be entirely explained by higher longevity. Part of the rise in education needs to be explained by other factors related to the return to education, such as skill-biased technical progress and public funding of education.

Another parameter that is likely to have changed over two centuries is the productivity parameter $A(t)$. Here we want to reflect the idea of 'population-induced' technical progress as in Galor and Weil (2000), Lagerlöf (2003), and Boucekkine, de la Croix, and Peeters (2007). This assumption is meant to capture a positive effect in more dense populations of transmission of skills and knowledge, that is, in regions with shorter geographical distance between people. To calibrate the changes in this process, we follow Lagerlöf (2006) by assuming that population

1 Robustness analysis shows that the value of θ, provided it remains small, does not influence the characteristics of our simulations.

TABLE 2
Elasticity of income to schooling

t	$\eta(t)$
1800	0.14
1850	0.14
1900	0.22
1950	0.37
2000	0.45

density exerts a positive effect only in a certain range.[2] We therefore calibrate a process of the form:

$$A(t) = \max\left[\mu_1, \mu_1 + \min\left[\mu_2 P_t^A, \mu_3\right]\right].$$

The parameters are chosen so that the distance between the growth of income per capita along the balanced growth path in 1760, 1835, 1865, 1895, 1925, 1955, and 1985 and the growth rate estimated by Maddison over the corresponding 30-year periods is minimized, yielding $\mu_1 = 0.846$, $\mu_2 = 0.000085$, and $\mu_3 = 0.288$. The implied level of efficiency is plotted as a function of time in figure 3. We observe that productivity starts to rise around 1780 once population passes a given threshold; by the end of the nineteenth century productivity had stopped increasing, and the scale effect no longer plays a role. Beyond that point, growth is only driven by the human capital externality. Hence, the density effect is necessary only to account for the early increase in income.

3.4. Simulation results

We ran our simulation with the assumption that the economy was on a balanced growth path prior to 1750. Then we use the method proposed by Boucekkine, Licandro, and Paul (1997) to solve models with differential-difference equations. The simulation covers the period 1750–2050 and we report the results for 1820–2003.[3]

3.4.1. Baseline

Figure 4 plots the cohorts' schooling time in years. The curve Data (our estimation) reports the series we computed from the enrolment rates presented above.

2 Notice also that the view according to which population density matters for growth is in accordance with the empirical literature, which finds that density appears as a significant factor in growth regressions across countries (see, e.g., Kelley and Schmidt 1995), across U.S. states (Ciccone and Hall 1996) and in large European countries (Ciccone 2002).

3 The last available year from Maddison's GDP is 2003. The forecasts of our model are combined with forecasts from other models in de la Croix, Lindh, and Malmberg (2007) to evaluate whether information on historical patterns helps to improve long-term forecasting of economic growth.

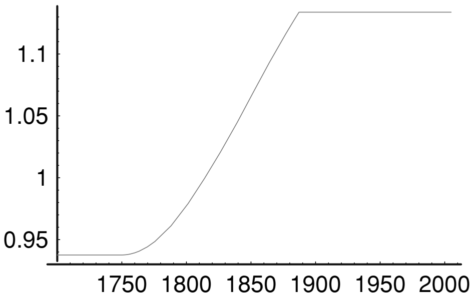

FIGURE 3 The efficiency level $A(t)$ over time

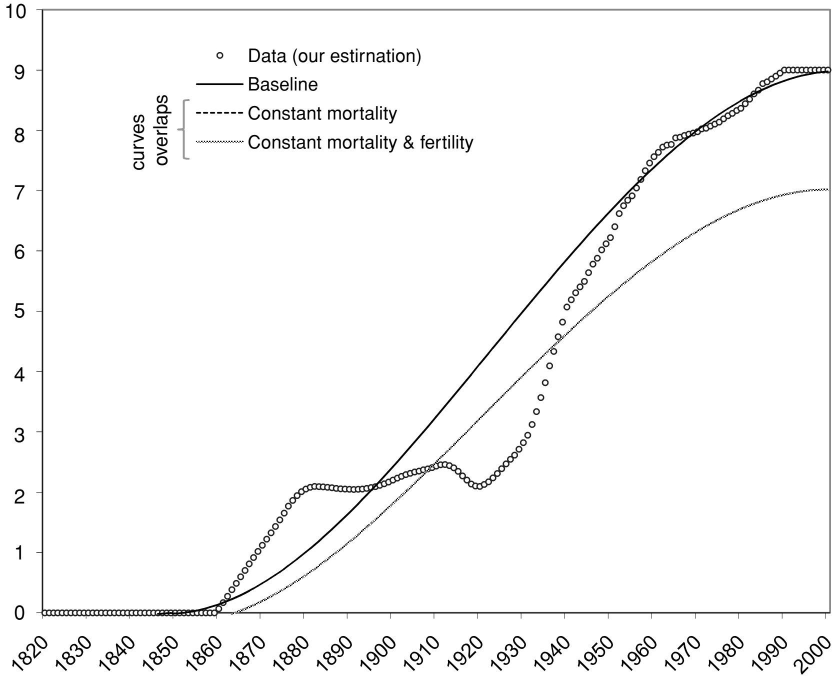

FIGURE 4 Cohorts' schooling time beyond age 10 (years)

The curve Baseline represents the simulated series in the baseline simulation: remember that we chose the process $\eta(t)$ in order to match the general trend in the data. Schooling starts to rise in 1860, accelerates until 1930, and decelerates thereafter. Figure 5 plots the GDP per capita (in logs). It compares the estimation of Maddison with our baseline simulation. Again the general trend is captured, thanks to the calibration of the productivity process $A(t)$: income starts from very low levels in the eighteenth century, begins to increase during the

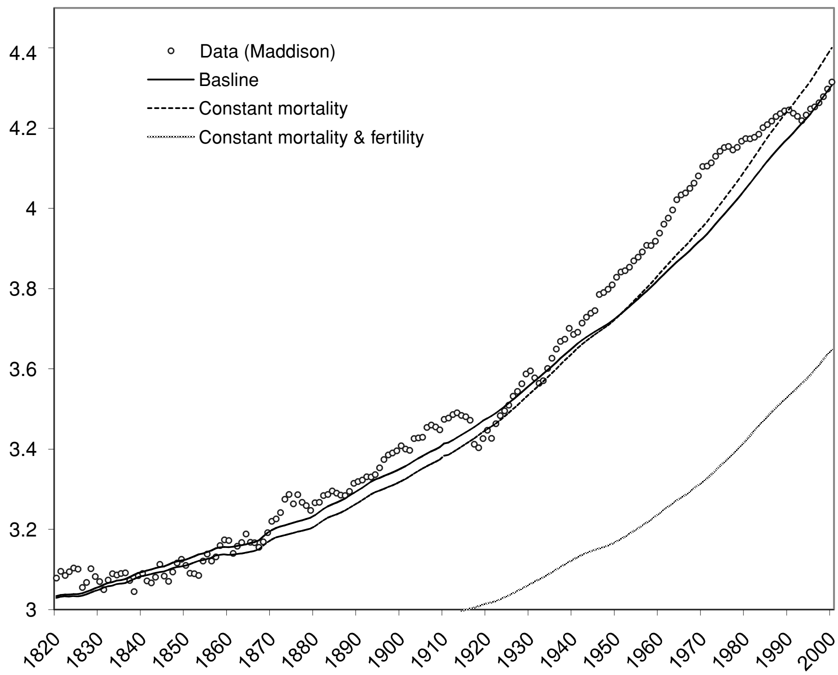

FIGURE 5 Income per capita (logs)

nineteenth century, and then follows a sustained increase. Growth stays sustained, since permanent changes in the return to education and in productivity have occurred.

3.4.2. Counterfactual experiments

To evaluate the role of demographic variables in these developments, we first analysed what would have happened if longevity had stayed at the 1750 level. To answer this question, we ran a counterfactual experiment by keeping the parameters α and β at their 1750 level. This has several implications. First, incentives to invest in education are reduced, and the length of schooling will never go beyond 11 years (7 + 4) instead of 13 in the baseline simulation (figure 4). Second, active population will be much lower, implying that the effect of scale on productivity is now smaller. Third, the age structure of the population is modified, with fewer old people at all dates. The total effect of these factors is to depress income per capita compared with the baseline during the nineteenth century (figure 5). After 1950 the effect is reversed, and GDP per capita with 1750 longevity is higher than in the baseline; during this period, the third effect dominates, and income benefits from the absence of old workers and retirees. On the whole, we conclude that changes in longevity may account for as much as 20% of the observed rise in education over the period 1800–2000, but have little effect on income growth over the period.

To further evaluate the role of demographic variables, we ‘shut down’ the second channel of demographic changes by keeping the process $N(t)$ constant at its 1750 level. In this simulation, all the population variables are constant between 1750 and 2000. Results of these counterfactual experiments are reported under the label Constant mortality and fertility. In this simulation, population density is constant, which implies that total factor productivity $A(t)$ is constant as well. From figure 4 we see that the length of schooling is unchanged compared with the ‘Constant mortality’ simulation, because the process $A(t)$ does not intervene in the determination of the investment in education. Considering now figure 5, we observe that GDP per capita is much smaller than in the previous case. This is mainly due to the fact that the rise in productivity $A(t)$ does not occur in this simulation, since total population (and hence population density) stays at its 1750 level. Other less important effects arise through the composition of the workforce. In this simulation, increases in GDP occur only via the exogenous rise in the return to schooling $\eta(t)$ and are kept sustained thanks to the human capital externality. To sum up, most of income growth over the period 1820–2000 would not have materialized if demographic variables had stayed constant since 1750. This simulation also shows that total factor productivity is the most important intermediate factor between demography and income per capita.

4. Conclusion

In the literature on demographic change and economic growth, the effect of longer life expectancy on the demand for longer education has been given a prominent place. Others have argued that population size (or density) might be an important factor in triggering technological progress. Finally, recent theoretical work has also argued that there is a link between age composition and economic growth.

In this paper, these mechanisms are confronted with empirical data by calibrating an endogenous growth model on Swedish long-term time-series of mortality, education, age structure, and per capita income.

The goal has been to reproduce the take-off process and the rise in growth rates from stagnation prior to the eighteenth century to 2% growth in the twentieth century. The main mechanisms at work are rises in life expectancy that increase the incentive to get an education, which in turn has permanent effects on growth through a human capital externality. There is also a scale effect from active population on growth going through total factor productivity.

Our conclusion is that changes in longevity may account for as much as 20% of the observed rise in education over the period 1800–2000. Thus, longevity plays an important role, but by itself cannot explain more than a part of the rise in the education level in a model with no credit restrictions. The remaining 80% should be sought elsewhere, probably in the development of public subsidies to education and/or to the acceleration of skill-biased technical progress.

The total effect of the demographic variables on growth is higher. Most income growth over this period would not have materialized if demographic variables had stayed constant since 1800.

The conclusion is that demography does indeed play an important role for long-run growth. However, a full understanding of the process of increasing education levels will require an even more elaborated model than the one we have used in this paper.

Appendix A: Calibration of the demographic processes

The programs (written in Mathematica 5.0) and data used to calibrate the model are available online through the CJE journal archive, http://economics.ca/cje/en/archive.php, and linked to this article.

Given that the probability taken at age 0 of being alive at age a is given by equation (1), life expectancy for a person born at time t taken at age b is given by

$$\Lambda_b(t) = \frac{\frac{\alpha(t)(b\beta(t)-\log(\alpha(t)))}{e^{b\beta(t)}-\alpha(t)} - 1}{\beta(t)}.$$

The demographic processes $\alpha(t)$ and $\beta(t)$ are constant before 1750 and after 2200. In between they are polynomial functions of time:

$$\ln\alpha(t) = \text{If } t > 2200,\ a_3\left(\frac{2200}{1900}-1\right)^3 + a_2\left(\frac{2200}{1900}-1\right)^2 + a_1\left(\frac{2200}{1900}-1\right) + a_0$$

$$\text{If } 2200 \geqslant t \geqslant 1750,\ a_3\left(\frac{t}{1900}-1\right)^3 + a_2\left(\frac{t}{1900}-1\right)^2 + a_1\left(\frac{t}{1900}-1\right) + a_0$$

$$\text{If } t < 1750,\ a_3\left(\frac{1750}{1900}-1\right)^3 + a_2\left(\frac{1750}{1900}-1\right)^2 + a_1\left(\frac{1750}{1900}-1\right) + a_0$$

$$\beta(t) = \text{If } t > 2200,\ b_3\left(\frac{2200}{1900}-1\right)^3 + b_2\left(\frac{2200}{1900}-1\right)^2 + b_1\left(\frac{2200}{1900}-1\right) + b_0$$

$$\text{If } 2200 \geqslant t \geqslant 1750,\ b_3\left(\frac{t}{1900}-1\right)^3 + b_2\left(\frac{t}{1900}-1\right)^2 + b_1\left(\frac{t}{1900}-1\right) + b_0$$

$$\text{If } t < 1750,\ b_3\left(\frac{1750}{1900}-1\right)^3 + b_2\left(\frac{1750}{1900}-1\right)^2 + b_1\left(\frac{1750}{1900}-1\right) + b_0.$$

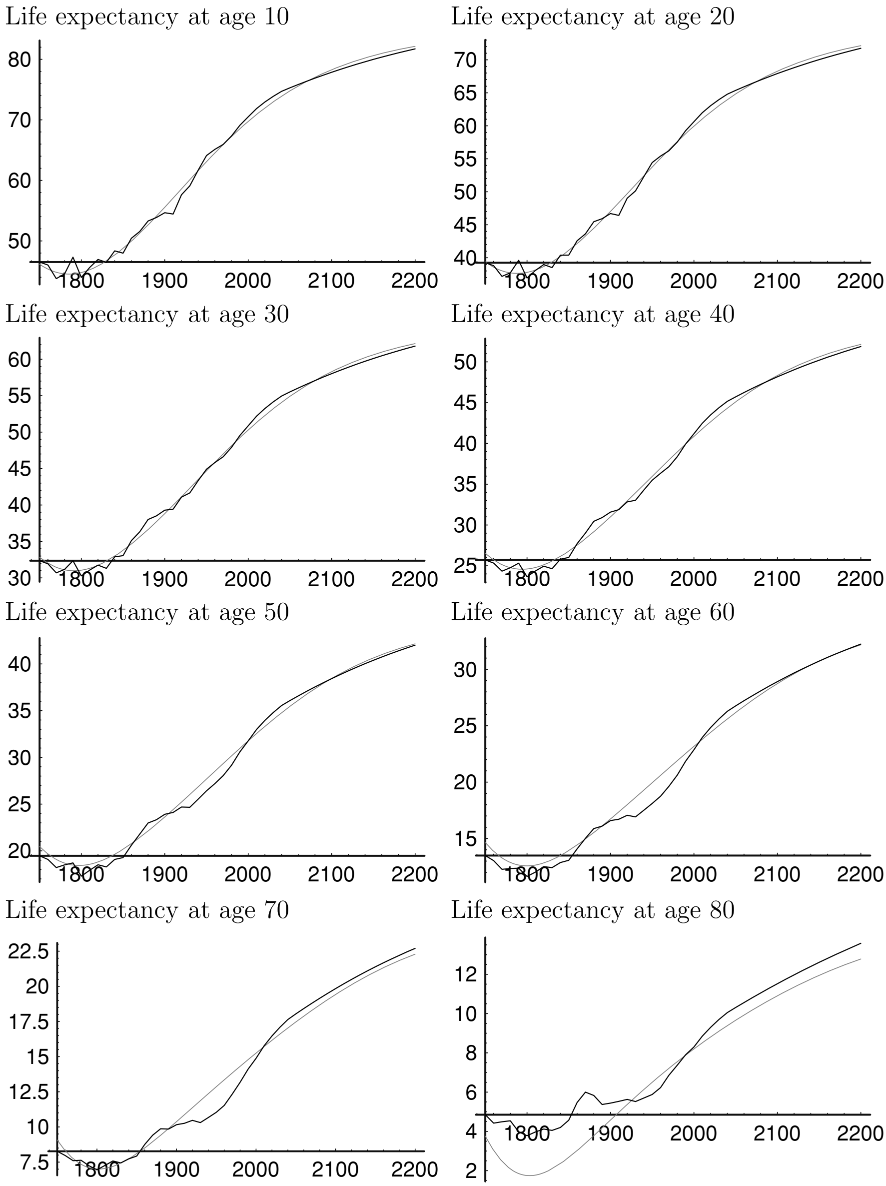

FIGURE A1 Life expectancy at different ages: data and model

Matrix Q gives the life expectancy data to which the processes will be calibrated. Each element $q(i, j)$ gives life expectancy of the generation born at date $i \in (1750, 1760 \ldots 2200)$ taken at age $j \in (10, 20, \ldots 80)$.

We choose the parameters in order to minimize

$$\sum_i \sum_j (\Lambda_j(i) - q(i, j))^2.$$

The result is

$$a_0 = 2.77, \quad b_0 = 0.035, \quad a_1 = 41.16, \quad b_1 = 0.46, \quad a_2 = 279.03,$$

$$b_2 = 2.92, \quad a_3 = 155.70, \quad b_3 = 2.98,$$

and the value of the criterion is 226.17. The achieved fit is displayed in figure A1.

The demographic process $N(t)$ is constant before 1750 and after 2200. In between, it is polynomial functions of time:

$$\ln N(t) = \text{If } t > 2200, \ln x_0 + x_3\left(\frac{2200}{1900} - 1\right)^3 + x_2\left(\frac{2200}{1900} - 1\right)^2 + x_1\left(\frac{2200}{1900} - 1\right)$$

$$\text{If } 2200 \geqslant t \geqslant 1750, \ln x_0 + x_3\left(\frac{t}{1900} - 1\right)^3 + x_2\left(\frac{t}{1900} - 1\right)^2 + x_1\left(\frac{t}{1900} - 1\right)$$

$$\text{If } t < 1750, \ln x_0 + x_3\left(\frac{1750}{1900} - 1\right)^3 + x_2\left(\frac{1750}{1900} - 1\right)^2 + x_1\left(\frac{1750}{1900} - 1\right).$$

Population is divided into five groups indexed by k: 0–5 years, 5–20, 20–40, 40–55, 55+ (age 0 corresponds to age 10 in the data). Each group size can be computed by integrating over the relevant age range. For example, the size of group 20–40 ($k = 3$) is given by

$$P_3(t) = \int_{t-40}^{t-20} N(z)m(t - z, z)\,\mathrm{d}z.$$

Matrix Z gathers the group sizes to which the process will be calibrated. Each element $q(i, k)$ gives thousands of persons of the generation born at date $i \in (1750, 1760 \ldots 2200)$ belonging to group k.

We choose the parameters in order to minimize

$$\sum_i \sum_k (P_k(i)/z(i, k) - 1)^2.$$

The result is

$$x_0 = 98.58, \quad x_1 = 7.62, \quad x_2 = -90.34, \quad x_3 = 296.1$$

and the value of the criterion is 2.87. Figure A2 presents the fitted values of the population groups, expressed as shares in total population.

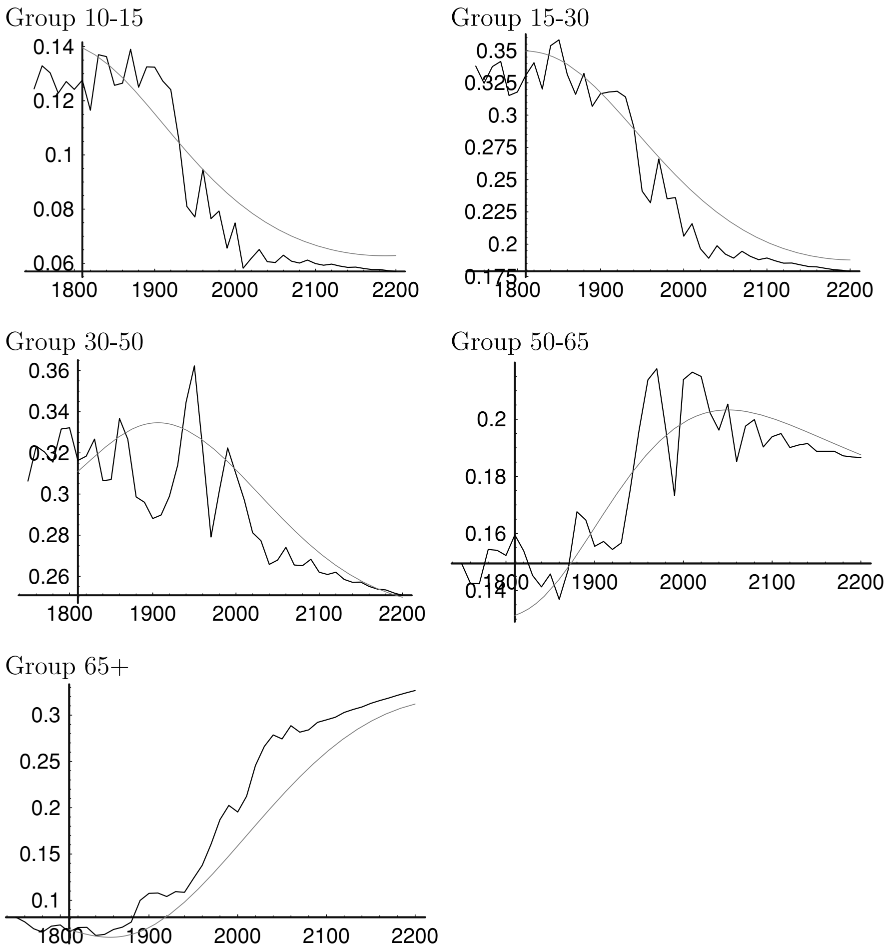

FIGURE A2 Population group; percentage of total population: data and model. Note different scales.

References

Aquilonius, K, and V Fredriksson (1941) *Svenska folkskolans historia* (Stockholm)

Blondal, Sveinbjørn, and Stefano Scarpetta (1997) 'Early retirement in OECD countries: the role of social security systems,' *OECD-Economic-Studies* 0(29), 7–54

Boucekkine, Raouf, David de la Croix, and Omar Licandro (2002) 'Vintage human capital, demographic trends and endogenous growth,' *Journal of Economic Theory* 104, 340–75

— (2003) 'Early mortality declines at the dawn of modern growth,' *Scandinavian Journal of Economics* 105(3), 401–18

Boucekkine, Raouf, David de la Croix, and Dominique Peeters (2007) 'Early literacy achievements, population density, and the transition to modern growth,' *Journal of the European Economic Association* 5, 183–226

Boucekkine, Raouf, Omar Licandro, and Christopher Paul (1997) 'Differential-difference equations in economics: on the numerical solution of vintage capital growth models,' *Journal of Economic Dynamics and Control* 21, 347–62

Ciccone, Antonio (2002) 'Agglomeration effects in europe,' *European Economic Review* 46, 213–27

Ciccone, Antonio, and Robert Hall (1996) 'Productivity and the density of economic activity,' *American Economic Review* 86, 54–70

de la Croix, David, and Matthias Doepke (2003) 'Inequality and growth: why differential fertility matters,' *American Economic Review* 93(4), 1091–1113

de la Croix, David, Thomas Lindh, and Bo Malmberg (2007) 'Demographic change and economic growth in Sweden: 1750–2050,' *Journal of Macroeconomics*, Historical Macroeconomics Special Issue 2008. http://dx.doi.org/10.1016/j.jmacro.2007.08.014.

Galor, Oded, and David Weil (2000) 'Population, technology, and growth: from the Malthusian regime to the demographic transition and beyond,' *American Economic Review* 90, 806–28

Kalemli-Özcan, Sebnem, Harl Ryder, and David Weil (2000) 'Mortality decline, human capital investment, and economic growth,' *Journal of Development Economics* 62, 1–23

Kelley, Allan, and Robert Schmidt (1995) 'Aggregate population and economic growth correlations: the role of the components of demographic changes,' *Demography* 32, 543–55

Lagerlöf, Nils-Petter (2003) 'From Malthus to modern growth: can epidemics explain the three regimes?' *International Economic Review* 44, 755–77

— (2006) 'The Galor-Weil model revisited: A quantitative exercise,' *Review of Economic Dynamics* 9, 116–42

Maddison, Angus (2003) *The World Economy: Historical Statistics* (Paris: OECD Development Centre)

Sjöstrand, W (1961) *Pedagogikens historia* (Lund: Gleerup)