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THE CHILD IS FATHER OF THE MAN: IMPLICATIONS FOR THE DEMOGRAPHIC TRANSITION*

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We propose a new theory of the demographic transition based on the evidence from natural sciences that physical development during childhood affects adult life expectancy positively. This theory is embodied in a continuous time OLG framework where fertility, longevity and education all result from individual decisions. We conclude that a sustained improvement in physical development is at the basis of the observed demographic transition in today's developed countries and may be an important factor in explaining the slow transition from the Malthusian towards the Modern era. The dynamics of the proposed model reproduce the key features of the demographic transition, including sustained improvements in child physical development, permanent increase in life expectancy, a hump-shaped evolution of both population growth and fertility and late increases in secondary educational attainments.

Providing children with appropriate hygienic conditions and good nutrition as well as a good attitude towards health during childhood are very effective ways of affording them a longer life. Starting with Kermack *et al.* (1934), who showed that the first 15 years of life were central in determining the longevity of the adult, the relationship between early development and late mortality has been well established. Fogel (1994) emphasises that nutrition and physiological status are at the basis of the link between childhood development and longevity. Another important mechanism stressed by epidemiologists links infections and related inflammations during childhood to the appearance of specific diseases in old age (Crimmins and Finch, 2006). In the same direction, Barker and Osmond (1986) relates lower childhood health status to higher incidence of heart disease in later life. It is in this sense that following Harris (2001), we echo Wordsworth's aphorism 'The Child is Father of the

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Man', meaning that the way a child is brought up determines what she or he will become in the future.[1]

It is well documented that the timing of fertility and mortality differs during the demographic transition. We illustrate it for Sweden in Section 1. First, child physical development and adult life expectancy have both permanently improved from the beginning of the nineteenth century. Second, the time profile of fertility rates, net of infant mortality, is hump-shaped, declining from the dawn of the twentieth century.[2] As is well known, the combination of these two forces also made population growth rates hump-shaped.

In this article, we propose a new theory of the demographic transition based on the cited evidence that child physical development favours adult longevity. We claim that the demographic transition has been shaped by a slow but permanent improvement in childhood development, promoting adult life expectancy. As pointed out by Galor (2005*a*) 'The reversal in the fertility patterns in England . . . suggests therefore that the demographic transition was prompted by a different universal force than the decline in infant and child mortality'. In our view, contrary to reductions in *infant and child* mortality, deliberate improvements in childhood development promoting *adult* survival have prompted the demographic transition, in particular the fact pointed out by Galor (2005*a*) that '. . . the mortality decline in Western Europe started nearly a century prior to the decline in fertility, and was associated initially with increasing fertility rates'.

The proposed theory borrows some key ingredients from Galor and Weil (2000)'s unified growth theory and is fundamentally in accordance with their quantity–quality trade-off fertility theory. However, by endogenising mortality through the childhood development hypothesis, we provide an alternative explanation of the demographic transition stressing the fundamental role of life expectancy. When today's developed world was in the Malthusian era, most individuals were living close to subsistence levels. Small changes in the environment inducing improvements in adult life expectancy slowly increased individuals' lifetime surpluses, allowing people to afford more and healthier descendants, which reinforced the initial effect of an improved environment on survival. As a consequence, net fertility rates were increasing as predicted by the Malthusian theory. At some point at the beginning of the nineteenth century, the Western world escaped the subsistence trap and the desire of having more children became dominated by the search of an individual better life. Net fertility rates remained high but stable for some decades while life expectancy kept growing. Finally,

[1] The state of the debate between nature and nurture may be synthesised by the following statement 'The effects of genes depend on the environment' (Pinker, 2004), where genes are associated with nature and the environment, as a shorthand for the effects of human behaviour with nurture. In this aricle, we are mainly interested in understanding how changes in human behaviour, for a given distribution of genes, affect childhood development and then demographics. By restricting the analysis to a representative cohort member, a standard assumption in OLG models, we do not pay much attention to within cohort differences in genes but concentrate on how changes in nurture over time affect childhood development on average. The implicit assumption is that the complex interaction between nature and nurture shaping the distribution of childhood development across cohort members in society has no significant effect on the mean over a period of time covering some few centuries.

[2] We are aware that improvements in child development may be associated not only with reductions in adult mortality but infant mortality too. By interpreting Becker's fertility theory as referring to net fertility, this article develops a theory of adult life expectancy, abstracting from infant mortality. The effect of falls in child mortality on the development process has been studied by Doepke (2005) and Bar and Leukhina (2010).

with the arrival of the twentieth century, most adults started finding attractive to invest in their own human capital for the first time in human history. This reduced the incentives to have children and consequently, net fertility rates. More educated, richer cohorts have additional incentives to invest in childhood development, keeping life expectancy permanently growing up to the contemporaneous times.

The model in this article is a continuous time overlapping generations economy built on Boucekkine *et al.* (2002) but where the key demographic variables, fertility and mortality, are all decided by individuals, instead of being exogenous. Parents like to have children but they also care about child longevity. By ensuring an appropriate physical development for their children, parents provide them with a longer life. Such provision is costly though, and its cost is increasing with the number of children. As a consequence, having many children forces parents to spend less on the physical development of each child, which makes longevity and fertility negatively related in the modern era.[3] We assume adults decide about their own education and we take basic education even if provided by parents, as being exogenously given. Adults face a trade-off between having children and improving their own education, which makes the number of children and schooling negatively related. This is similar to the trade-off faced by parents in a Beckerian world, where they care about the quantity and quality (education) of their offspring.[4] Finally, the mechanism relating demographics and education is the Ben-Porath hypothesis; longevity positively affects education by extending individual active life.[5]

The model dynamics display the key features of the demographic transition, including the observed permanent rise in adult life expectancy, the hump-shaped profile of net fertility and the late increase in secondary educational attainments. The economy evolves towards the Modern era moving endogenously through two corner regimes (Malthusian and Post-Malthusian). The key assumptions for the existence of these corner regimes are subsistence consumption, as in Galor and Weil (2000), and positive human capital at zero education, borrowed from Boucekkine *et al.* (2002). Subsistence consumption is extensively used in this literature. It is a simple way of

[3] We are aware that longevity does not depend solely on childhood development. Adults' investment in health and government spending on the elderly also contribute considerably to reductions in mortality. However, adding these mechanisms into our setup would not alter the trade-off we want to put forward and therefore we abstract from them in order to streamline the argument. We are also aware that there are at least two different types of health capital, as pointed out by Murphy and Topel (2006). One extends life expectancy so that individuals can enjoy consumption and leisure for longer; the other increases the quality of life, raising utility from a given quantity of consumption and leisure. In this article, as we are mainly interested in longevity, we restrict the analysis to the first type of health capital.

[4] A general representation of human capital accumulation would encompass both education by parents and education by individuals, making fertility negatively correlated with primary and secondary education respectively. However, the evidence for Sweden reported in Section 2 shows that net fertility is correlated with secondary education only, which has induced us to restrict the analysis to the particular case where education is undertaken by adults only.

[5] Conditions for this mechanism to hold in the presence of endogenous fertility are derived in Hazan and Zoabi (2006). The main argument in our article would also hold if, as in Hazan and Zoabi, childhood development affects education directly because healthier children perform better. The Ben–Porath mechanism has been recently subject to criticisms by Hazan (2009). He shows that the lifetime labour input of American men born in 1840–1970 declined despite the dramatic gains in life expectancy. Hazan further argues that a rise in the lifetime labour supply is a necessary implication of the Ben-Porath type model, which casts doubts on the possibility of such a model to explain the rise in schooling. Cervellati and Sunde (2009) show that Hazan's critique is only valid under specific assumptions and is much less general than claimed.

generating a Malthusian regime, where any increase in income encourages people to have more children. The assumption of positive human capital at zero education relies on the evidence that humanity was able to produce goods for millennia before the industrial revolution, without almost any type of formal education. In the numerical exercise, the economy is initially on the Malthusian regime and faces a smooth reduction in the cost of providing children with better health and nutrition. It enables parents to invest more in childhood development, inducing an increase in life expectancy. Historical records, see Section 3.1, support the assumption that a change in the cost of childhood development had occurred well before the industrial revolution. Unfortunately, there are no available data to support any particular path for this change; there is not even a simple magnitude for the total reduction. We do not claim that the cost of childhood development falls in the magnitude following the particular pattern assumed in the numerical exercise. What we claim is that if it were to be the case, our model would provide a good picture of the demographic transition in Sweden.

For this reason, we claim that childhood physical development and adult life expectancy played a fundamental role in explaining the demographic transformations faced by Western economies. In particular, it promoted an initial increase in fertility, with improvements in secondary education and reductions in fertility arriving later at the beginning of the twentieth century.[6]

This article differs from the previous attempts in the literature to endogenise fertility and longevity. Many articles have the standard education/fertility trade-off with exogenous longevity, for example, Doepke (2004) and Soares (2005). Other articles model health investment either by households (Chakraborty and Das, 2005; Sanso and Aisa, 2006) or by the government (Chakraborty, 2004; Aisa and Pueyo, 2006) but have exogenous fertility. A few treat both fertility and longevity as endogenous variables but the mechanism leading to longer lives always relies on an externality: more aggregate human capital or more aggregate income leads to higher life expectancy (Blackburn and Cipriani, 2002; Kalemli-Ozcan, 2002; Lagerlöf, 2003; Cervellati and Sunde, 2005, 2007; Hazan and Zoabi, 2006). Fernandez-Villaverde (2001) is an exception to the last group; however, unlike us, he assumes that survival depends positively on individual consumption.

Two recent articles have modelled the trade-off between the number and survival of children exclusively in the context of pre-modern societies. In Galor and Moav (2005), there is an evolutionary trade-off (i.e. not faced by individuals but by nature) between the survival to adulthood of each offspring and the number of offspring that can be supported. Lagerlöf (2010) suggested that agents choose how aggressively to behave, given that less aggressive agents stand a better chance of surviving long enough to have children but gain less resources and so more of their children die early from starvation. In both cases, the trade-off is between the number and survival rate of children, whereas in our article it is between the number of children and adult longevity.

This article is organised as follows. Section 1 presents some evidence on the link between the improvement in childhood development and the demographic transition.

[6] The role of life expectancy on raising income well before the industrial revolution has been stressed by Boucekkine *et al.* (2003).

In Section 2.1, we present and solve the problem for individuals. Section 2.2 is devoted to the study of the dynamics of dynasties. The demographic transition is analysed in Section 3. Implications for growth are studied in Section 4. Section 5 presents our conclusions.

1. Childhood Development and Demographic Transition

Height at age 18 is a good measure of childhood development, as both better nutrition and lower exposure to infections leads to increased height, and a good predictor of adult life expectancy.[7] According to Waaler (1984), the trend towards greater height found in the data means that younger cohorts, who have grown up under better conditions, are more developed and live longer as adults. Height is also frequently used as a health indicator in microeconomic studies. Weil (2007) finds that the effect on wages of an additional centimetre of height ranges between 3.3% and 9.4%. In a second step, he exploits the correlation between height and direct measures of health, such as the adult survival rate, to evaluate the role of health in accounting for income differences among countries; he finds that eliminating health variations would reduce world income variance by a third.

The height of conscripts has been systematically recorded by the Swedish army since 1820, which provides a unique source of time-series information on changes in child physical development throughout the demographic transition. Figure 1 presents data for the cohorts born between 1760 and 1960. The top panel shows that the height of soldiers (measured at approximately age 20) is highly correlated with life expectancy at age 10.[8] The bottom panel of Figure 1 reports net fertility rates, as well as years of schooling. We observe that fertility rises for cohorts born in the period 1800–30, then becomes relatively stable and decreases sharply from the beginning of the twentieth century. Years of elementary schooling were growing well before the decline of fertility but years of secondary schooling only began to increase when net fertility started to decline. Permanent improvements in survival rates over the 19th and 20th centuries and the hump-shaped profile of fertility rates during the demographic transition are well-established facts for most developed countries, as reported by Galor (2005*a*).

Further insights into the links between childhood development and fertility during the demographic transition can be gained by combining two data sets. Baten (2003) classified the former provinces of the German empire into six categories according to conscripts' height in 1906, i.e. for men born in the 1880s. In Figure 2, we retain the two extreme categories: provinces with the tallest (168.70 cm and more) and the shortest (166.50 cm and less) soldiers. The Princeton European Fertility Project provides information on fertility in these provinces for the years 1867–1933 (Knodel, 1974). In the period 1870–90, which is when the soldiers of 1906 were born, we can see that

[7] According to Silventoinen (2003), height is a good indicator of childhood living conditions (mostly family background), not only in developing countries but also in modern Western societies. In poor societies, the proportion of cross-sectional variation in body height explained by living conditions is larger than in developed countries with lower heritability of height as well as larger socioeconomic differences in height.

[8] Notice that this strong correlation over time can also be established in a cross-section of countries: Baten and Komlos (1998) regressed life expectancy at birth on adult height and explained 68% of the variance for a sample of 17 countries in 1860.

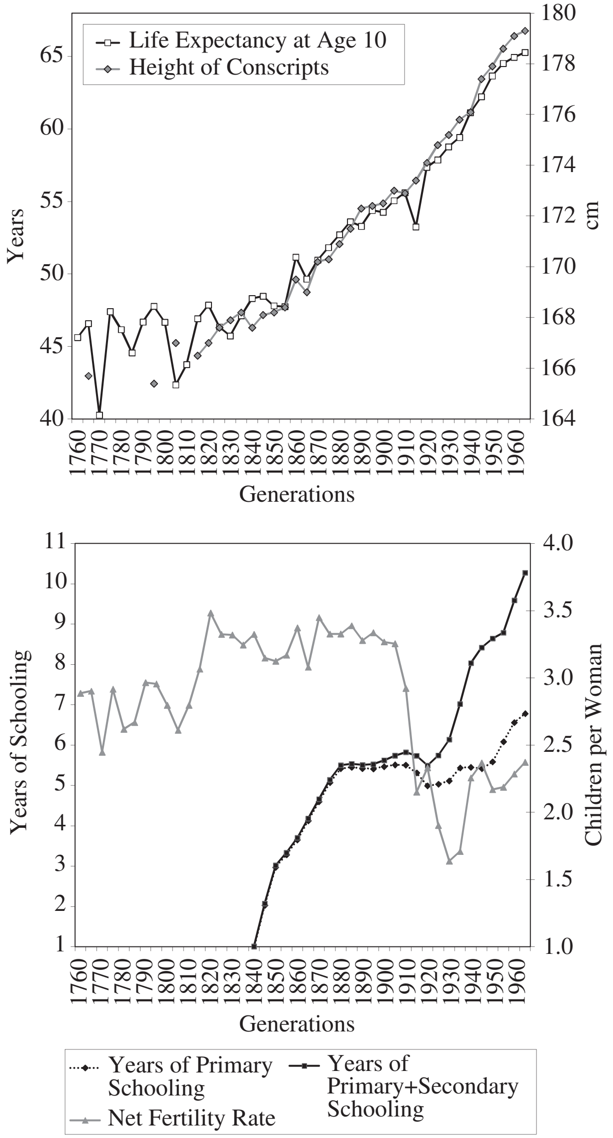

Fig. 1. *Height, Life Expectancy, Fertility and Education in Sweden*
Sources. Sandberg and Steckel (1997) for height data from 1820; Floud (1984) for height data before 1820 from Denmark); The 'Human Mortality Database' for life expectancy data; and De la Croix *et al.* (2008) for education data. Net fertility is computed as the product of the fertility rate (Statistics Sweden) with the probability of survival until age 15 (Human Mortality Database).

fertility rates were systematically higher in the provinces with shorter soldiers, which is consistent with the idea of a trade-off between the number of children and childhood development (as measured by adult height). In later years, fertility rates dropped and converged.

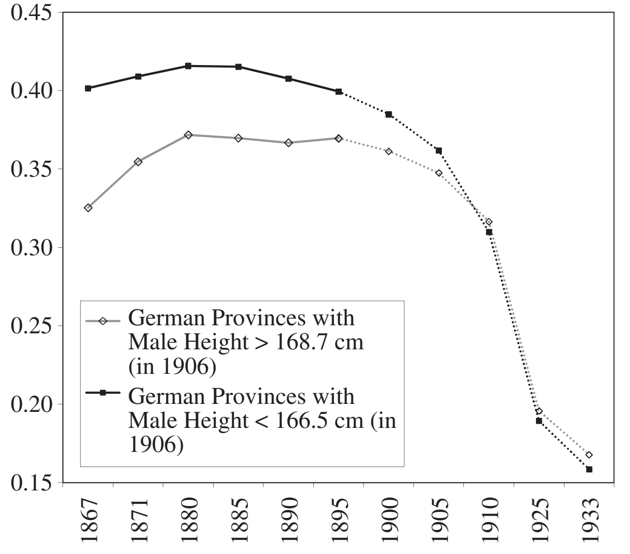

Fig. 2. *Fertility Rates in Germany*
Sources. Baten (2003) for height data; Knodel (1974) for fertility data. Fertility is the ratio of total fertility rate to a benchmark.

2. The Model

The model is a continuous-time overlapping generations economy with endogenous fertility and mortality inspired by De la Croix and Licandro (1999) and Boucekkine *et al.* (2002), who modelled the link between longevity and education in a framework where all the demographic variables are exogenous. The interest of using continuous time rather than discrete is to be able to model *length* of schooling and *length* of life in a meaningful way.

There is a continuum of dynasties defined in the time domain. However, a dynasty is an ordered sequence of individuals born at different points in time. In the following, the individual problem is solved first, then the dynasty problem and finally the aggregates.

2.1. *Individuals*

Let us denote by B the age of puberty, i.e. the age at which individuals acquire regular fertility. B is assumed to be strictly positive and constant. Individuals reaching puberty at time t are said to belong to cohort t, whose size is denoted by $P(t)$. Life expectancy at age B is denoted by $A(t)$, which is referred to as life expectancy below. We abstract from infant mortality, and assume that the survival law is rectangular, with mortality rates equal to zero for ages below $B + A$, and individuals dying with probability one at this age. Consequently, $B + A$ is life expectancy at birth. Individuals are assumed to become adults after reaching puberty,[9] with preferences represented by (we drop the cohort index to ease the exposition)

[9] Modelling family behaviour is not a simple issue. As children grow, parents increasingly take child preferences into account, but retain an important decision power until offspring find a job, leave home and become fully independent. As modelling this complex process is beyond the objective of this article, we assume that children become fully independent instantaneously at puberty.

$$\int_0^A c(t)\ \mathrm{d}t + \left(\beta \ln \hat{n} + \delta \ln \hat{A}\right). \tag{1}$$

Preferences are linear in consumption $c(t)$ and the time preference parameter is assumed to be zero. Under this assumption, the equilibrium interest rate is zero and the marginal value of the intertemporal budget constraint, the associated Lagrange multiplier, is unity. In addition to their own consumption flow, individuals value the number of children, denoted by $\hat{n}$, as well as the life expectancy of their children, denoted by $\hat{A}$. Parameters β, the utility weight of the number of children and δ, the utility weight of the children's life expectancy are both strictly positive.

Preferences are consistent with the objectives pursued by human beings as a species. Of primary concern, let us impose the restriction

$$C = \int_0^A c(t)\ \mathrm{d}t \geq \bar{C}$$

where $\bar{C}$, $\bar{C} \geq 0$, represents subsistence consumption. It imposes the requirement that consumption is above a survival threshold.[10] Reproduction covers the two relevant dimensions in the transmission of genes: the quantity and survival of descendants. Modelling in this way allows parents to develop different fertility–mortality patterns.[11]

Human capital production depends on the time allocated to education, denoted by T:

$$h = \mu(\theta + T)^{\alpha}.$$

The productivity parameter μ and the parameter θ, which relates to schooling before puberty, are strictly positive and $\alpha \in (0, 1)$. θ ensures that human capital and hence income are positive even if individuals choose not to go to school after age B.

The budget constraint takes the form

$$\int_0^A c(t)\ \mathrm{d}t + \hat{n}\Psi(\hat{A}) = \mu(\theta + T)^{\alpha}(A - T - \phi\hat{n}). \tag{2}$$

The right-hand side is the total flow of labour income under the assumption that one unit of human capital produces one unit of good. Note however that real wages depend on education, being large if people study long. For simplicity, we assume that people have and raise their children immediately after finishing their studies but before becoming active in the labour market. This greatly simplifies the dynastic structure of the model. Raising a child takes a time interval of length $\phi > 0$, implying that individuals work for a period of length $A - T - \phi\hat{n}$. Parental expenditure on each child's development is

[10] Linear consumption utility is a simplifying assumption. The critical assumption is the existence of a subsistence level of consumption. When wealth is small enough, consumption is constrained by subsistence and the economy behaves as Malthus predicted. However, when wealth is large enough, the Beckerian mechanism relating fertility and output is at work. In this sense, we follow Galor and Weil (2000), who also impose a subsistence consumption level in their unified growth theory.

[11] Anderson *et al.* (2008) study the different fertility–mortality patterns developed by nature for different species.

$$\Psi(\hat{A}) = \kappa \frac{1}{2} \frac{1}{A} \hat{A}^2, \tag{3}$$

which implies that the expenditure is quadratic in $\hat{A}$ and inversely related to A. Expenditures Ψ can be seen as covering both nutrition and improvements in fighting diseases. Fogel (2004) shows the improvements in daily caloric supply in France and England over the period 1700–1989 (Table 1.2), although he stresses in the text that not all social classes benefited from this improvement. The History of Epidemics in Britain written in 1894 is full of examples of improvements in health affecting children: Concerning London in 1720, it is written that

> The life indoors was equally adverse to infants. (...) a tenement-house was apt to be pervaded by the excremental effluvia from the vault at the bottom of the stair. (...) Doubtless drink was then used, as it is sometimes now, to drug the fretful infants into torpor. (...) In all these respects there has been so great improvement in London that, although its population now exceeds four millions, its death-rate from infantile diarrhoea, a distinctively urban disease, exceeds only by a little the mean of all England and Wales.

Of course, such improvements result from overall improvements in infrastructure but also from changes in habits and from private investments in better houses.

The convex form of the function is consistent with many actual mechanisms through which investment may enhance health. One example is given by Dalgaard and Strulik (2006), where the metabolic energy to create a new cell is an exponential function of the body mass the individual wants to reach. Another example comes from the interpretation of (3) as a production function for health *à la* Grossman (1972). For an investment level Ψ made by a parent with life expectancy A, child's life expectancy is CRS in the two, $\hat{A} = (2A\Psi/\kappa)^{1/2}$. The exponent 1/2 is related to inter-generational transmission of longevity and can be compared to values found in the literature. Mevlude and Kugler (2008) explicitly estimated the parameter of the inter-generational transmission of height between mothers and children, on modern US data. They find values between 0.34 and 0.42, depending on the specification. The 0.5 assumed in the article is therefore not far from the 0.42 found in this article. Weight and Body Mass Index are also transmitted from parents to children with a similar rate.

Finally, by stressing the difficulty of raising life expectancy above that of the parents, this formulation is consistent with the complex interaction between nurture and nature observed by biologists and psychologists. The gains in the life expectancy of children resulting from parents' investments in childhood development (nurture) are conditional on parents' genes as measured by parents' life expectancy (nature). Parameter κ, $\kappa > 0$ measures the costs of developing children in a broad sense.

Figure 3 summarises the life cycle of a representative individual of generation z, born at $z - B$, becoming independent at z, going to school until $z + T$ and entering the labour market at $z + T + \phi\hat{n}$. Her children belong to generation $z + T + B$, as T is the age at which individuals have children, and children reach puberty after a period of length B. Individuals choose their own education T and the number, $\hat{n}$, and life expectancy, $\hat{A}$, of their children. Their choices depend on three types of parameters. First, those related to preferences, β and δ. Second, the parameters associated with

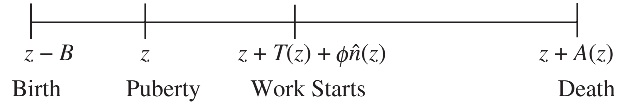

Fig. 3. *The Life Cycle*

child rearing and childhood development, ϕ, B and κ. Finally, the educational technology parameters θ, μ and α.

The maximisation of utility, (1) subject to the budget constraint (2) and to the positivity constraints $T \geq 0$ and $C \geq \bar{C}$, can result in interior or corner solutions. Note that the integral in (2) may be substituted into (1). The resulting objective function, depending on $\hat{A}$, $\hat{n}$ and T, is concave. We make the following assumption about preferences:

Assumption 1. *Preferences satisfy $\delta < 2\beta$.*

As can be seen in Proposition 1, Assumption 1 is required for $\hat{n}$ to be positive. It states that the preference weight attached to childhood development, δ, cannot exceed twice the weight attached to the number of children, β. The trade-off between the number of children and their survival depends on the ratio of marginal utilities to marginal costs, which crucially depends on a factor of two because of the quadratic form of the childhood development costs. A similar condition can be found in De la Croix and Doepke (2009), when parents face the standard fertility/education trade-off.

Let us make the following assumptions about the education technology:

Assumption 2. *The productivity of education technology satisfies:*

$$\mu > \max\left[\frac{(\beta-\delta/2)\alpha^2}{\theta^{1+\alpha}(1+\alpha)}, \frac{\delta\alpha}{2\theta^{1+\alpha}}\right] \equiv \underline{\mu}.$$

This assumption requires the productivity co-efficient, μ, to be large enough. Let us establish the main proposition of individual behaviour.

Proposition 1. *Under Assumptions 1 and 2, there exist two thresholds $\underline{A}$ and $\bar{A}$, $0 < \underline{A} < \bar{A}$, such that: If $A \geq \bar{A}$, there is a unique interior solution satisfying*

$$\hat{A}^2 = \frac{\delta}{\kappa\hat{n}}A, \tag{4}$$

$$T = \frac{\alpha}{1+\alpha}(A-\phi\hat{n}) - \frac{\theta}{1+\alpha}, \tag{5}$$

$$\hat{n} = \frac{\beta-\delta/2}{\mu\phi}(\theta+T)^{-\alpha}. \tag{6}$$

If $\underline{A} \leq A < \bar{A}$, *there is a unique corner solution with consumption above subsistence satisfying*

$$\hat{A}^2 = \frac{\delta}{\kappa \hat{n}} A, \tag{7}$$

$$T = 0, \tag{8}$$

$$\hat{n} = \frac{\beta - \delta/2}{\mu \phi \theta^{\alpha}}. \tag{9}$$

If $\bar{C}/\mu\theta^{\alpha} < A < \underline{A}$, *there is a unique corner solution with subsistence consumption satisfying*

$$\hat{A}^2 = \frac{\delta}{\kappa} \frac{\mu \theta^{\alpha} \phi}{\beta - \delta/2} A, \tag{10}$$

$$T = 0, \tag{11}$$

$$\hat{n} = \frac{\beta - \delta/2}{\beta \phi} A - \frac{\beta - \delta/2}{\beta \phi \mu \theta^{\alpha}} \bar{C}. \tag{12}$$

Proof. Using the Kuhn–Tucker conditions for constrained optimisation, we can identify the two thresholds $\underline{A}$ and $\bar{A}$, and characterise the different regimes. See online Appendix A.

At the interior solution, $A \geq \bar{A}$ in Proposition 1, (5) and (6) determine schooling and fertility, T and n respectively. An increase in individuals' life expectancy A makes the return to education larger, inducing individuals to study longer. This is the well known Ben–Porath mechanism. As a consequence, the marginal cost of having children becomes larger dissuading parents from having as many children as before. Finally, (4) shows the trade-off faced by parents between the number and the life expectancy of their children. The relation is negative, as the total cost of providing children with good physical development increases as their number increases. As a consequence, a raise in parents life expectancy induces an additional increase in the life expectancy of their children. It is interesting to see that despite the assumption of quasi-linear preferences, linear in consumption, fertility and child development choices depend on individual rents at the interior solution, making the elasticity of fertility with respect to income work the right way.

When $\underline{A} \leq A < \bar{A}$, parental life expectancy A is not long enough to render optimal a positive investment in education. For lower levels of life expectancy, i.e. when $A < \underline{A}$, education is zero and consumption is at subsistence. Expected life time earnings are so low that parents use all their resources in bearing a limited number of children. Life expectancy A has to be strictly larger than $\bar{C}/\mu\theta^{\alpha}$, otherwise individuals cannot support the minimum consumption $\bar{C}$.

From now on, the interior solution (4)–(6), and the corner solutions (7)–(9) and (10)–(12), are referred to as $\hat{A} = f_A(A)$, $T = f_T(A)$ and $\hat{n} = f_n(A)$. The effect of an increase in A is given by Corollary 1:

Corollary 1. *$f'_A(A) > 0$; $f'_n(A) < 0$ for $A \geq \bar{A}$, $f'_n(A) = 0$; for $\underline{A} \leq A < \bar{A}$, and $f'_n(A) > 0$ otherwise $f'_T(A) > 0$ for $A \geq \bar{A}$, and $f'_T(A) = 0$ otherwise.*

Proof. See online Appendix A.

In the interior solution, increased life expectancy raises optimal schooling and human capital levels via the Ben–Porath effect. This increases the opportunity cost (time cost) of raising children. Hence, the optimal number of children drops as life expectancy increases.

In the corner solutions, as $T = 0$, a change in parental life expectancy does not affect education, cancelling the Ben–Porath effect. In the corner regime (7)–(9), the number of children remains constant whatever the life expectancy, but childhood development is still positively affected by life expectancy as the efficiency of child physical development activities depends positively on parental life expectancy. However, in the corner regime (10)–(12), when consumption is at the subsistence level, the effect of life expectancy on the number and survival of children reverses, as the number of children is directly determined by the $C = \bar{C}$ constraint, which allows for more children as life expectancy, and hence life-cycle income, increases. This is a pure income effect as in the Malthusian 'positive check' hypothesis.

2.2. *Dynasties*

Since individual decisions do not depend on aggregate variables, we can study the dynamics of life expectancy, fertility and education within dynasties separately, before the analysis of the aggregates.

Let us consider the dynamics of life expectancy first. At any point t, individuals reaching puberty belong to a representative dynasty with life expectancy $A(t)$. Let us denote as A_1 the life expectancy of the first generation of this dynasty. The operator f_A defined above consists in a different equation governing the evolution of the dynasty's life expectancy as

$$A_{i+1} = \hat{A}_i = f_A(A_i),$$

where the index $i = 1, 2, 3, \ldots$ is associated with generations. From Proposition 1, for any initial value A_1 there exists a sequence of solutions $T_i = f^i_T(A_1)$, $\hat{A}_i = f^i_A(A_1)$ and $\hat{n}_i = f^i_n(A_1)$ for $i = 1, 2, 3, \ldots$, where X^i is the ith consecutive application of operator X. In the following, we characterise the dynamics of life expectancy. Once this has been done, the sequence $\{A_1, A_2, \ldots\}$ determines through the operators f_T and f_n the date and size of the following generations.

Proposition 2. *Under Assumptions* 1 *and* 2*, a stationary solution $A = f_A(A)$ exists, is unique and globally stable.*

Proof. See online Appendix A.

Proposition 2 states that life expectancy converges to a constant value in the long run. Consequently, from Proposition 1, fertility and education also converge to a constant value. Demographic variables are then stationary, meaning that the demographic transition only occurs, as the name itself indicates, as a transitional phenomenon.

The results obtained so far allow us to assess some theoretical characteristics of the demographic transition in our model. Consider Figure 4. The lower panel plots the function $f_A(A)$. It describes a situation where the globally stable steady state is in the modern regime. The top panel shows fertility as a function of life expectancy. Suppose now that initial life expectancy is very low, below $\underline{A}$. The dynamics of life expectancy will be monotonic and converge to the steady state. A rise in life expectancy will first drive fertility up (as long as the economy is in the Malthusian regime $A < \underline{A}$) then fertility will peak in the zone where, $\underline{A} \leq A < \bar{A}$ (i.e. where $T = 0$, but $C > \bar{C}$) and then decrease in the modern era. (Secondary) schooling will be zero until we reach the modern regime and will then increase monotonically at the time fertility is decreasing. This sharp characterisation is very much in line with the stylised facts of the demographic transition as reported in Figure 1.

In this description of the theoretical dynamics, we have assumed a steady state in the interior regime. A condition for such a situation to occur is given by Remark 1.

Remark 1. *The steady state is in the modern regime if,*

$$\kappa < \frac{4\alpha\delta\theta^{2\alpha}\mu^2\phi}{(2\beta-\delta)[\alpha(2\beta-\delta)+2\theta^{1+\alpha}\mu]} \equiv \bar{\kappa}. \tag{13}$$

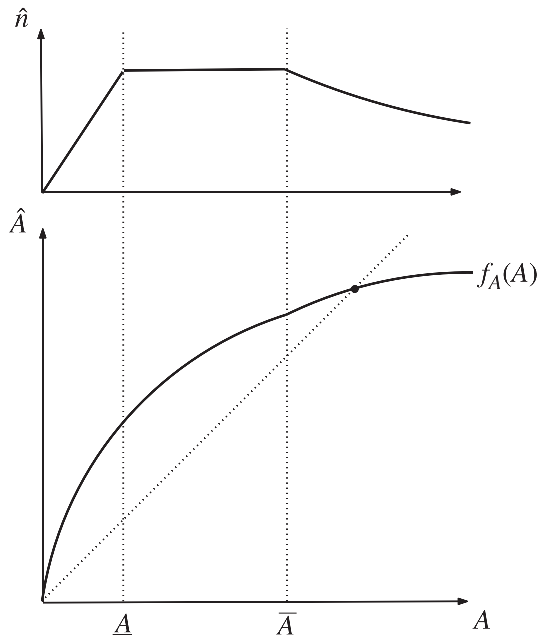

Fig. 4. *A Steady State in the Interior Regime*

Proof. See online Appendix A.

Condition (13) states that if the childhood development technology is cheap enough, there is an interior steady state with positive education. Changing the value of κ is a natural way of generating a demographic transition: if κ is initially high, the economy may be in one of the corner regimes. Once κ decreases, childhood physical development becomes more affordable and the new steady state may move to the modern regime with life expectancy converging monotonically.

3. Simulating the Demographic Transition

In this Section, we investigate to what extent changes in the cost of childhood development help to reproduce the key facts of the demographic transition. The transition is studied as the reaction to a change in the environment which occurred slowly from 1700 and led the economy to a new balanced growth path in the twenty-first century characterised by longer lives. For this purpose, we implement a change in cost of childhood development as measured by parameter κ and analyse how the economy adjusts to this change.[12]

3.1. *The Change in Parameter κ*

Before analysing the demographic transition as a response to a reduction in the cost of childhood development, we need to discuss briefly the interpretation to be given to such a change. The quantitative exercise requires, as explained in the following subsection, a slow and long reduction in κ which started in the 18th century and lasted to the Modern era, with more than 80% of this reduction occurring between 1840 and 1960. Reducing the cost of child physical development may be as a result as improvements in hygienic habits, medical treatments and nutrition. The references below claim that improvements in these dimensions started in fact, before the nineteenth century.

Johansson (1999) argues against the therapeutic nihilism that denies medicine had any effectiveness before the end of the nineteenth century. First, in the period 1500–1800, medicine showed an increasingly experimental attitude: no improvement was effected on the grounds of the disease theory (which was still mainly based on traditional ideas) but significant advances were made based on practice and empirical observations. For example, although the theoretical understanding of how drugs work only came progressively in the 19th century with the development of chemistry (Weatherall, 1996), the effectiveness of the treatment of some important diseases was improved, thanks to the practical use of new drugs coming from the New World. Second, the number of books containing lifestyle advice increased significantly over the period 1750–800, which provides some indirect evidence of the fact that personal and domestic cleanliness, for example, became popular before the nineteenth century. Third, as early as 1829, Dr. F.B. Hawkins wrote a book entitled *Elements of Medical*

[12] A more sophisticated version of the model, in line with Galor and Weil (2000), would allow the demographic transition to be associated with an endogenously generated industrial revolution. This could be achieved by letting the physical development technology, as measured by the inverse of κ, depend upon population size or density, for example.

Statistics, in which he described what could be called an early modern epidemiological transition. He describes a set of diseases which were the leading causes of death, but could at the time be treated effectively: leprosy, plague, sweating sickness, ague, typhus, smallpox, syphilis and scurvy. The cumulative effects of these improvements could have produced a net increase in the efficacy of medicine as early as the beginning of the nineteenth century; see De la Croix and Sommacal (2009) for further arguments.

However, medicine did not play a major role during the 19th century as claimed by Omran (1971): 'The reduction of mortality in Europe and most western countries during the nineteenth century … was determined primarily by ecobiologic and socioeconomic factors. The influence of medical factors was largely inadvertent until the twentieth century, by which time pandemics of infection had already receded significantly.' In the same vein, Landes (1999), referring to the first half of the 19th century, argues that: 'Much of the increased life expectancy of these years has come from gains in prevention, cleaner living rather than better medicine.' He relates it to reductions in the price of washable cotton, along with the mass production of soap. In a recent survey conducted by the *British Medical Journal*, medical professionals consider the sanitary revolution of the 19th century as the major medical milestone since 1840, leading medical innovations as antibiotics, anaesthesia and vaccines.

The fundamental role of nutrition improvements on the reduction of mortality during and before the Industrial Revolution has been stressed by McKeown and Record (1962), and recently restated by Harris (2004). For example, after potatoes were brought in Europe from the New World, and following the study by French physician Parmentier (Examen chymique des pommes de terres, Paris, 1774) who showed their enormous nutritional value, the annual potato crop soared in Europe in the first half of the nineteenth century. Potatoes were adopted by households as they became affordable, yielding from two to four times more calories per acre than grain does. Here there are individual choices to grow, sell and consume potatoes, as well as knowledge externalities which helped to reduce the cost of feeding children, in particular.

3.2. *The Demographic Transition*

3.2.1. *Calibration*

Some parameters are set *a priori*. Subsistence consumption is normalised to zero. The age of puberty, B, is assumed equal to 13.5 (average between women, 12 and men, 15). The rearing cost per child, ϕ, is set to two years. The elasticity of human capital to schooling, α, is equal 1/6, which is a conservative value. Finally, the length of basic skills, θ, is equivalent to six years. We next calibrate the remaining parameters to reproduce a steady state having the following properties in the pre-1700 balanced path: low life expectancy at age B ($A = 29$), no education after puberty ($T = 0$) and a population growth rate of 0.5% per year. We also set the parameters to obtain the thresholds $\underline{A} = 31$, which ensure that the economy is initially in the Malthusian regime and ends in the modern regime. Parameters μ, κ, δ and β have been computed to match the properties given above. This leads to the following results: $\mu = 0.7418$, $\kappa = 1.7315 \equiv \kappa_0$, $\delta = 57.4256$ and $\beta = 31$. For these values, the life expectancy threshold leading to the modern regime, $\bar{A}$, is 38.2872, and Assumption 1 and 2 hold.

The demographic transition is generated by a change in the cost of childhood development increasing life expectancy to 76.5 years at the new steady state (implying $B + A = 90$ in 2100 from Li and Lee (2005)), which requires $\kappa = 0.7315 \equiv \kappa_1$. This change is assumed to take place smoothly, following a logistic curve:

$$\kappa(t) = \kappa_0 + \frac{\kappa_1 - \kappa_0}{1 + e^{1900-t}/50}.$$

Under these assumptions, most of the change takes place after 1840,[13] which is consistent with the observed effect on life expectancy, as depicted in Figure 5 below of the medical discoveries, prevention practices and nutrition improvements described in Section 3.1. We also assume that $\kappa(t)$ is specific to generation t. Hence, any change only affects new generations leaving past decisions unaffected.

3.2.2. *Simulation*

Figures 5 and 6 compare the simulation results with the Swedish data reported in Section 1. The model matches very well the monotonic increase in cohorts' life expectancy. Simulated cohorts' secondary education remains nil up to the beginning of the 20th century, as in the Swedish data, and monotonically increases since then, to the extent that the economy enters the modern regime. Cohorts' fertility per women first increases as long as the economy is in the Malthusian regime, then peaks in the intermediary regime, to monotonically drop as a consequence of the trade-off between education and the number of children in the modern era. Notice that, vertical axes have different scales for simulation (right axis) and data (left axis) on the pictures for

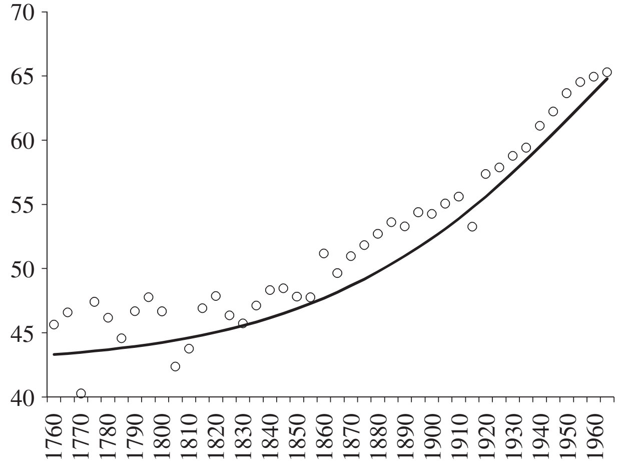

Fig. 5. *Example of Dynamics – Drop in κ – Effect on A*
Note. Dots: data (left axis), solid line: simulation (right axis).

[13] If instead, the change in κ was discrete, we would observe intervals of times with no births corresponding to periods where everybody increases their length of schooling in a discrete way, giving rise to permanent replacement echoes which are typical of models with delays (Boucekkine *et al.*, 1997*a*). In this case, the economy keeps fluctuating forever, moving from baby booms to baby busts. Non-monotonic convergence also occurs in the Galor and Weil model – see Lagerloef (2006).

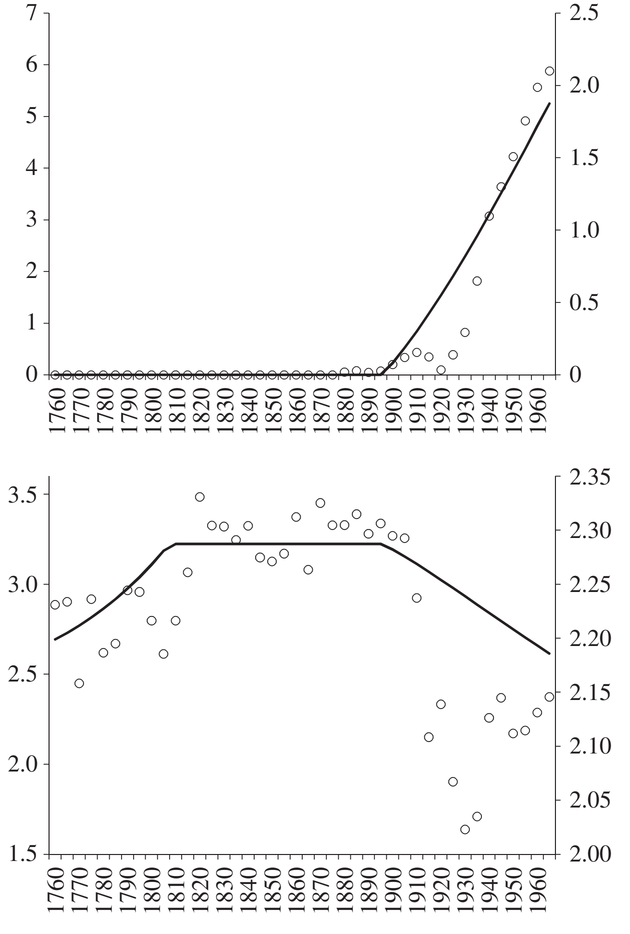

Fig. 6. *Example of Dynamics – Drop in* κ *– Effect on* T *and* n

Note. Dots: data (left axis), solid line: simulation (right axis).

education and fertility. Indeed, in the case of education, the simulation reproduces about one third of the total increase and even less in the case of fertility. This is not surprising since the simulation completely neglects sources of change other than the drop in the cost of health, such as the rise of education policy and changes in the skills demand by firms. We conclude that our model is able to capture the key qualitative features of the data but one would need a richer model if the aim is to reproduce the magnitudes well.

3.2.3. *Possible extension to the developing countries*

The simulation above anchors the model in Western Europe's demographic transition. Modern transitions in developing countries differ from the historical experience in two ways. First, successful transitions have occurred much more rapidly and at lower income levels than in the past. The speed of the demographic transition in the model is governed by two factors: the exogenous speed of change in the cost of childhood development and the internal propagation mechanism relating fertility and longevity decisions with the dynamics of overlapping generations. As far as the first element is concerned, it seems reasonable to assume that the speed of the exogenous progress was higher in developing countries, as most medical knowledge had not to be reinvented and was readily available from developed countries (for example, vaccines have not to be researched for). Hence, the model can generate much faster transitions by assuming a fast drop in κ; the dynamics of the population still impose a minimum feasible delay between the drop in κ and the corresponding increase in life expectancy and drop in fertility. Secondly, the fact that a number of developing countries in Africa did not reduce their fertility (yet) despite some rise in life expectancy (still very low in sub-saharian Africa) may be related to other factors absent from our model, as gender discrimination. Indeed, in a non-unitary model of the family, it is the mother who would bear most of the opportunity cost of having children (De la Croix and Vander Donckt, 2010). If she is discriminated on the labour market, fertility would not react to women's life expectancy.[14]

3.3. *Regional Variations*

We conclude from the above simulation exercise that our model is able to reproduce the main features of the demographic transition. Another question is whether we can also shed some light on regional variations in the demographic transition. Considering the German data presented in Figure 2, we have seen that adult height (a proxy for childhood development) and fertility were negatively associated across provinces on the eve of the twentieth century.

At that time, the prevailing regime is the one where consumption is above subsistence but it is not yet optimal to invest in (secondary) education. One reason for different places exhibiting different fertility and height levels during this phase of demographic transition is that the productivity parameter μ could vary in different places. The high μ regions will have lower fertility and taller citizens, as it is clear from (7) and (9). A similar argument can be made by letting the other parameters vary across regions. For example, regions with a higher θ or ϕ will also have tall parents with few children.

In Figure 2, we also observe that differences across regions seem to vanish as soon as the interior regime is reached in the beginning of the twentieth century. This convergence could reflect a reduction in the variance of the distribution of μ across regions, which would be the case, for example, if the education system is increasingly framed by a central authority.

4. From Malthus to Modern Growth

The transition from a world of low economic growth with high mortality and high fertility to one with low mortality and fertility but sustained growth, has been the

[14] It might be the case that discrimination against women was also prevalent in Western Europe at the time of the demographic transition, but the slow pace of this transition left time for discrimination to shrink. In the case of Africa and other least developed countries (LDCs), the transition is faster, and discrimination against women still needs time to disappear.

subject of intensive research in recent years.[15] In this literature, the relation between growth and fertility results from the quantity/quality trade-off faced by parents between the number of children and their education. Indeed, the gradual increase in the observed level of human capital during the 19th century 'has led researchers to argue that the increasing role of human capital in the production process induced households to increase investment in the human capital of their offspring, ultimately leading to the onset of the demographic transition' (Galor, 2005*b*).

A key open question is what is at the basis of the initial improvements in human capital. This article stresses the role of life expectancy and its determinants.

4.1. A *Growth Model*

We introduce endogenous growth to the model in Section 2 by adding a human capital externality in the education technology:

$$h = \mu(\theta + T)^{\alpha}\bar{H},$$

where $\bar{H}$ is human capital per worker. It may reflect, for example, the quality of education or the cultural ambience in the society.

To keep utility balanced in a growing economy, we assume that preferences are

$$\int_0^A c(z)\ \mathrm{d}z + \bar{H}\big(\beta \ln \hat{n} + \delta \ln \hat{A}\big), \tag{14}$$

where $\bar{H}$ now multiplies the term associated with children, implying that the value of children also grows with cultural ambience in the society. Finally, for similar reasons, childhood development costs are also indexed on average human capital per worker:

$$\Psi(\hat{A}) = \kappa\, \frac{1}{2}\frac{\bar{H}}{A}\hat{A}^2. \tag{15}$$

These assumptions do not affect the household decision problem and all the results in the previous Sections can be applied directly.

4.2. *Aggregates*

Aggregation of the model is possible because of explicit and implicit neutrality assumptions of human capital on the aggregate level. Utility is balanced by a human capital externality, and wages per unit of human capital are fixed exogenously. There are no general equilibrium effects from aggregate education and fertility dynamics. Allowing for feedbacks on the macro level would make the model impossible to solve analytically.[16]

[15] Rostow (1960) presents an early attempt to understand the transition from stagnation to growth. The first modern treatment of the issue is in the seminal article by Galor and Weil (2000). See Doepke (2008) for a recent survey.

[16] It would also make the numerical resolution more difficult, requiring the use of algorithms such as those developed by Boucekkine *et al.* (1997*b*). Dynamics would be altered with more propagation due to the forward looking elements. Compared with the existing literature, we substantially improved the modelling compared to simple two period life overlapping generations model. Moving further by incorporating the forward looking dimension could be seen as a next step.

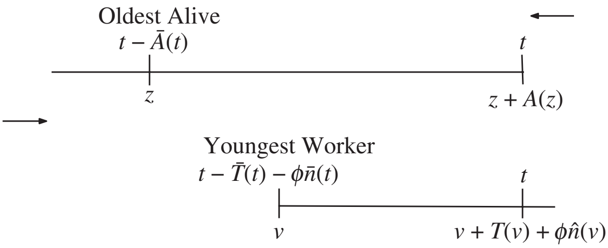

Fig. 7. *Life Cycle (from left to right) and Living Cohorts (from right to left)*

Some definitions are useful to study the dynamics of population growth and output growth. In Figure 7, t and z represent time and cohort respectively. Let us define $\tilde{A}(t)$ as the age of the oldest cohort still alive at time t, which then represents the life expectancy at time t of cohort $t - \tilde{A}(t)$. By definition, $A(z)$ is the life expectancy of cohort z. Then, given that generations z and $t - \tilde{A}(t)$ are the same, $A(z)$ has to be equal to $\tilde{A}(t)$, implying that

$$\tilde{A}(t) = A[t - \tilde{A}(t)].$$

A similar argument applies to functions $T(\cdot)$ and $\hat{n}(\cdot)$. Let us define $\tilde{T}(t)$ and $\tilde{n}(t)$ as the schooling time and the number of children of the youngest cohort entering the labour market at time t, i.e. cohort $v = t - \tilde{T}(t) - \phi\tilde{n}(t)$ in Figure 7. As $\tilde{T}(t) = T(v)$ and $\tilde{n}(t) = \hat{n}(v)$,

$$\tilde{T}(t) = T[t - \tilde{T}(t) - \phi\tilde{n}(t)]$$

and

$$\tilde{n}(t) = \hat{n}[t - \tilde{T}(t) - \phi\tilde{n}(t)].$$

Total population is computed by integrating over all the living cohorts:

$$N(t) = \int_{t-\tilde{A}(t)}^{t+B} P(z)\,\mathrm{d}z, \tag{16}$$

from the oldest $t - \tilde{A}(t)$ to the youngest $t + B$. The cohort size $P(z)$ is given by

$$P[z + T(z) + B] = \hat{n}(z)P(z), \tag{17}$$

as members of cohort z have $\hat{n}(z)$ children at time $z + T(z)$, who belong to cohort $z + T(z) + B$.

Aggregate human capital is defined by the human capital of active cohorts

$$H(t) = \int_{t-\tilde{A}(t)}^{t-\tilde{T}(t)-\phi\tilde{n}(t)} P(z) \underbrace{\mu[\theta + T(z)]^{\alpha}\bar{H}(z)}_{h(z)}\,\mathrm{d}z \tag{18}$$

where average human capital per worker is given by

$$\bar{H}(t) = \frac{H(t)}{E(t)},$$

and total employment $E(t)$ is

$$E(t) = \int_{t-\tilde{A}(t)}^{t-\tilde{T}(t)-\phi\tilde{n}(t)} P(z)\mathrm{d}z.$$

The technology producing the consumption good, the only final good in this economy, is linear in aggregate human capital with productivity one, implying that the real wage per unit of human capital is unity. Output per capita is then $H(t)/N(t)$.

4.3. *Balanced Growth Path*

A balanced growth path is an equilibrium path where population grows at rate η, human capital at rate γ and the demographic variable T, n and A are all constant. From (17), the growth rate of cohorts' size is such that $\mathrm{e}^{\eta(T+B)}=n$, i.e.

$$\eta = \frac{\ln(n)}{T+B},$$

with $P(t) = P^*\mathrm{e}^{\eta t}$, $P^* > 0$. The population growth rate depends on the fertility rate n and on the age at child's birth $B + T$. At a given fertility rate, the smaller the parental age at birth, the larger the frequency of births and thus the population growth rate.

Total population as defined in (16), evolves along a balanced growth path following:

$$N(t) = N^*\mathrm{e}^{\eta t} = P^* \frac{\mathrm{e}^{\eta B} - \mathrm{e}^{-\eta A}}{\eta}\mathrm{e}^{\eta t},$$

where the constants N^* and P^*, both strictly positive, depend on initial conditions. Population also grows at rate η and its size depends positively, as expected, on life expectancy. When η approaches zero, i.e. when population is constant, its size is given by $N(t) = P^*(B + A)$, which is the product of the cohort size and life expectancy at birth. Along a balanced growth path, the active population is given by

$$E(t) = E^*\mathrm{e}^{\eta t} = P^* \frac{\mathrm{e}^{-\eta(T+\phi n)} - \mathrm{e}^{-\eta A}}{\eta}\mathrm{e}^{\eta t}.$$

Similarly as for total population, when η approaches zero $E(t)$ converges to $P^*(A - T - \phi n)$, where the term in brackets is the length of active life.

Finally, the growth rate of human capital γ at the balanced growth path satisfies

$$\gamma = \frac{P^*}{E^*}\mu(\theta + T)^{\alpha}[\mathrm{e}^{-\gamma(T+\phi n)} - \mathrm{e}^{-\gamma A}].$$

To understand this result better, let us differentiate the definition of $H(t)$ in (18) with respect to time at the balanced growth path:

$$H'(t) = P(t - T - \phi n)h(t - T - \phi n) - P(t - A)h(t - A).$$

The change in aggregate human capital is the difference between the human capital of the youngest workers and that of the oldest. From the human capital technology and using the balanced growth path assumption

$$\gamma = \frac{H'(t)}{H(t)} = \frac{P^*}{E^*}\mu(\theta + T)^\alpha[e^{-\gamma(T+\phi n)} - e^{-\gamma A}].$$

The first term on the r.h.s, P^*/E^*, derives directly from the assumption that per worker human capital affects the human capital of the current cohort. If instead of normalising total human capital by E, we normalised it by P, this term would vanish. It basically corresponds to the length of active life. The second term reflects the fact that both the oldest and the youngest cohort share the same human capital technology with a common length of education. For this reason, the term $\mu(\theta + T)^\alpha$ is common. Finally, the last term in brackets reflects the fact that aggregate human capital was not the same at the time the two cohorts were at school, the difference depending on the growth rate itself and the age difference between the cohorts.

4.4. *Simulating the Transition to Modern Growth*

No theorem is available to assess the asymptotic behaviour of the solutions of our dynamic system directly, and in particular, whether income per capita converges to its balanced growth path.[17] In the simulation below though, the solution converges asymptotically to the balanced growth path.[18]

Figure 8 illustrates the complex relationship between the demographic transition and the transition from Malthus to Modern growth. As long as the economy is in the Malthusian regime, an increase in life expectancy induces an increase of the population growth rate. As fertility goes up, the associated rise in the dependency ratio reduces income *per capita*. In the intermediary regime, with consumption above subsistence but still no education, increases in life expectancy promote growth because it raises adult longevity and the number of workers per dependent children. Finally, in the modern era, the take-off of education generates an acceleration in growth and a switch to a balanced growth path with positive income growth.[19] Notice that the model does not generate enough growth compared with observations, as it relies only on population and human capital as the engine of growth.

5. Conclusion

The epidemiology literature stresses that life expectancy depends greatly on physical development during childhood. Both better nutrition and lower exposure to infections leads to increased height and a longer life. We have proposed a theory of the demographic transition based on this fact. The novel mechanism is that parents face a trade-off between the quantity of children they have and the amount they can afford to spend on each child's development. Parents like to have many children but they also care about their longevity. Having many children forces parents to spend less on the physical development of each child. If the cost decreases, parents will increase investment in

[17] No direct stability theorem is available for delay differential systems with more than one delay as the stability outcomes depend on the particular values of the delays. See Mahaffy *et al.* (1995).

[18] The simulation was performed using the method in Boucekkine *et al.* (1997*b*).

[19] The slowdown around 1900 is related to the fact that the first educated generations postpone their entry on the labour market.

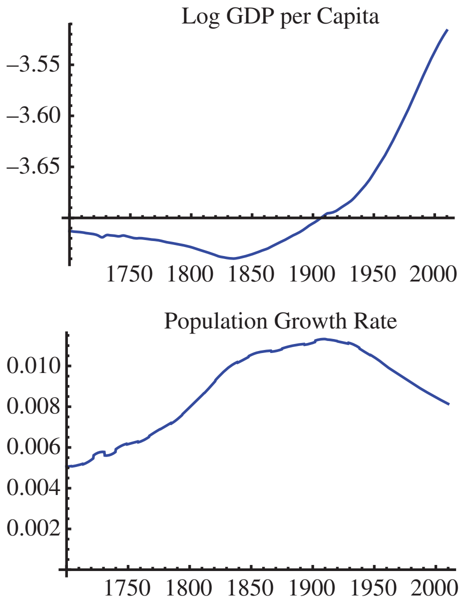

Fig. 8. *Example of Dynamics – Drop in κ – Human Capital*

their children's longevity. The number of children will first increase in the Malthusian regime as a consequence of higher lifetime income. As longevity rises, fertility starts falling as a result of the trade-off faced by parents between investing in their own human capital and spending time rearing children. Following the trade-off between the number of children and childhood development, adult longevity keeps increasing.

The model we have developed ably reproduces the characteristics of the demographic transition, displaying the appealing features that longer education delays birth and reduces fertility. Our theory can be seen as an alternative to the one based on a rise in the return to human capital investment induced by economic progress, leading parents to substitute quality for quantity. A distinctive implication of our theory is that improvements in childhood development should precede the increase in education. Taking height as a proxy for childhood development, we have observed just such a pattern in Swedish historical data.

Our theory can also provide an explanation for the puzzling fact that height at age 18 is a strong predictor of education attained later in life (Magnusson *et al.* (2006) showed that Swedish men taller than 194 cm were two to three times more likely to obtain a higher education than men shorter than 165 cm), even after controlling for parental socioeconomic position, other shared family factors and cognitive ability. A further test of our theory would consist of checking whether family size is related to childhood development as measured by average height on historical micro-data.

Clark (2007) argues that a Beckerian quality–quantity substitution could not have driven the British fertility transition as households leaving higher bequests were not those with smaller families. Our article sheds some light on this claim from two different angles. First, bequests are not the only vector of quality, health (and education) is another one. Second, our theory predicts indeed that health bequest should have been higher in small families at the time of the drop in fertility. But in our corner regime, bequests should be larger in larger families, which is in line with Clark's observation on testators in Suffolk, 1620.

In a more general framework, parents also care about child primary education and their own health during adulthood. The article shows that the modelling strategy of excluding these two additional features has been successful in replicating the key patterns of the demographic transition, with the additional benefit of making the description of the childhood development mechanism clearer. Adding the first assumption would help to replicate the evidence reported in Figure 1 that primary education in Sweden started to grow during the middle of the nineteenth century. The second feature would help to measure the relative contribution of child *versus* adult health efforts for the observed growth of adult life expectancy.

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Additional Supporting information may be found in the online version of this article:

Appendix A. Proofs of Propositions.

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