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ABSTRACT

Life Expectancy and Economic Growth: The Role of the Demographic Transition*

In this paper we investigate the causal effect of life expectancy on economic growth by explicitly accounting for the role of the demographic transition. In addition to focusing on issues of empirical identification, this paper emphasizes the role of the econometric specification. We present a simple theory of the economic and demographic transition where individuals' education and fertility decisions depend on their life expectancy. The theory predicts that before the demographic transition improvements in life expectancy primarily increase population. Improvements in life expectancy do, however, reduce population growth and foster human capital accumulation after the onset of the demographic transition. This implies that the effect of life expectancy on population, human capital and income per capita is not the same before and after the demographic transition. Moreover, a sufficiently high life expectancy is ultimately the trigger of the transition to sustained income growth. We provide evidence supporting these predictions using data on exogenous mortality reductions in the context of the epidemiological revolution.

JEL Classification: E10, J10, J13, N30, O10, O40

Keywords: life expectancy, demographic transition, epidemiological revolution, heterogeneous treatment effects

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1 Introduction

Across countries, high life expectancy is associated with high income per capita. But do improvements in life expectancy cause increases in per capita income? In theory, increasing life expectancy may have positive or negative effects. On the one hand, lower mortality may increase income per capita by increasing the productivity of available resources (most notably human capital). On the other hand, lower mortality may lead to an increase in population size. In the presence of fix factors of production a larger population tends to reduce income per capita. Evidence at the micro level points to a robust positive causal relationship between life expectancy and human capital, see Jayachandran and Lleras-Muney (2009).[1] Recent empirical investigations on the macro level, however, come to different conclusions about the causal impact of life expectancy on economic performance. Lorentzen, McMillan and Wacziarg (2008) use cross-country (longitudinal) data and find evidence for higher life expectancy leading to faster economic growth.[2] Acemoglu and Johnson (2007), on the other hand, find that improvements in life expectancy lead to some growth in aggregate incomes, but mainly trigger faster population growth, and therefore have a negative causal effect on income per capita.

Previous empirical investigations have mainly concentrated on the problem of the econometric *identification* of the causal effect of life expectancy by exploiting appropriate exogenous variation.[3] This paper complements the literature by focussing on the issue of the appropriate *specification* of the empirical analysis. In particular, we investigate the causal macroeconomic effect of changes in life expectancy on growth taking into consideration endogenous changes in fertility behavior and investments in human capital which are associated with the so-called demographic transition. We show that explicitly accounting for different phases of the demographic and economic transition that emerge along the development path allows for a reconciliation of the seemingly contradictory empirical findings.

We provide a simple theory that predicts that the causal effect of life expectancy varies across different stages of demographic development. This idea is motivated by the observation that the demographic transition represents a marked change in population dynamics, reflected by a pronounced drop in fertility that follows a reduction in mortality. The typical dynamics of the demographic transition are depicted in

[1]There is also evidence for a positive effect of health on human capital on the micro level, see e.g., Bleakley (2007), and Bleakley and Lange (2009). See also Thomas and Frankenberg (2002) for an extensive survey.

[2]Findings of a positive effect of life expectancy on income per capita based on cross-country regressions are reported by, e.g., Bloom and Sachs (1998), Gallup, Sachs, and Mellinger (1999), and Bloom et al. (2003). Using simulations based on microeconomic estimates to infer the role of health improvements for income per capita, Shastry and Weil (2003), Weil (2007) and Ashraf et al. (2008) also find positive, but smaller, effects on income per capita.

[3]Different identification strategies have been proposed in the literature. Lorentzen, McMillan and Wacziarg (2008) exploit permanent differences in the mortality environment related to geography, climate and the potential exposure to diseases like malaria. Acemoglu and Johnson (2007), on the other hand, exploit within-country variation in life expectancy in terms of shocks to mortality related to the introduction of better treatments like penicillin. More details are provided below.

Figure 1 (which reproduces Fig. 1.1 from Chesnais, 1992, and Fig. 4.2 from Livi-Bacci, 1992).[4] Initially, both birth and death rates are high and natural population growth is low. At some point in time, A, mortality begins to fall, while fertility still remains high. The consequence is an increase in the natural rate of population growth.[5] Fertility begins to fall only with some delay, at time B, thereby leading to a reduction in birth rates. The reduction in fertility eventually leads to a reduction in the rate of population growth. In the usual terminology, a country experiences a demographic transition when the natural rate of population growth begins to fall in response to reductions in mortality and fertility. In other words, the demographic transition is observed when the reduction in fertility is sufficiently pronounced to compensate for the mechanical increase in population due to the lower mortality.

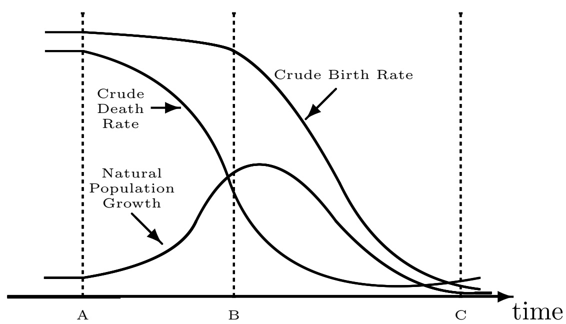


Figure 1: The Stages of the Demographic Transition

The main predictions concerning the causal effect of life expectancy for income per capita can be illustrated by looking at Figure 1. Consider an exogenous reduction in mortality in a country during phase $[A, B]$. As long as fertility rates remain high, the mortality reduction leads to an acceleration in population growth, which, in turn, tends to reduce income per capita by increasing the population base. The opposite effect emerges for a country that has already undergone the demographic transition and experiences an exogenous increase in life expectancy during phase $[B, C]$. In this situation, a drop in mortality accelerates the reduction in fertility thereby reducing population growth. This mechanism is complemented by the existence of a negative relationship between fertility and human capital investments along the process of development.[6] Hence, an additional positive effect on income that works through increased human capital and productivity becomes stronger when fertility falls in response to a drop in mortality. Taken together, these demographic and economic mechanisms imply that a negative Malthusian "population effect" may dominate the causal impact of life expectancy on income per capita until the onset of the demographic transition, while mortality reductions have an unambiguously positive effect on

[4] These patterns of the demographic transition have been well documented in historical and contemporaneous context, see also Chesnais (1992), Livi-Bacci (1992), Lee (2003), and Galor (2005).

[5] Notice that the picture plots crude birth and death rates, that is, the total number of births and deaths divided by the size of the total population alive at each point in time. In the initial phase after time A, the birth rates decline slightly as consequence of the increase in population size although total fertility is unchanged.

[6] See Galor and Weil (2000), Galor (2005), Soares (2005), and Cervellati and Sunde (2007).

per capita income when population growth falls. In addition, exogenous reductions in mortality increase the probability of triggering the demographic transition if they are large enough to bring a country out of the "high fertility - low education trap" that characterizes pre-transitional economies.

We empirically investigate these predictions using data for the period 1940 to 2000. We adopt an empirical specification that allows for different effects of life expectancy on per capita income, population growth and education depending on whether a country is pre-transitional or post-transitional at the beginning of the observation period in 1940. The identification of the stages of the transition follows the classification criteria used in the demographics literature. In order to account for problems of reverse causality and to investigate the causal effect of life expectancy on income per capita growth, we apply the data and identification strategy suggested by Acemoglu and Johnson (2007). Their instrument exploits within-country reductions in mortality predicted by the epidemiological transition which took place after 1940, and which was exogenous to a particular country's level of economic development.

We find that the effects of life expectancy improvements differ drastically depending on whether the country under consideration is pre-transitional or post-transitional. In countries before the demographic transition, the main effect of reductions in mortality is to accelerate population growth, which tends to reduce per capita income, while there is little effect on education. In countries that have completed the transition, however, reductions in mortality reduce population growth, accelerate human capital formation and increase income per capita. Consistent with the theoretical predictions, we find a positive and significant effect of life expectancy on the share of educated individuals in post-transitional countries. Most countries that are pre-transitional before 1940 experience reductions in fertility around 1970, although the effect on human capital is not significant by 1980. By 2000, however, the effect of life expectancy on education is positive and significant for all countries. This is consistent with the prediction of a positive but delayed response of human capital to reductions in mortality. Finally we find that improvements in life expectancy increase the probability of a country undergoing the demographic transition. Taken together, the empirical evidence strongly supports the theoretical predictions.

These findings have several implications. The results suggest a new interpretation of the existing evidence on the role of life expectancy for development. The seemingly contradictory findings in the literature can be reconciled by explicitly considering the effect of mortality on fertility and education choices. The findings also suggest that the causal effect of life expectancy that is estimated when the demographic transition is not accounted for, crucially depends on the composition of the sample in terms of pre-transitional and post-transitional countries. This implies that the economic interpretation of causal effects of life expectancy on income per capita obtained with linear specifications is problematic, because reductions in mortality influence the population and human capital dynamics non-linearly. Finally, the results have implications for policy, in particular in view of the fact that most developing countries have recently experienced the onset of the demographic transition.

The paper is structured as follows. Section 2 presents a simple theoretical framework that helps illustrate the main idea. Based on this theory we develop an estimation framework and discuss its empirical implementation in Section 3. Section 4 presents the main results, and Section 5 concludes. All proofs are collected in the appendix.

2 Mortality, Fertility, and Income per Capita

This section presents a simple micro-founded growth model which is used to frame the empirical analysis in the following section. The theory predicts different effects of mortality on (per capita) income in the different phases of (demographic) development and suggests that sufficiently large reductions in mortality are needed to trigger the economic and demographic transition.

2.1 Set-up

Consider a closed-economy neoclassical growth model in continuous time t along the lines of the model studied by Acemoglu and Johnson (2007). A unique consumption good is produced with a constant returns to scale aggregate production function

$$Y_t = (A_t H_t)^{\alpha} L_t^{1-\alpha} \tag{1}$$

where $0 < \alpha < 1$ and $L_t \equiv L$ denotes factors of production like physical capital or land that are taken to be in fix supply in the short and medium run.[7] The aggregate human capital (or the aggregate amount of effective units of labor) is supplied inelastically and given by,

$$H_t = h_t N_t \tag{2}$$

where h_t denotes the individual level of human capital and N_t is the size of population. Technology (or productivity) is captured by A_t.

In the short and medium run, improvements in health or life expectancy primarily influence total production by affecting technology, human capital and the size of population. Denote by T_t the level of life expectancy. In Acemoglu and Johnson (2007), the role of life expectancy for total factor productivity and human capital in reduced form is assumed to be iso-elastic

$$A_t = \overline{A} T_t^{\theta} \tag{3}$$

with $\theta \geq 0$ and

$$h_t = \overline{h} T_t^{\eta} \tag{4}$$

with $\eta \geq 0$. Reductions in mortality mechanically affect population size directly, since more people survive

[7]The assumption of a fixed stock of physical capital is without consequence for the main results, see also the discussion in Acemoglu and Johnson (2007).

at each point in time, and indirectly, if the likelihood of surviving until childbearing age increases. Both effects jointly imply that reduced mortality mechanically increases population size.[8] Restricting attention to iso-elastic specifications, these mechanical effects of mortality on population can be captured as

$$N_t = \overline{N} T_t^{\lambda} \tag{5}$$

or, in logs, $\ln N_t = \ln \overline{N} + \lambda \ln T_t$, with $\lambda > 0$. The level of log per capita income is then given by

$$\ln y_t = \alpha \ln A_t + \alpha \ln h_t - (1-\alpha) \ln N_t + (1-\alpha) \ln L_t \,. \tag{6}$$

Consider for the moment the stock of L_t as being independent from life expectancy which is a reasonable assumption in the short and medium run.[9] Using (3), (4) and (5) we have

$$\ln y_t = \pi \ln T_t + B_t$$

where $B_t = (1-\alpha) \ln L_t + \alpha \left(\ln \overline{A} + \ln \overline{h} \right) - (1-\alpha) \ln \overline{N}$ and

$$\pi = \alpha(\theta + \eta) - (1-\alpha)\lambda \gtrless 0 \tag{7}$$

where π is the parameter linking log per capita income to log life expectancy. Equation (7) illustrates the main source of ambiguity concerning the role of life expectancy for income per capita. If life expectancy increases population size, then income per capita is reduced in the presence of fixed factors of production and decreasing marginal productivity of N. This is a negative Malthusian "population effect": $-(1-\alpha)\lambda < 0$. Life expectancy, however, may have a positive "human capital" effect which tends to increase income per capita through its effect on productivity A and the stock of human capital, $\alpha\,(\theta + \eta) > 0$.

2.2 Fertility and Population Size

The theoretical prediction of an ambiguous effect of life expectancy on per capita income, reflected by (7), is derived under the assumption that fertility is constant, or at least unrelated to mortality. Note that the evolution of the population depends on the net rate of reproduction, NRR,[10] which is defined

[8] These mechanical effects are qualitatively identical. The direct effect has only temporary consequences, however, since it affects the level of population but not its long-run rate of growth (see Preston et al., 2001, pp. 158-159). To simplify illustration, and since only the change in the probability of childbearing have long run effects on population growth, we only consider this channel in our illustrative theory.

[9] Restricting attention to the medium run without adjustment of physical capital is without loss of generality for the argument. As shown in Acemoglu and Johnson (2007), considering a full adjustment of the capital stock only implies a larger effect of life expectancy on income per capita growth since the constraint of a fix factor of production is less binding. This has no implications for the prediction that the population and human capital effects of changes in life expectancy are of opposite signs before and after the demographic transition, however.

[10] The net reproduction rate, NRR, is the average number of daughters that would be born to a woman if she survived through her fertile age and conformed to the age-specific fertility and mortality rates. For simplicity, we restrict to a model of asexual reproduction, and therefore treat the net reproduction rate as the number of offspring born to a representative individual of a cohort.

as

$$NRR = np(\varphi) \ . \tag{8}$$

The variable n denotes the total fertility rate, TFR, which measures the number of children that would be born to an individual over her lifetime if that individual were to survive until the end of reproductive life. The variable φ denotes the mean age of reproduction, which is also referred to as the mean length of a generation. The probability of surviving until the (mean) age of reproduction φ is denoted by $p(\varphi)$ and depends on the death rates in infant, child and young ages. Equation (8) states that the natural rate of reproduction depends on planned fertility n net of mortality up to fertile age, $1-p(\varphi)$. Alternatively the NRR can be interpreted with reference to the whole population as the expected total number of children that the representative individual has during her fertile life.

Consider an initial period $t_0 = 0$ in which population size is given by N_0. Population at time $t \geq t_0$, after a period $\Delta t = t - t_0$, can be expressed as,

$$N_t = N_0 \left[NRR \frac{\Delta t}{\varphi} \right] \tag{9}$$

which implies that population grows in proportion to NRR.[11] Over the course of one generation, i.e., when $\Delta t = \varphi$, the population grows exactly by a factor NRR.

For simplicity, we keep assuming that the mechanical effect of population on life expectancy is reflected by an iso-elastic reduced form relationship (5), so that $\ln p(\varphi) = \lambda \ln T_t$. Making use of (8) and taking logs we can therefore rewrite condition (9) as,

$$\ln N_t = [\ln N_0 + \ln(\Delta t/\varphi) + \ln n_t] + \lambda \ln T_t \tag{10}$$

where $\lambda \geq 0$ captures the mechanical effect of mortality on population for given total fertility rates. Hence, mortality can affect the size of population by inducing changes in fertility, n, and by (mechanically) increasing the probability of surviving to mean age of childbearing, $p(\varphi)$.

Notice that if the total fertility rate n is constant, or independent from life expectancy, then equation (10) is qualitatively equivalent to the formulation (5), and reductions in mortality lead to a *larger* rate of population growth. If this is the only effect at work then $\partial \ln N / \partial \ln T = \lambda > 0$. In general, however, the total "population" effect implied by equation (10) depends on how life expectancy T affects the total fertility rate n. In fact, recalling the discussion of Figure 1, the response of fertility to mortality differs before and after the demographic transition. By its very definition, the demographic transition is identified by the reduction in fertility rates n, which is closely linked to the (preceding) reduction in mortality rates. In the notation of our model, a demographic transition takes place only when population growth falls in

[11] The evolution of population size could be equivalently expressed in terms of the implicit rate of population growth that is necessary to increase population size by an amount NRR within a period of time φ. In fact, equation (9), is the linear version of the relationship between the population growth rate and NRR in the Lotka stable population model (see Preston et al., 2001, p. 152).

response to a reduction of mortality (or an increase in life expectancy), that is $\partial \ln N / \partial \ln T < 0$. This is the case only when the reduction in fertility, $\ln n$, is larger than the mechanical effect on population size, $\lambda \ln T$. Once an economy enters the demographic transition, the reduction in fertility rates more than compensates the mechanical increase in population so that increases in life expectancy lead to lower rates of population growth. This implies that after the onset of the demographic transition the predicted effect of mortality reductions on per capita income is unambiguously positive. To obtain a more thorough understanding of the determinants of the net reproduction rate and human capital we next incorporate endogenous education and fertility choices into the framework.

2.3 A Simple Model of the Economic and Demographic Transition

Three main mechanisms that link changes in mortality to changes in fertility have been investigated in the literature. The first involves a precautionary demand for children by parents that care for the number of children surviving to adulthood in the presence of stochastic fertility and mortality, see Kalemli-Ozcan (2003). This precautionary demand effect is likely to be stronger in the context of mortality affecting young adults than for child and infant mortality, because replacing children is easier than replacing adult offsprings.[12] The second mechanism works through a shift from the quantity of children to their quality in response to their increasing longevity, see, Soares (2005). The third mechanism links life expectancy to fertility through individuals' acquisition of their own human capital, coupled with differential fertility between individuals with different education. Reductions in mortality increase the returns to investments in (own) education, as well as the (opportunity) cost of raising children. This creates a differential fertility effect which materializes in a negative relationship between parental education and fertility, see Cervellati and Sunde (2007).

These channels are likely to be jointly at work, and to complement each other, in explaining the reduction in fertility following reductions in mortality during to the demographic transition. We illustrate our argument by restricting attention to the third mechanism based on a differential fertility effect. We do this for two main reasons. First, this channel predicts a direct link between the observation of the demographic transition (reduction in mortality and fertility) and the economic transition (the acquisition of human capital). Second, a unique prediction that distinguishes this channel is that the reduction in fertility may take place with some delay after the reduction in mortality, since fertility reductions are observed only when the parent generation has completed their education and fertility. In fact, the consideration of a possible temporal mismatch between mortality reductions and fertility reductions may be important in interpreting empirical evidence over a time horizon of few generations.[13]

Consider the following simple theory of the economic and demographic transition. At each point in

[12] Technically, modeling this effect requires considering that parents derive utility only from children surviving to adulthood (which depends on $p(\varphi)$) within a non-homothetic formulation of preferences.

[13] The large body of evidence on differential fertility related to education is summarized in Skirbekk (2008).

time t there is a continuum of individuals alive with total mass N_t, which includes individuals of different cohorts. We identify cohort j by its date of birth. Members of a given age cohort j are homogeneous. To highlight the main point in the simplest way, we restrict attention to comparing steady states within a stable population model. In a stable population model, the net rate of reproduction can be non-zero in the long run and is independent of the age structure, which is constant.[14] Under these conditions the total lifetime fertility of a particular member of a cohort coincides with the fertility obtained by integrating across age cohorts at a particular point in time. This is convenient since it allows to directly map variables relating to cohorts j into variables relating to periods t. A useful implication of this is that for any given distribution of age specific mortality rates we have $n_t = n_j$.[15] For the purpose of conducting comparative statics with respect to life expectancy across steady states, this implies that the optimal (lifetime) fertility behavior of a representative individual of a particular cohort can be used to characterize the fertility behavior of the population at a given point in time. We can therefore focus attention to studying the optimal total fertility rate n_j in a representative cohort j.

Individuals of cohort j derive utility from their (lifetime) consumption, c_j, and the number of their children n_j,[16]

$$U_j = c_j^{\gamma} n_j^{1-\gamma} \ . \tag{11}$$

The main trade-off that individuals face is about the use of available lifetime. They can invest their time in acquiring human capital, raising children, and producing income. Denote by $e \in [0, T_j]$ the time that agents spend in acquiring human capital, i.e., to increase their effective labor. We follow Cervellati and Sunde (2005) and assume that investments in education are effective in increasing human capital only if they are large enough. We therefore assume that individuals are endowed with a basic level of human capital, $\overline{h}$. If no time is invested in education, then the level of effective labor is not increased. Formal education adds in terms of effective human capital only if it is sufficiently large. This is modeled as,

$$h_j = \max\left\{\overline{h} e_j^{\eta}, \overline{h}\right\} \tag{12}$$

with $\eta \in (0, 1)$.[17]

[14] Necessary conditions for a stable population are constant age-specific fertility and death rates, see Preston et al. (2001, ch. 7). In the model presented below, we follow the typical assumptions in the long-run growth literature and abstract from life cycle considerations as long as they satisfy these conditions.

[15] Notice that the age structure of the population is irrelevant for the main prediction that the population effect and human capital effect of mortality change with the demographic transition. Restricting to a stable population model is therefore without any loss of generality for the argument.

[16] The specification of preferences essentially follows Galor and Weil (2000), where the second component generates a link between generations that can be interpreted as a warm glow type of altruistic preferences. Given homothetic preferences, the optimal decisions are unaffected by assuming that utility depends on (planned) fertility rather than the number of surviving offspring or realized gross fertility. Also, it is implicitly assumed that individuals can perfectly smooth consumption as well as the utility from children over their life, but, crucially, they cannot perfectly substitute utility from their own consumption with utility derived from their offspring.

[17] This is formally equivalent to assuming that the production of human capital is characterized by a fix cost in terms of

Next, denote by $k(T_j)$ the total lifetime cost of raising a child,

$$k(T_j) = kT_j^{x(e)} \,. \tag{13}$$

In order to model the differential fertility associated with an individual's own education in the simplest way, we assume that the lifetime (opportunity) cost of raising children increases for educated parents so that and $x(e) = 1$ if $e = 0$ while $x(e) = 1 + x$ if $e > 0$ with $x \in (0, 1)$. We assume that $\eta\gamma > x(1 - \gamma)$. This parametric restriction implies that the returns to investments in education are large enough to compensate for the increasing (opportunity) cost of raising children so that investing in education may be profitable. This formulation implies that educated parents face a larger opportunity cost of fertility.[18] Taken together, (12) and (13) imply that the relative cost of education compared to raising children is decreasing with life expectancy, i.e., greater life expectancy induces the acquisition of more education and leads to lower total fertility rates n_j.

To simplify matters, and since there is no inequality in resource ownership, it is assumed that all income is distributed to human capital, so that the return to a unit of human capital equals its average product as in Galor and Weil (2000). Denote by $w_j(T_j)$ the average wage paid to each unit of effective human capital during the life of cohort j.[19] The lifetime budget constraint is,

$$c_j \leq w_j(T_j)\, h(e_j)\, [T_j - k(T_j)\, n_j - e_j] \tag{14}$$

where $w_j(T_j)\, h(e_j) T_j$ is the total potential lifetime income that would be earned by $h(e_j)$ units of effective labor for a lifetime T_j. The choice problem of agents in cohort j is given by,

$$\begin{aligned} \{n_j^*, e_j^*\} &= \arg \max_{n \geq 0, e \geq 0} c_j^{\gamma} n_j^{1-\gamma} \\ & \qquad s.t.\ (12) \text{ and the budget constraint } (14)\,. \end{aligned}$$

We next characterize the optimal total fertility rate and the optimal investments in human capital, and then derive the implications of reducing mortality for the patterns of the economic and demographic transition.

Lemma 1. *There exists a unique level of life expectancy* $\underline{T} = \left[\frac{(1+\eta\gamma)^{(1+\eta\gamma)}}{(\eta\gamma)^{\eta\gamma}}\right]^{\frac{1}{\eta\gamma - x(1-\gamma)}}$ *above which positive education investments are profitable. The equilibrium levels of human capital and fertility are given by:*

$$\begin{aligned} h_j^* &= \overline{h} && \text{and} \quad n_j^* = \tfrac{1-\gamma}{k}; && \text{if } T_j \leq \underline{T}; \\ h_j^* &= \overline{h}\left(\tfrac{\gamma\eta}{1+\gamma\eta}\right)^{\eta} T_j^{\eta} && \text{and} \quad n_j^* = \tfrac{1-\gamma}{(1+\gamma\eta)k} T_j^{-x} && \text{if } T_j > \underline{T}\,. \end{aligned}$$

time, $\underline{e} \geq 1$, which has to be covered for education to be effective, see, e.g. Cervellati and Sunde (2005).

[18] Notice that the acquisition of own education would also reinforce the fertility reduction in a quantity-quality framework *a la* Soares (2005) if educated parents face a lower cost producing educated children.

[19] This is given by

$$w(T) = \frac{\int_0^{\infty} w(a)\, p(a)\, da}{\int_0^{\infty} ap(a)\, da}$$

where $p(a)$ represents the probability of surviving until age a and life expectancy is given by $T = \int_0^{\infty} ap(a)\, da$.

Proof. See Appendix. □

The Lemma points out four implications of the model: 1) life expectancy must be large enough to induce investments in human capital; 2) the total fertility rate is, *ceteris paribus*, lower in absolute terms whenever the individual invests in education;[20] 3) education does not increase with T if $T_j \leq \underline{T}$, but education is increasing in T if $T_j > \underline{T}$; 4) life expectancy does not affect total fertility rates as long as $T_j \leq \underline{T}$, while total fertility decreases in life expectancy if $T_j > \underline{T}$.

In words, the optimal choice of education and fertility depends on whether the economy is characterized by a level of life expectancy below or above the critical level $\underline{T}$ that separates the pre-transitional and post-transitional demographic regimes. If mortality is too high and life expectancy too low, individuals do not find it profitable to make large investments in education. In this case, their low life expectancy constrains individuals in their education choices.[21] If life expectancy is sufficiently high, optimal investments in education are positive, and an increase in life expectancy leads to an increase in education investments and to a decrease in fertility.

Recall that with time invariant age specific death rates we have $n_t = n_j$ and $T_t = T_j$. The aggregate level of human capital can therefore still be expressed as in (2), $H_t = h_t N_t$ for any t. Using the equilibrium level of human capital from Lemma 1 we have,

$$\ln H_t = \begin{cases} \ln \overline{h} + \ln N_t & \text{if} \quad T_t \leq \underline{T} \\ \ln \overline{h} + \ln \left(\frac{\gamma\eta}{1+\gamma\eta}\right)^{\eta} + \eta \ln T_t + \ln N_t & \text{if} \quad T_t > \underline{T} \end{cases}$$

Using the equilibrium total fertility rate, the (log) net rate of reproduction is given by

$$\ln NNR_t = \begin{cases} \ln \frac{1-\gamma}{k} + \lambda \ln T_t & \text{if} \quad T_t \leq \underline{T} \\ \ln \frac{1-\gamma}{(1+\gamma\eta)k} - x \ln T_t + \lambda \ln T_t & \text{if} \quad T_t > \underline{T} \end{cases}$$

An economy experiences a demographic transition when the net population growth rate, NRR, falls in response to reductions in mortality. From Lemma 1 and considering the expression for $\ln NRR$, we have,

Lemma 2. *A country undergoes the demographic transition when* $\partial \ln NRR / \partial \ln T < 0$. *Hence, a demographic transition takes place if* $T_t > \underline{T}$, *and if*

$$x > \lambda \, . \tag{15}$$

The previous Lemma states that a necessary condition for observing a demographic transition is that life expectancy is large enough. Condition (15) implies that, in order for a demographic transition to be observed, the reduction in total fertility rates, n, must be larger than the mechanical increase in

[20] In light of the literature, this is consistent with differential fertility across different education groups.

[21] This mechanism would be at work in a pre-transitional phase also if subsistence levels in consumption were considered, see, e.g., Galor and Weil (2000) or de la Croix and Licandro (2009).

population size, λ, as consequence of a reduction in mortality. To illustrate the role of the demographic transition we assume that condition (15) holds.[22]

2.4 Effects of Life Expectancy on Population, Human Capital and Income

Recall the expression for log per capita income, (6),

$$\ln y_t = \alpha \ln A_t + \alpha \ln h_t - (1-\alpha) \ln N_t + (1-\alpha) \ln L_t \, .$$

Substituting the expression for population size at t, (10), and using the iso-elastic relationship between life expectancy and total factor productivity (3), we have

$$\begin{aligned} \ln y_t &= \alpha \ln \overline{A} + \alpha\theta \ln T_t + \alpha \ln h_t - (1-\alpha)(\ln n + \lambda \ln T_t) \\ &\quad -(1-\alpha)(\ln N_0 + \ln(\Delta t/\varphi))(1-\alpha)\ln L_t \end{aligned}$$

From Lemma 1 it follows that the effect of T on $\ln n$ and $\ln h$ depends on whether the country is pre-transitional or post-transitional. In pre-transitional countries, with $T \leq \underline{T}$,

$$\begin{aligned} \ln y_t^{pre} &= \alpha \ln \overline{A} + \alpha\theta \ln T_t + \alpha \ln \overline{h} - (1-\alpha)[\lambda] \ln T_t \\ &\quad -(1-\alpha)[\ln N_0 + \ln(\Delta t/\varphi) + \ln(1-\gamma) - \ln k](1-\alpha)\ln L_t \\ &= \zeta + \pi^{pre} \ln T_t - (1-\alpha)[\ln(\Delta t/\varphi)] \end{aligned} \tag{16}$$

where $\zeta = \alpha \left[\ln \overline{A} + \ln \overline{h}\right] - (1-\alpha)[\ln N_0 + \ln(1-\gamma) - \ln k](1-\alpha)\ln L_t$ and

$$\pi^{pre} = \alpha\theta - (1-\alpha)\lambda < (>)\, 0 \, . \tag{17}$$

Hence, in pre-transitional countries, a reduction in mortality increases population. The coefficient π^{pre} is therefore positive only if the externality of life expectancy on productivity A is sufficiently large to more than compensate the negative population effect.

Repeating the same reasoning for post-transitional countries with $T > \underline{T}$, we have

$$\begin{aligned} \ln y_t^{post} &= \alpha \ln \overline{A} + \alpha\theta \ln T_t + \alpha \ln \overline{h} + \alpha\eta \ln T_t + \alpha\eta \ln[\gamma\eta/(1+\gamma\eta)] + (1-\alpha)[x-\lambda]\ln T_t \\ &\quad -(1-\alpha)[\ln N_0 + \ln(\Delta t/\varphi) + \ln(1-\gamma) - \ln[(1+\gamma\eta)k]](1-\alpha)\ln L_t \\ &= \zeta + \pi^{post} \ln T_t - (1-\alpha)\ln(\Delta t/\varphi) + \sigma \end{aligned} \tag{18}$$

where $\sigma = \alpha\eta \ln[\gamma\eta/(1+\gamma\eta)] + (1-\alpha)\ln[(1+\gamma\eta)]$. The parameter of interest is given by

$$\pi^{post} = \alpha(\theta+\eta) + (1-\alpha)[x-\lambda] > 0 \tag{19}$$

[22]Cervellati and Sunde (2007) present a more general theory in which lower mortality induces parents to spend more time on their own education, thereby devoting less lifetime to work and reduce fertility. They also study the conditions under which a demographic transition can take place and present evidence on the role of differential fertility and mortality.

where we assume that condition (15) holds, so that, from condition (8) the net replacement rate decreases following the reduction in mortality, that is, the country has undergone the demographic transition. Notice that a drop in net fertility is only a sufficient but not a necessary condition for an increase in per capita income, however. In fact, π^{post} can be positive even if net fertility has not dropped yet due to the existence of a positive human capital effect $\alpha(\theta + \eta) > 0$.

We summarize the results in

Proposition 1. *An increase in life expectancy T implies:*

- *In pre-transitional countries, [i.e., $T \leq \underline{T}$]: an ambiguous effect on log per-capita income, $\partial \ln y / \partial \ln T < (>) 0$, a positive effect on the rate of population growth, $\partial \ln N / \partial \ln T > 0$, and a negligible effect on human capital, $\partial \ln h / \partial \ln T = 0$;*

- *In post-transitional countries [i.e., $T_i > \underline{T}$]: a positive effect on per-capita income, $\partial \ln y / \partial \ln T > 0$, a negative effect on the rate of population growth, $\partial \ln N / \partial \ln T < 0$, and a positive effect on human capital, $\partial \ln h / \partial \ln T > 0$.*

Proof. Follows directly from Lemma 1, (17) and (19). □

The effect of life expectancy on per capita income goes in opposite directions in pre-transitional and post-transitional countries. In pre-transitional countries, the main effect of an increase in life expectancy is to increase population size rather than investments in human capital. The effect of lower mortality on population size can dominate the effect on productivity, thereby leading to a reduction in income per capita. In post-transitional countries, on the other hand, improvements in life expectancy lead to lower fertility and larger investments in human capital. As a result, per-capita income increases.

Finally notice that reductions in mortality are necessary, but not sufficient, conditions to induce a demographic transition. In fact, the larger the increase in T and the closer the initial level of life expectancy to $\underline{T}$ the more likely is that reductions in mortality trigger a transition and, consequently, an increase in per capita income. This last prediction is summarized in,

Proposition 2. *An increase in life expectancy increases the probability of observing an economic and demographic transition.*

Proof. Follows directly from Lemma 1. □

This simple model captures three features that are central to the recent literature on the economic and demographic transition. First, in pre-transitional economies reductions in mortality increase the rate of population growth but have little effect on investments in human capital. Second, in post-transitional economies, in which investments in education are already positive, improvements in longevity lead to a reduction in fertility and to an increase in education investments. Third, an increase in life expectancy makes a demographic transition more likely, inducing positive (and increasing) investments in education and reversing fertility behavior. This is particularly likely to happen once life expectancy is already fairly large.[23] The main testable predictions of the model, summarized in Propositions 1 and 2, are therefore that increases in life expectancy have a positive effect on population growth, little effect on human capital, and an ambiguous or even negative effect on per capita income before the demographic transition. After the transition, the effect on population growth is negative and the effect on per capita income is positive. Finally, reductions in mortality increase the likelihood of observing a transition.

3 Estimation Framework and Empirical Implementation

We now turn to the empirical implementation of the model and the data description.

3.1 Estimation Framework

The estimation framework directly follows from the previous derivation. As anticipated above, we restrict attention to investigating the medium-run effects of a change in life expectancy. That is, we follow Acemoglu and Johnson (2007) in assuming that the total capital stock K remains fixed at its initial level. As discussed above, taking into account endogenous adjustments in the capital stock leaves the main predictions concerning opposite effects of life expectancy on per capita income for pre-transitional and post-transitional countries unaffected.

Denoting a country by subscript i, rewriting conditions (16) and (18) and adding an error term, we obtain

$$\ln y_{it} = \pi^{pre} \ln T_{it} + \zeta_i^{pre} + \mu_t^{pre} - (1-\alpha) \ln (\Delta t/\varphi) + \varepsilon_{it}^{pre}$$

as expression for log per capita income in pre-transitional countries, that is with $T < \underline{T}_i$. For post transitional countries $T > \underline{T}_i$ log income is given by

$$\ln y_{it} = \pi^{post} \ln T_{it} + \zeta_i^{post} + \mu_t^{post} - (1-\alpha) \ln (\Delta t/\varphi) + \varepsilon_{it}^{post} \; .$$

The time invariant, but potentially country-specific, components of the expressions that are functions of parameters are collected in country fixed effects ζ, while time varying factors common to all pre-transitional or post-transitional countries are collected in the time fixed effects, μ^{pre} and μ^{post}.[24] The coefficients $\pi^{pre}$and π^{post} are the respective parameters of interest. As in Acemoglu and Johnson (2007), the consideration of a long-difference regression with two observations per country implies that the estimation of the previous equations is equivalent to the estimation of the first-difference specifications

$$\Delta \ln y_i^{pre} = C^{pre} + \pi^{pre} \Delta \ln T_i + \Delta \mu_t^{pre} + u_{it}^{pre} \quad (20)$$

$$\Delta \ln y_i^{post} = C^{post} + \pi^{post} \Delta \ln T_i + \Delta \mu_t^{post} + u_{it}^{post} \quad (21)$$

[23]Note that the model predictions could equivalently be cast in terms of crude birth and death rates, and are therefore consistent with the patterns depicted in Figure 1.

[24]In particular, the fixed effects in the specification for post-transitional countries also include the term σ_i.

where $\Delta \ln T \equiv \ln T_2 - \ln T_1$. The constants also depends on the time spell, that is the term $-(1-\alpha)[\ln(\Delta t_2) - \ln(\Delta t_1)]$ which results from taking first differences, where $\Delta t_2 \equiv t_2 - t_0$ and $\Delta t_1 \equiv t_1 - t_0$, in both pre-transitional and post-transitional countries.

Recall that from the theory we would expect $\pi^{pre} \gtreqless 0$ and $\pi^{post} > 0$ and that the difference between the two essentially depends on the different human capital and fertility levels. In fact, notice that if h were assumed to be generically iso-elastic in T as in (4) and n were taken to be unrelated to life expectancy, then (17) and (19) would collapse to equation (7),

$$\pi^{pre} = \pi^{post} = \pi = \alpha(\theta + \eta) - (1-\alpha)\lambda \gtreqless 0\,, \tag{22}$$

which coincides with the coefficient estimated by Acemoglu and Johnson (2007). This provides the possibility for a direct test of whether the incorporation of considerations about the demographic transition are empirically relevant.

3.2 Data and Empirical Implementation

The main outcome variables of interest for the empirical investigation are GDP, GDP per capita, population size and human capital; the main explanatory variable of interest is life expectancy at birth.[25] The estimation of the causal effects of life expectancy uses the predicted mortality instrument proposed by Acemoglu and Johnson (2007). This instrument exploits information on the reduction in mortality following the epidemiological transition in the 1940s to predict the mortality decline. Three components of the epidemiological transition motivate this instrument: the wave of drug and chemical innovations that led to effective vaccines and medicines for major diseases (like vaccines for yellow fever, antibiotics, or chemicals like DDT); the establishment of international institutions like the WHO or UNICEF that facilitated the distribution of medical and public health technology; and, finally, the change in international values leading to a fast dissemination of medical knowledge. Importantly, as consequence of the global character of these innovations, the exclusion restriction – that the instrument is exogenous to a particular country's level of development and does not affect income or population through other channels than life expectancy – appears valid.[26] The base sample consists of 47 countries for which all relevant data on the predicted mortality instrument, life expectancy, and outcome variables on the second stage are available for 1940 and 1980 (or 2000). In further investigations of the human capital channel we also use data on the population share without schooling and on the average years of schooling in the population of

[25] The essential data sources are the UN Demographic Yearbook, and Maddison (2003), see Acemoglu and Johnson (2007) for details.

[26] Essentially, the exclusion restriction in Acemoglu and Johnson (2007) is based on the fact that no treatment or vaccine existed worldwide for the main killer diseases as of 1940, such that mortality due to these diseases depended on country-specific features, but not on income. Also, due to the nature of the epidemiological transition, i.e., due to the discovery and the world-wide dissemination of drugs and vaccines, mortality from these diseases dropped to the world frontier by 1980 in all countries.

working age constructed by Soto and Cohen (2007).

Following Acemoglu and Johnson (2007), we estimate the models (20) and (21) in long differences, i.e., using panel data with only two observations per country, (1940 and 1980, or 1940 and 2000). The choice of a forty years horizon is justified by the fact that changes in fertility behavior and investments in human capital are likely to take place over the course of generations and, therefore, need a sufficiently long observation period to take place and to be detected. Changes in life expectancy that take place at some point in time after 1940 are expected to affect fertility and education decisions in the following decades and should be captured by 1980 or 2000, but potentially not before.

According to Proposition 1, an empirical specification should explicitly discriminate between countries which are pre-transitional and post-transitional in order to identify the effect of improvements in life expectancy. Ideally, one would take into account when the mortality reduction treatment is applied to a country and whether the country is pre-transitional or post-transitional at the time of treatment. In principle, the available data on fertility and realized mortality do allow for a fairly precise identification of the onset of the demographic transition within a range of about ten years (see the discussion below). However, the data on the predicted mortality instrument only contain country-specific information for the predicted change in mortality over the full period.

We therefore consider a classification of countries into pre-transitional and post-transitional as of 1940, i.e., before the treatment in terms of the mortality reduction due to the epidemiological revolution took place. Countries can be classified as pre-transitional or post-transitional according to several alternative criteria. We use the three main criteria that have been used in the demography literature to identify the demographic transition, see, e.g., Chesnais (1992, p. 19). First, a country is considered post transitional when mortality is sufficiently low. The usual threshold for life expectancy at birth is taken to be fifty years. Second, the onset of the demographic can be identified by the drop in fertility. The second criterion therefore identifies the period from which on fertility, or the crude birth rate, exhibits a sustained decline. Third, a country is post-transitional if the crude birth rates is sufficiently low. The typical threshold is taken to be around 30 births per 1000 inhabitants. According to these criteria, we consider a country to be post-transitional if, before the epidemiological revolution, that is before 1940, the following criteria are satisfied:

1. life expectancy at birth exceeds 50;

2. fertility or the crude birth rate has already exhibited a sustained decline;

3. the crude birth rate has fallen below the threshold of 30/1000.[27]

[27]As discussed below, for robustness we also consider the threshold of 25/1000 which, however, is more restrictive and fragile to short term fluctuations in birth rates like, e.g., the baby boom. Likewise, we also considered a less restrictive threshold of 35/1000. All results are qualitatively identical.

The first requirement is expected to be, on average, the least restrictive one in defining post-transitional countries because the drop in mortality precedes the drop in fertility (often substantially). The second requirement, in turn, is less restrictive than the third criterion since it classifies a country as post-transitional when the sustained fertility reduction has started although the process may not be complete (so that the crude birth rate may be still above 30/1000).

In the following we classify a country depending on whether it was already post-transitional before the treatment was applied, i.e., in 1940, by considering each one of the three requirements. To verify the second requirement we follow Reher (2004) and consider a country to be post transitional if it has entered the falling trend in terms of the 5-year averages of crude birth rates by the year 1935. It turns out that, in the sample of countries considered by Acemoglu and Johnson (2007), the application of each of the three different criteria leads to the same classification of countries. This classification delivers 25 pre-transitional and 22 post-transitional countries in 1940, i.e. before the onset of the epidemiological revolution. This classification also coincides with the one proposed by Reher (2004) using the second requirement only. Exceptions are Greece, Ireland and New Zealand, which are not classified in Reher (2004).[28] In our baseline classification we consider these three countries as post-transitional in 1940 since they clearly satisfy requirements 1 and 3. Nonetheless, for robustness we also use the alternative classification and consider them as pre-transitional (Criterion 2a). As a second robustness check we also consider a more restrictive requirement and classify the countries as post transitional only if, together with requirements 1 and 2, the crude birth rate in 1940 is below 25/1000 (Criterion 3a). This is the most restrictive criterion and delivers 31 pre-transitional countries and only 16 post-transitional countries. In this case Argentina, Canada, Finland, the Netherland, New Zealand and Portugal are also classified as pre-transitional in 1940. For a graphical illustration of the demographic dynamics underlying these criteria, Figure 2 in the Appendix depicts the crude birth rates of all 47 countries in our sample over the period 1940-2000.

Finally, for comparability, we also apply the classification of Acemoglu and Johnson (2007) according to which countries are grouped by initial income in 1940 (rich and non-rich countries). This classification can also be justified in view of the fact that the economic and demographic transitions tend to be closely related. It is important to notice, however, that this classification does not directly relate to the theoretical argument based on the demographic transition presented above, since the level of income does not perfectly coincide with the stages of the demographic transition. This implies that the classification in terms of rich and non rich countries cannot, strictly speaking, be interpreted in line of the theory presented above.[29] The classification of countries according to all these criteria is listed in Table 12 in the appendix.

[28]In the case of Greece the problem is the lack of reliable data before 1950. Ireland and New Zealand display a very flat profile of crude birth rates around 30/1000 after 1940 and a clear drop only in 1980 and 1960 respectively.

[29]For example in 1940 several European countries are classified as non rich although they are clearly post-transitional.

We apply the three classification criteria also in 1980 (and 2000). This allows us to distinguish countries that entered the demographic transition (the fertility decline) during the observation window 1940-1980 (and 1940-2000), from countries that remained fully pre-transitional throughout the observation window. We use these classifications for further robustness, and in order to investigate the prediction stated in Proposition 2 that reductions in mortality should facilitate the demographic transition in the countries that are still pre-transitional in 1940. As expected all post-transitional countries in 1940 remain post transitional during the entire observation window, while some countries undergo the demographic transition (see below for more details on this classification). Table 13 reports the baseline classification of the countries into post-transitional, intermediate (undergoing the transition between 1940 and 1980), and pre-transitional throughout 1940-1980, together with the two robustness classifications and the classification in rich and non rich countries.

Table 1 provides descriptive statistics on the variables of interest for the estimation. The base sample corresponds to the base sample investigated by Acemoglu and Johnson (2007). Compared to the base sample, in which average life expectancy at birth is 49.3 years in 1940, average life expectancy in in pre-transitional countries is only 38.8 years, while in post-transitional countries it equals 61.2 years. By 1980, average life expectancy has increased to 67.6 years, with substantial convergence across the two samples: life expectancy at birth is 62.3 years in pre-transitional countries, while in post-transitional countries, life expectancy is 73.7 by 1980.

4 Estimation Results

4.1 The Effect of Life Expectancy in Pre and Post Transitional Countries

Preliminary Analysis. To gain a visual impression of the demographic dynamics in post-transitional and pre-transitional countries, we begin by graphing the dynamic evolution of the average crude death rates, crude birth rates and natural rate of population growth. Figure 3(a) depicts these variables for the countries which are already post-transitional before 1940.[30] In these countries the death rates are about 12/1000 in 1940, decline by about 25 percent until 1960, and stabilize afterwards.[31] The crude birth rate and the net rate of population growth decline by about 50 percent by 1980 and keep decreasing until year 2000.

Figure 3(b) plots the respective series for countries which are still pre-transitional in 1940. As expected, for this group of countries both death and birth rates are larger in 1940. The average crude death rate in 1940 is almost 20/1000 and displays a clear negative trend. Death rates are reduced by about

[30] The lines reflect the average of the respective variables for countries classified as post-transitional according to the first column of Table 12. The shaded area represents 95 percent confidence intervals.

[31] In fact, life expectancy at birth keeps increasing although the crude death rate stabilizes due to the increase in the share of elderly in these countries.

50 percent in 1970 when they reach 10/1000, which is about the average death rate of post transitional countries in 1940. After 1970, death rates drop by about 20 percent in the next twenty years and eventually stabilize. The crude birth rate is essentially unchanged until 1960 and displays a sizable decline only after 1970. Accordingly, the natural rate of population growth is initially increasing and display a sustained decline only after 1970. By 1990, the natural population growth rate is about the same as in 1940.

Figure 3 illustrates the different phases of the demographic transition. Reductions in mortality breed larger population growth until the onset of the demographic transition, but this trend is reversed afterwards and turns negative for post-transitional countries. It is noteworthy that only after 1970 the time series of pre-transitional countries resemble those of countries which are already post-transitional in 1940.

To gain further visual impression of the time series patterns of the variables of interest, Figure 4 depicts the time series of average log income per capita and log population in post-transitional and pre-transitional countries, respectively. The figure illustrates the smaller increase in population size in post-transitional countries compared to pre-transitional countries. At the same time, the increase in log income per capita is less pronounced in pre-transitional countries. The difference in the slopes of the series of income and population for the two groups appears larger before 1980 than afterwards.

Figure 5 depicts the change in log GDP per capita from 1940 to 1980 (panel a), and from 1940 to 2000 (panel b) against the change in log life expectancy at birth over the respective period, separately for pre-transitional and post-transitional countries. It appears that pre-transitional countries experienced larger increases in life expectancy, but that a larger increase in life expectancy was associated with a lower growth in gdp per capita. In contrast, among post-transitional countries, larger improvements in life expectancy were associated with faster growth in income per capita, as indicated by the positive slope of the regression line. This provides a first indication for the importance of distinguishing between pre-transitional and post-transitional countries when investigating the effect of life expectancy on growth.

Since life expectancy might be endogenous to economic development, Figure 6 provides scatter plots of the reduced form relationship between Acemoglu and Johnson's (2007) instrument, the predicted mortality reductions due to the epidemiological transition, and changes in life expectancy, log population and GDP per capita from 1940 to 1980 (left panels) and from 1940 to 2000 (right panels). Notice that the predicted mortality variable implies that a more negative realization (a larger drop in mortality) is associated with a larger increase in life expectancy. Panels (a) and (b) illustrate visually that larger predicted mortality reductions are indeed positively correlated to changes in life expectancy in both pre and post transitional countries. Panels (c) and (d) show that log population is decreasing with predicted mortality reductions in post-transitional countries, while population remains large and even growing in pre-transitional countries. The differential effect of life expectancy on population growth in pre and post transitional countries is larger over the longer time horizon as illustrated in Panel (d). Panels (e) and (f) show that the changes in log GDP per capita are large and increasing in predicted mortality in post-transitional countries, while they are lower and decreasing in predicted mortality in pre-transitional countries.

Next, we present OLS results for the effects of changes in life expectancy on log GDP per capita as dependent variable in Table 2. Panel (A) collects the results for the period 1940-1980, while Panel (B) shows results for the longer horizon 1940-2000. The overall coefficient of life expectancy obtained for the entire sample is negative, irrespective of the time horizon, as is shown in column (1). When splitting the sample into pre-transitional and post-transitional countries, however, the effect is generally negative and fairly weak for pre-transitional countries, but positive and highly significant for post-transitional countries. This pattern emerges for all different classification criteria, and over both time horizons. The coefficient is opposite when considering log population as dependent variable, see Table 3, since life expectancy is positively associated to population growth in pre-transitional countries, but the correlation is negative (but not significant) in post-transitional countries. These estimates provide first evidence in favor of the different effects depending on the onset of the demographic transition predicted by the theory. However, these findings have to be interpreted with caution because of the obvious endogeneity problems with regards to life expectancy.

Causal Effect of Life Expectancy on Income and Population. In order to circumvent these problems and to estimate effects that can be interpreted causally, we adopt the identification strategy based on the mortality change that can be attributed to the epidemiological transition as instrument, suggested by Acemoglu and Johnson (2007). Reduced form estimates using this instrument rather than log life expectancy as primary regressor of interest reveal a similar pattern as the OLS results.

Table 4 presents the main results concerning the causal effect of life expectancy for GDP per capita as dependent variable, using the predicted mortality change instrument. Again, panel (A) contains estimation results for the base sample with observations in 1940 and 1980, while Panel (B) contains results for the period 1940 to 2000. Column (1) replicates the analysis by Acemoglu and Johnson (2007). The average effect of an increase in life expectancy, instrumented by predicted mortality reductions, on income per capita is significantly negative. The explanation for this finding can be seen in column (1) of the respective panels of Tables 5 and 6: An increase in life expectancy overall significantly increases the population, but only has a weak and insignificant effect on aggregate GDP.

Columns (2) and (3) show the results for the sub-samples of countries that are pre-transitional and post-transitional by 1940. We find a significant positive effect of life expectancy on GDP per capita for the post-transitional countries. This effect is almost twice as large, but of the opposite sign, compared to the average effect obtained with the pooled sample. For pre-transitional countries, the effect of an increase in life expectancy on GDP per capita is negative. This effect is larger than the effect obtained with the pooled sample, but it is insignificant. Notice, however, that the standard errors of the coefficient estimates for this group of countries are fairly large.

Columns (4) and (5) report the results using the alternative classification criterion 2a according to which Greece, Ireland and New Zealand are classified as pre-transitional in 1940. The same pattern emerges and this classification leaves the results for post-transitional countries unchanged. The negative effect on pre-transitional countries is now significant at the 10 percent level.

Columns (6) and (7) report the results for the sample with the most restrictive classification based on birth rates below 25/1000. The results are qualitatively identical. The effect of an increase in life expectancy is significantly negative only for pre-transitional countries, while it is significantly positive for post-transitional countries. Interestingly, the effects become quantitatively smaller the more restrictive the criterion for selecting post-transitional countries. The point estimates tend to converge towards the average effect of -1.32. This is consistent with the fact that, with this classification, some of the pre-transitional countries enter the fertility decline soon after 1940, with the consequence of a slow-down of population growth and a positive effect on income per capita.

Finally, when countries are classified in terms of their initial income levels, see columns (8) and (9), the results are qualitatively similar. As shown by Acemoglu and Johnson (2007), the effect of life expectancy on income per capita is significantly negative for the poor and middle income countries. For completeness we include also the effect for rich countries, which is positive. It should be noted, however, that strictly speaking these results cannot be directly interpreted in light of the theoretical argument on the role of the demographic transition. Nonetheless they provide another indication for the heterogenous effect of reduced mortality.

Panel B of Table 4 displays the results for the longer observation period 1940-2000. The results are essentially identical to those in panel A, but the coefficient estimates are generally larger. This implies that the results on the different effects of life expectancy on per capita GDP in pre-transitional and post-transitional countries are not driven by the length of the observation period.

Compared to the OLS estimates in Table 2, the IV estimates deliver coefficients that are of the same sign and that are similar or even slightly larger in absolute magnitude across all specifications. The differences between OLS and IV results tend to be larger for pre-transitional countries. This is confirmed by Hausman-type endogeneity tests that reject the null of exogeneity of log life expectancy in the pooled sample and in the pre-transitional samples of columns (1), (2), (4) and (6) at conventional levels. However, the null of exogeneity cannot be rejected for the samples of post-transitional countries in specifications (3), (5), and (7).[32] One possible explanation for this finding is that life expectancy is measured with larger errror in the sample of pre-transitional countries, and that the instrumentation helps reducing the incidence of attenuation bias particularly in this sample.[33]

The lower parts of the two panels of Table 4 depict test statistics for the first stage performance of the

[32] The null of exogeneity can be rejected for both income samples, columns (8), and (9). Detailed results are available upon request.

[33] On this point see also Lorentzen et al. (2008, p. 103).

instrument (F-statistics of excluded instruments and Shea's partial R-square statistics). As consequence of the small sample sizes in the split samples, the first stage partial F of the instrument becomes smaller, but, by and large, the instrument performs fairly well, as was to be expected already from the extensive tests provided by Acemoglu and Johnson (2007). The Shea's partial R-square statistic is reasonably high, usually around 0.3 or above, indicating that the instrument explains a substantial part of the variation in the instrumented variable.[34]

Another way of investigating the role of the demographic transition for the effects of life expectancy on per capita income is to apply Chow tests of the null that the coefficient of life expectancy is the same in the sub-samples of pre-transitional and post-transitional countries, i.e., testing whether $\pi^{pre} = \pi^{post}$ as in condition (22). The advantage is that these tests are performed on a nested model, which makes the results more robust and directly comparable to the results obtained from the pooled sample.[35] The test statistics from these tests are reported in the bottom part of each panel of Table 4 and indicate that, with one exception in panel (A) where the estimate for the pre-transitional countries is very imprecise, the null of equal coefficients can be rejected at conventional levels.[36] This provides further evidence in support of the theoretical prediction that the effect of life expectancy is not the same in pre-transitional and post-transitional countries.

Table 5 shows the effect of life expectancy on population. The effect appears to be overall negative in post-transitional countries and positive in pre-transitional countries, regardless of the classification criterion. The effects are also more significant over the longer period 1940-2000 (panel B).[37] Finally, Table 6 shows that the effect of total GDP tends to be positive in post transitional countries and negative in pre-transitional countries, but the effect is usually not statistically significant.[38]

Causal effect of Life Expectancy on Education. The theory also predicts a different effect of life expectancy on income per capita due to the correlation between investments in education and fertility. From Proposition 1, life expectancy leads to higher education and lower fertility after the onset of the transition. Life expectancy is expected to have little causal effect on education until the onset of the transition, however. In other words, life expectancy has strong effects on education when it

[34]The only exception is the pre-transitional sample according to the specification in column (2).

[35]It should be noted that the coefficient estimates for log life expectancy for pre-transitional and post-transitional countries obtained with the nested specification are identical to those obtained with split samples.

[36]The first stage performance of the instrument is stronger in the nested sample with respective partial F statistics for excluded instruments being in the proximity 10.

[37]Complementary evidence of a negative relationship between life expectancy and fertility during the demographic transition is found by Kalemli-Ozcan (2006) in the context of reductions in longevity due to the HIV/AIDS epidemics in Africa.

[38]In fact, repeating the analysis and restricting attention to observation periods that follow the (average) fertility drop, such as 1970-2005, the causal effect of life expectancy on GDP per capita becomes insignificant and the coefficient becomes very small for pre-transitional countries. This suggests that the countries that had not entered the demographic transition by 1940 appear to benefit from improvements in life expectancy only later on. Detailed results are available upon request.

simultaneously leads to reductions in fertility. The effect of life expectancy on education should therefore be large and positive in countries that are post-transitional in 1940, but can be small in countries that are pre-transitional in 1940.

As preliminary investigation we run again OLS estimates of the effect of life expectancy on education. Data for education are available from 1960. Table 7 reports the estimates of the effect of life expectancy on the share of population of more than 15 years of age without any formal schooling.[39] Panel (A) reports the effect of changes in life expectancy in 1940-1980 on the change in the share of population without schooling in 1960-1980. The effect is negative and significant for all countries. The effect is stronger over the time horizon 1960-2000 as shown in panels (B) and (C) (which measure the change in education over the horizon 1960-2000 using variation in life expectancy between 1940 and 1980 or 1940 and 2000, respectively).

The corresponding IV estimates are reported in Table 8. The average effect is negative and significant over all time horizons. Panel (A) shows that by 1980 the effect is strong and significant only in post-transitional countries. In Panel (B) the effect turns positive by 2000 although it is slightly lower in pre-transitional than in post transitional countries. The only exception is column (7) where the effect is significant also for pre-transitional countries by 1980 and where over the longer period the effect is larger in pre-transitional than in post-transitional countries. This is to be expected since this classification considers only the set of countries which are post transitional in 1940 according to most restrictive criteria. The effect on the share of non educated individuals is lower since this share is already very low in 1940 in these post-transitional countries. Panel (C) reports the overall effect considering also the change in life expectancy until 2000. In this case the average effect is very similar for all countries. In line with the predictions, the findings suggest a delayed response of education to reductions in mortality in pre-transitional countries which is sizable only over the longer horizon, i.e., when the demographic transition is completed. Similar findings emerge when looking at the changes in the share of population with no schooling aged 25 and above.[40]

Another prediction of Proposition 1 concerns the relationship between average years of education and life expectancy. Life expectancy has no effect on average years of schooling before the demographic transition, while average years of schooling increase proportionally with life expectancy after the demographic transition. Repeating the analysis for average years of schooling in the population of working age (15-64), reveals patterns that are consistent with these predictions. The causal effect of life expectancy is generally positive and significant for post-transitional countries but statistically not different from zero in pre-transitional countries. This is true in particular when looking at longer time horizons (1960-2000),

[39]The data are taken from Soto and Cohen (2007). Similar results obtain for the widely used data provided by Barro and Lee (2001) and are available upon request.

[40]The results are reported in the Appendix in Table 15. The main difference is that the effect on pre-transitional countries is less significant even by 2000. This is to be expected since this measure excludes all individuals aged 15 to 25 by 2000 which are the cohorts most likely affected by the reduction in fertility of the late seventies.

in line with the view that average years of schooling increases with the level of life expectancy.[41]

4.2 Life Expectancy and the Demographic Transition

According to Proposition 2, reductions in mortality can trigger a demographic transition if they lead to a sufficiently large level of life expectancy. That some pre-transitional countries undergo a demographic transition during the observation period is suggested already by Figure 3.

As first investigation of the strength of the effects in countries that undergo the transition, we split the sample of pre-transitional countries into countries that satisfy the criteria of a post-transitional country by the end of the observation period in 1980 (or 2000). This is done to further investigate the role of the demographic transition and as a robustness exercise. Differently from the classification which is obtained by applying the criteria in 1940, however, the consideration of intermediate countries that undergo the transition between 1940 and 1980 differs depending on the particular classification criterion that is applied.[42] Correspondingly, one can consider three different ways of defining intermediate and pre-transitional countries over the horizon 1940-1980 (or 1940-2000, respectively). We report the results for the classifications obtained applying each of the three criteria separately.[43]

Table 9 presents results for GDP per capita separately for the countries that are already post-transitional in 1940 (which are the same post-transitional countries as before), for countries undergoing the transition between 1940 and 1980, and for countries which remain pre-transitional until 1980. Countries can be classified as intermediate or pre-transitional if they display a life expectancy less than 50 years in 1940, but greater than 50 years (or still below 50 years) in 1980 or 2000 (columns (1), (2) and (3)). Alternatively, countries can be classified intermediate according to whether they exhibit a sustained decline in fertility by 1980 or 2000 (columns (4), (5) and (6)).[44] We consider crude birth rates below 30/1000 in columns (7), (8) and (9). Finally, for robustness, columns (10)-(12) display the results for the alternative criterion 2a.

Panel A of Table 9 reports the results for GDP per capita in the period 1940-1980. Panel B extends the estimation until 2000. Finally, Panel C considers the effects on growth of GDP per capita in 1940-

[41]See Table 16 for details. The fact that the demographic transition is typically associated with a rapid change in the composition of the population and a lower medium run effect on average years of schooling has been studied in more detail in Cervellati and Sunde (2007).

[42]As discussed above, the different criteria tend to capture somewhat different phases of the demographic transition. It is likely that these criteria lead to the same classification for 1940 since most of post transitional countries in 1940 did undergo the transition in the late nineteenth and early twentieth century.

[43]Defining a country as intermediate if it satisfies all three criteria by 1980 delivers results similar to the most restrictive criterion of crude birth rates below 30/1000.

[44]The requirement of sustained fertility decline corresponds to the refined classification proposed by Reher, who defines countries that entered the fertility decline between 1950 and 1964 as "followers", and countries that entered the fertility decline between 1965 and 1979 as "trailers". Countries for which the fertility decline only began after 1980 are classified as "latecomers".

2000, classifying the demographic transitions which take place from 1940 to 2000. Table 10 reports the corresponding results for population as dependent variable. The findings are consistent with the previous results: post-transitional countries benefit most, in terms of GDP per capita, from an increase in life expectancy. The effect on GDP per capita for countries undergoing the transition in the period of observation is typically insignificant although it tends to be negative and larger in absolute size than the average effect for the full set of pre-transitional countries (as reported in Table 4). In fact, recall that at the onset of the transition fertility remains large. As illustrated in Figure 1 the natural population growth rate is largest for countries around time B, i.e., just when they are about to undergo the demographic transition, larger than than for countries that are still fully pre-transitional, i.e., in time A. Therefore it is to be expected that largest cumulative increase in population is displayed by countries undergoing the transition in the observation period. Table 10 shows that, irrespective of the classification, the increase in population growth is largest for countries undergoing the transition. This translates in the largest negative population effect on income per capita.

Finally, we investigate the prediction of Proposition 2 that increases in life expectancy might be causal for triggering the demographic and economic transition. We estimate linear probability models with the binary variable whether or not a country has undergone the demographic transition, using the same identification strategy based on the predicted mortality instrument as before.[45] The dependent variable now takes value 1 if a country passes from being pre-transitional to being post transitional in 1980 (or 2000) and it takes value 0 otherwise. Note that the instrumentation strategy should still be valid in this context, as the exclusion restriction that the instrument (the predicted drop in mortality due to the epidemiological revolution) is exogenous to the outcome of interest (the probability to undergo the demographic transition) and affects the outcome through no other channel than through its effect on life expectancy is still satisfied.

The results are displayed in Table 11. Panel A contains results for undergoing the transition during the observation period 1940-1980, while panel B shows results for the period 1940-2000. Column (1) shows that an increase in life expectancy significantly increases the probability of a country that has life expectancy at birth below 50 years in 1940 to undergo a transition to life expectancy above 50 by 1980 (panel A) or by 2000 (panel B). Similar results obtain for a transition in terms of entering a phase of a sustained fertility drop, see column (2). Concerning a transition in crude birth rates, the effect is positive but insignificant over the shorter horizon, but positive and significant over the longer horizon. This might have to do with the fact that according to this criterion only 8 countries undergo the transition between 1940 and 1980, but 20 countries undergo the transition by 2000. Column (4) presents the results for the alternative criterion of a sustained fertility drop, 2a. Overall, the increase in life expectancy appears to significantly increase the probability that a country undergoes the demographic transition. This is especially true for the less restrictive criteria of reaching life expectancy above 50 and displaying

[45] Results for Probit models are qualitatively identical and available upon request.

a sustained fertility decline by 1980 or 2000. Fewer countries reach birth rates below 30/1000 in the respective observation period, and according to this requirement the effect of increasing life expectancy on the probability of observing a transition is positive but less significant. Finally, Column (5) presents a robustness check based on a more restrictive criterion of a country coded as pre-transitional by criteria 1, 2, and 3 making a substantial transition of crude birth rates falling below 25/1000. The coefficients are insignificant, however, most likely due to the small number of countries making the transition according to this fairly restrictive criterion.

4.3 Discussion

Before concluding we briefly discuss our finding of a heterogeneous causal effect of life expectancy during the different phases of the demographic transition.

As mentioned in the introduction, estimates of the effect of life expectancy on income per capita are generally lower on the macro level compared to the to the evidence based on micro data, and sometimes even of the opposite sign. One reason for these differences might be that macro data capture general equilibrium effects, like the role of population size, or externalities. A Malthusian effect related to the increase in population growth is indeed the main explanation proposed by Acemoglu and Johnson (2007) for the negative effect of life expectancy on income per capita. Our findings suggest that, in line with the nonlinear population dynamics associated with the demographic transition, the general equilibrium effects depend on the stages of the demographic transition. In fact, in post-transitional countries we find a large and positive effect of life expectancy on income per capita, which is not only associated with an increase in human capital but also with a slow down in the rate of population growth.

Another issue concerns the possibility of measurement error affecting aggregate measures of life expectancy in the cross-country context, which may bias coefficient estimates towards zero. A particular problem arises when life expectancy is measured with more error in underdeveloped countries.[46] This implies that the problem of measurement error is likely to be more pervasive in pre-transitional countries as of 1940. Consequently, the estimated causal effect of life expectancy in pre-transitional countries is more likely to suffer from attenuation bias than the estimates for post-transitional countries, as is also indicated by the larger discrepancies between OLS and IV results for pre-transitional countries. It is important to note, however, that this does not affect the finding of different signs of the causal effect for pre-transitional and post-transitional countries, but suggests, if anything, that the estimates are more

[46]For example, vital statistics on which life tables, and hence data on life expectancy, are based are often incomplete or missing. These measurement and registration problems are particularly severe in countries where the vital registration system is deficient, where a sizable proportion of the population has never attended school, or in countries where infant mortality is very high, see, e.g., *United Nations* (1983, p.2). As consequence, errors associated with the indirect projection measures that are used to produce life tables might be more severe in developing countries, i.e., countries that are pre-transitional as of 1940.

reliable for post-transitional countries.

Finally, life expectancy at birth is affected by both infant mortality as well as mortality at later ages. In theory, education decisions are primarily determined by adult longevity.[47] If the variation in aggregate data on life expectancy at birth is largely driven by changes in child mortality, one may expect only little effects on human capital formation.[48] This argument could provide a complementary explanation for our finding that human capital is mostly affected by life expectancy after the demographic transition, if most of the increase in life expectancy in pre-transitional countries is due to reductions in child mortality.

5 Concluding Remarks

This paper proposed a simple theory predicting that increases in life expectancy mainly increase population size until the onset of the demographic transition, which tends to reduce per capita income. The effect is opposite after the transition, when life expectancy leads to an increase of income per-capita. The theory also predicts that improvements in life expectancy are important triggers of the transition. As a result, the causal effect of life expectancy on income per capita is likely to differ systematically during the different phases of economic and demographic development.

We empirically investigate these predictions by explicitly accounting for whether countries have undergone the demographic transition already before the exogenous reductions in mortality. We find that increases in life expectancy increase population growth, affect human capital little and therefore tend to reduce income per capita in pre-transitional countries. Life expectancy, however, leads to lower population growth, greater human capital and strongly increases income per capita in post-transitional countries. On average, countries which are pre-transitional in 1940 undergo the transition around 1970. Accordingly, for these countries the effect of life expectancy on education is not significant by 1980 but is positive and significant by 2000. We also find evidence supporting the second theoretical prediction that greater life expectancy increases the likelihood of a country undergoing the demographic transition. The findings appear to be robust to applying alternative criteria for distinguishing pre-transitional and post-transitional countries, and over different time horizons.

The results may help reconcile the seemingly contradictory findings in the literature. In the presence of non-linear dynamics of population and human capital in response to reductions in mortality, the (local) average treatment effect of life expectancy strongly depends on the sample composition in terms of the relative numbers of pre-transitional and post-transitional countries in the estimation sample. Our estimates suggest that the effect of life expectancy was significant and positive for post-transitional countries in the period 1940-2000. Nonetheless, if the sample contains countries that are still predominantly pre-

[47] See Soares (2005) and Cervellati and Sunde (2007) for theories studying the different effects of child mortality and adult longevity on human capital and fertility.

[48] This issue has been raised by Lorentzen et al. (2008) and Jayachandran and Lleras-Muney (2009), among others.

transitional or just about to undergo the demographic transition in the observation period, life expectancy may have weak or even negative causal effects on income per capita in the pooled sample.

The results also have potentially important implications for policy interventions. Given that most countries by now have made progress towards a demographic transition, the average causal effect of improvements in life expectancy on per capita income is likely to be positive for health innovations and mortality reductions if applied today. The results presented above also provide evidence for pronounced increases in population size especially around the onset of the transition. This should be taken into account when devising interventions aimed at reducing mortality. Finally the results suggest that the causal effect of life expectancy actually triggering the transition should be taken into consideration when analyzing the economic returns of improvements in life expectancy.

References

Acemoglu, D., and S. Johnson (2007): "Disease and Development: The Effect of Life Expectancy on Economic Growth," *Journal of Political Economy*, 115(6), 925–985.

Ashraf, Q. H., A. Lester, and D. N. Weil (2008): "When Does Improving Health Raise GDP?," *mimeo, Brown University.*

Barro, R. J., and J. Lee (2001): "International Data on Educational Attainment: Updates and Implications," *Oxford Economic Papers*, 53(3), 541–563.

Bleakley, H. (2007): "Desease and Development: Evidence from Hookworm Eradication in the American South," *Quarterly Journal of Economics*, 122(1), 73–117.

Bleakley, H., and F. Lange (2009): "Chronic Disease Burden and the Interaction of Education, Fertility, and Growth," *Review of Economics and Statistics*, 91(1), 52–65.

Bloom, D. E., D. Canning, and J. Sevilla (2003): *The Demographic Dividend.* RAND, Santa Monica.

Bloom, D. E., and J. D. Sachs (1998): "Geography, Demography, and Economic Growth in Africa," *Brookings Papers on Economic Activity*, 2, 207–273.

Cervellati, M., and U. Sunde (2005): "Human Capital, Life Expectancy, and the Process of Development," *American Economic Review*, 95(5), 1653–1672.

——— (2007): "Human Capital, Mortality and Fertility: A Unified Theory of the Economic and Demographic Transition," *IZA Discussion Paper*, 2905.

Chesnais, J.-C. (1992): *The Demographic Transition: Stages, Patterns and Economic Implications. A Longitudinal Study of Sixty-Seven Countries Covering the Period 1720-1984.* Clarendon Press, Oxford.

de la Croix, D., and O. Licandro (2009): "The Child is Father of the Man: Implications for the Demographic Transition," *mimeo, EUI Florence.*

Gallup, J. L., J. D. Sachs, and A. D. Mellinger (1999): "Geography and Economic Development," *International Regional Science Review*, 22(2), 179–232.

Galor, O. (2005): "From Stagnation to Growth: Unified Growth Theory," in *Handbook of Economic Growth*, ed. by P. Aghion, and S. Durlauf, chap. 4. Elsevier Science B.V., Amsterdam.

Galor, O., and D. N. Weil (2000): "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90(4), 807–828.

Jayachandran, S., and A. Lleras-Muney (2009): "Life Expectancy and Human Capital Investments: Evidence from Maternal Mortality Declines," *Quarterly Journal Economics*, 124(1), 349–398.

Kalemli-Ozcan, S. (2003): "A Stochastic Model of Mortality, Fertility, and Human Capital Investment," *Journal of Development Economics*, 70(1), 103–118.

——— (2006): "AIDS, "Reversal" of the Demographic Transition and Economic Development: Evidence from Africa," *NBER Working Paper*, 12181.

Lee, R. (2003): "The Demographic Transition: Three Centuries of Fundamental Change," *Journal of Economic Perspectives*, 17(4), 167–190.

Livi-Bacci, M. (1992): *A Concise History of World Population.* Blackwell, Oxford.

Lorentzen, P., J. McMillan, and R. Wacziarg (2008): "Death and Development," *Journal of Economic Growth*, 13(2), 81–124.

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

Preston, S. H., P. Heuveline, and M. Guillot (2001): *Demography: Measuring and Modeling Population Processes.* Blackwell, Oxford.

Reher, D. S. (2004): "The Demographic Transition Revisited as a Global Process," *Population, Space and Place*, 10(1), 19–41.

Shastry, G. K., and D. Weil (2003): "How Much of the Cross-Country Variation in Income is Explained by Health?," *Journal of the European Economic Association*, 1(2-3), 387–396.

Skirbekk, V. (2008): "Fertility Trends by Social Status," *Demographic Research*, 18, 145–180.

Soares, R. (2005): "Mortality Reductions, Educational Attainment, and Fertility Choice," *American Economic Review*, 95(3), 580–601.

Soto, M., and D. Cohen (2007): "Growth and human capital: Good data, good results," *Journal of Economic Growth*, 12(1), 51–76.

Thomas, D., and E. Frankenberg (2002): "Health, Nutrition, and Prosperity: A Microeconomic Perspective," *Bulletin of the World Health Organization*, 80(2), 106–113.

UN (1983): *United Nations, Manual X: Indirect Techniques for Demographic Estimation*. United Nations, New York.

Weil, D. N. (2007): "Accounting for the Effect of Health on Economic Growth," *Quarterly Journal of Economics*, 122(3), 1265–1306.

A Proofs and Tables

Proof of Lemma 1. The optimal education and fertility choices of individual j are given by:

$$\left\{e_j^*, n_j^*\right\} = \arg \max_{e \geq 0, n \geq 0} \left[w_j h_j \left(T_j - k\left(T_j\right) n_j - e_j\right)\right]^{\gamma} \cdot \left[n_j\right]^{(1-\gamma)}$$

where $h_j = \max\left\{\overline{h} e_j^{\eta}, \overline{h}\right\}$. The first order conditions for an interior optimum imply:

$$e_j = \frac{\eta}{1+\eta}\left(T_j - k(T_j)n_j\right) = \frac{\eta}{1+\eta}\left(T_j - kT_j^{1+x} n_j\right)$$

and

$$n_j = \frac{(1-\gamma)(T_j - e_j)}{k(T_j)} = \frac{(1-\gamma)(T_j - e_j)}{kT_j^{1+x}}$$

and solving one obtains:

$$e_j^* = \frac{\eta\gamma}{1+\eta\gamma} T_j \tag{23}$$

for education and

$$n_j^*|_{e_j^*>0} = \frac{1-\gamma}{(1+\eta\gamma)k} T_j^{-x} \tag{24}$$

for fertility, respectively. Notice that there is also a possible corner solution in which no investments in education are undertaken $e_j^* = 0$. In this case the optimal fertility is given by

$$n_j^*|_{e_j^*=0} = \frac{1-\gamma}{k} \tag{25}$$

The interior solution with a positive level of education is optimal if and only if the indirect utility is larger than the indirect utility that arises from the corner solution. This implies that education and fertility are given by (23) and (24) if and only if they deliver an indirect utility which is larger than the one obtained with $e_j^* = 0$ and (25). Comparing the indirect utility we have,

$$\begin{aligned} U\left(e_j^* > 0, n_j^*|_{e_j^*>0}\right) &> U\left(e_j^* = 0, n_j^*|_{e_j^*=0}\right) \Longleftrightarrow \\ \frac{(\gamma\eta)^{\eta\gamma}}{(1+\gamma\eta)^{1+\gamma\eta}} \frac{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}{k^{1-\gamma}} T_j^{\gamma+\gamma\eta - x(1-\gamma)} &> \frac{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}{k^{1-\gamma}} T_j^{\gamma} \Longleftrightarrow \\ \Longleftrightarrow \quad T_j > \underline{T} &\equiv \left[\frac{(1+\eta\gamma)^{(1+\eta\gamma)}}{(\eta\gamma)^{\eta\gamma}}\right]^{\frac{1}{\eta\gamma - x(1-\gamma)}} \end{aligned} \tag{26}$$

Therefore if $T_j < \underline{T}$, then the optimal interior investment in education (23) is not sufficient to provide an individual with as high a level of life time utility as that arising from supplying the baseline level of human capital.

Table 1: Descriptive Statistics

	Year	Base Sample		Pre-transitional Countries		Post-Transitional Countries	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Life expectancy at birth	1940	49.3	12.7	38.8	6.17	61.2	5.38
	1980	67.6	7.41	62.3	6.25	73.7	1.70
	2000	72.9	5.46	69.1	4.65	77.4	1.55
Predicted mortality	1940	0.47	0.28	0.65	0.23	0.27	0.17
Log GDP per capita	1940	7.74	0.73	7.21	0.50	8.34	0.39
	1980	8.62	0.95	7.91	0.72	9.44	0.29
	2000	8.96	0.96	8.22	0.68	9.81	0.32
Log Population	1940	9.11	1.53	9.03	1.80	9.20	1.20
	1980	9.81	1.48	10.0	1.68	9.55	1.20
	2000	10.1	1.49	10.4	1.63	9.67	1.21
Log GDP	1940	9.94	1.59	9.34	1.58	10.6	1.32
	1980	11.5	1.49	11.0	1.49	12.1	1.31
	2000	12.1	1.55	11.8	1.68	12.6	1.30

Sample sizes are 47 countries in the base sample, 25 pre-transitional countries and 22 post-transitional countries. The classification follows criteria 1, 2 and 3 described in the text.

Table 2: Effect of Life Expectancy on Log GDP Per Capita

Observation Period	**Panel (A): 1940-1980**								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	-0.81***	-0.29	2.03***	-0.48	1.79***	-0.70*	1.73***	-1.17***	4.34***
	[0.26]	[0.65]	[0.44]	[0.44]	[0.52]	[0.38]	[0.46]	[0.38]	[0.92]
Number of countries	47	25	22	28	19	31	16	36	11
R^2	0.14	0.01	0.35	0.03	0.27	0.07	0.29	0.16	0.40
Observation Period	**Panel (B): 1940-2000**								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	-1.14***	-1.95	2.15***	-1.56**	1.92**	-1.23**	1.69**	-1.82***	1.72
	[0.29]	[1.14]	[0.67]	[0.75]	[0.82]	[0.50]	[0.69]	[0.44]	[2.41]
Number of countries	47	25	22	28	19	31	16	36	11
R^2	0.18	0.17	0.23	0.18	0.19	0.14	0.18	0.27	0.07

Results from OLS regressions, the dependent variable is log GDP per capita, $\ln y$. Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. The samples in Panel (A) column (1) and Panel (B) column (1) correspond to the base sample of Acemoglu and Johnson (2007). Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). The classification in rich and non-rich countries in 1940 in columns (8) and (9) follows the classification by Acemoglu and Johnson (2007), the results in Panel (A) column (8) and Panel (B) column (8) replicate their results in Table 9B(3) and 9B(4), respectively. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 3: Effect of Life Expectancy on Log Population

Observation Period	Panel (A): 1940-1980								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	1.62***	0.50	-0.53	1.13***	-0.28	1.05***	-0.12	1.86***	-3.00
	[0.18]	[0.38]	[0.42]	[0.38]	[0.42]	[0.23]	[0.49]	[0.24]	[2.00]
Number of countries	47	25	22	28	19	31	16	36	11
R^2	0.54	0.07	0.05	0.30	0.01	0.33	0.003	0.52	0.12

Observation Period	Panel (B): 1940-2000								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	1.97***	0.33	-0.79	1.31**	-0.55	1.28***	-0.36	2.21***	-2.70
	[0.22]	[0.50]	[0.50]	[0.48]	[0.52]	[0.30]	[0.60]	[0.30]	[2.87]
Number of countries	47	25	22	28	19	31	16	36	11
R^2	0.55	0.02	0.06	0.28	0.03	0.32	0.02	0.51	0.06

Results from OLS regressions. The dependent variable in Table 2 is log GDP per capita, $\ln y$; the dependent variable in Table 3 is log population, $\ln N$. Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. The samples in Panel (A) column (1) and Panel (B) column (1) correspond to the base sample of Acemoglu and Johnson (2007). Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). The classification in rich and non-rich countries in 1940 in columns (8) and (9) follows the classification by Acemoglu and Johnson (2007), the results in Panel (A) column (8) and Panel (B) column (8) replicate their results in Table 9B(3) and 9B(4), respectively. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 4: Causal Effect of Life Expectancy on Log GDP Per Capita

Observation Period	**Panel (A): 1940-1980**								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	-1.32***	-5.45	2.28***	-2.35*	2.23***	-1.72**	1.79*	-2.35**	11.21*
	[0.36]	[5.48]	[0.67]	[1.35]	[0.74]	[0.69]	[0.94]	[0.79]	[5.79]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.50	0.05	0.37	0.20	0.35	0.35	0.28	0.28	0.27
First Stage F-Stat.	47.3	1.2	5.5	5.4	4.8	14.3	3.4	13.8	3.7
Chow-Test: Equality of π		p< 0.17		p< 0.01		p< 0.01		p< 0.02	
Joint First Stage F-Stat.		7.28		8.05		8.40		9.19	

Observation Period	**Panel (B): 1940-2000**								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	-1.51***	-5.28	2.74***	-3.14*	2.64***	-2.02**	1.83***	-2.68***	14.25
	[0.41]	[3.22]	[0.75]	[1.62]	[0.87]	[0.92]	[0.79]	[0.96]	[9.99]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.61	0.22	0.41	0.37	0.39	0.49	0.33	0.41	0.11
First Stage F-Stat.	60.2	5.7	6.5	10.9	5.8	23.0	4.2	21.8	2.0
Chow-Test: Equality of π		p< 0.02		p< 0.01		p< 0.01		p< 0.09	
Joint First Stage F-Stat.		7.37		8.22		12.77		13.09	

Results from 2SLS regressions, the dependent variable is log GDP per capita, $\ln y$, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. The samples in Panel (A) column (1) and Panel (B) column (1) correspond to the base sample of Acemoglu and Johnson (2007), the results replicate their results in Table 9B(1) and Table 9B(2), respectively. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). The classification in rich and non-rich countries in 1940 in columns (8) and (9) follows the classification by Acemoglu and Johnson (2007), the results in Panel (A) column (8) and Panel (B) column (8) replicate their results in Table 9B(3) and 9B(4), respectively. First stage F-tests correspond to the partial F test of the instrument. F-Tests of the null of equality of π are Chow tests of equality of coefficients in the two sub-samples, conducted in a nested specification, F-statistics for the instrument on the first stage of these specifications are also reported as joint first stage F-tests. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 5: Causal Effect of Life Expectancy on Log Population

Observation Period	Panel (A): 1940-1980								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	1.67***	-0.06	-1.14*	1.31	-1.09	1.07**	-0.52	2.04***	0.52
	[0.34]	[1.73]	[0.57]	[0.88]	[0.63]	[0.48]	[0.56]	[0.67]	[6.33]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.50	0.05	0.37	0.20	0.35	0.35	0.28	0.28	0.27
First Stage F-Stat.	47.3	1.2	5.5	5.4	4.8	14.3	3.4	13.8	3.7
Chow-Test: Equality of π		$p< 0.56$		$p< 0.04$		$p< 0.04$		$p< 0.81$	
Joint First Stage F-Stat.		7.28		8.05		8.40		9.19	

Observation Period	Panel (B): 1940-2000								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	1.96***	0.54	-1.61**	1.51*	-1.58*	1.34***	-0.85	2.19***	0.22
	[0.36]	[1.12]	[0.75]	[0.76]	[0.81]	[0.48]	[0.78]	[0.62]	[12.3]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.61	0.22	0.41	0.37	0.39	0.49	0.33	0.41	0.11
First Stage F-Stat.	60.2	5.7	6.5	10.9	5.8	23.0	4.2	21.8	2.0
Chow-Test: Equality of π		$p< 0.12$		$p< 0.01$		$p< 0.03$		$p< 0.87$	
Joint First Stage F-Stat.		7.37		8.22		12.77		13.09	

Results from 2SLS regressions, the dependent variable is log population, $\ln N$, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. The samples in Panel (A) column (1) and Panel (B) column (1) correspond to the base sample of Acemoglu and Johnson (2007), the results replicate their results in Table 9B(1) and Table 9B(2), respectively. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). The classification in rich and non-rich countries in 1940 in columns (8) and (9) follows the classification by Acemoglu and Johnson (2007), the results in Panel (A) column (8) and Panel (B) column (8) replicate their results in Table 8A(3) and 8A(4), respectively. First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 6: Causal Effect of Life Expectancy on Log GDP

Observation Period	Panel (A): 1940-1980								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	0.31	-5.89	1.14	-1.17	1.15	-0.72	1.26	-0.39	11.73
	[0.50]	[6.47]	[0.71]	[1.58]	[0.78]	[0.87]	[0.84]	[0.93]	[10.8]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.50	0.20	0.35	0.35	0.28	0.05	0.37	0.28	0.27
First Stage F-Stat.	47.3	1.2	5.5	5.4	4.8	14.3	3.4	13.8	3.7
Chow-Test: Equality of π		$p< 0.29$		$p< 0.20$		$p< 0.11$		$p< 0.25$	
Joint First Stage F-Stat.		7.28		8.05		8.40		9.19	

Observation Period	Panel (B): 1940-2000								
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a		Income	
Sample	All	Pre	Post	Pre	Post	Pre	Post	Non-Rich	Rich
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log life expectancy	0.42	-4.91*	1.13	-1.71	1.06	-0.74	0.99	-0.55	14.47
	[0.37]	[2.55]	[0.89]	[1.35]	[1.04]	[0.78]	[0.83]	[0.78]	[16.9]
Number of countries	47	25	22	28	19	31	16	36	11
Shea Partial R^2	0.61	0.41	0.41	0.37	0.39	0.49	0.33	0.22	0.11
First Stage F-Stat.	60.2	6.5	21.8	10.9	5.8	23.0	4.2	5.7	2.0
Chow-Test: Equality of π		$p< 0.03$		$p< 0.12$		$p< 0.14$		$p< 0.36$	
Joint First Stage F-Stat.		7.37		8.22		12.77		13.09	

Results from 2SLS regressions, the dependent variable is log GDP, $\ln Y$, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. The samples in Panel (A) column (1) and Panel (B) column (1) correspond to the base sample of Acemoglu and Johnson (2007), the results replicate their results in Table 9B(1) and Table 9B(2), respectively. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). The classification in rich and non-rich countries in 1940 in columns (8) and (9) follows the classification by Acemoglu and Johnson (2007), the results in Panel (A) column (8) and Panel (B) column (8) replicate their results in Table 9A(3) and 9A(4), respectively. First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 7: Effect of Life Expectancy on Population Share Without Schooling

Observation Period	Panel (A): Schooling 1960-1980, Life Expectancy 1940-1980						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.43***	-0.05	-0.46***	-0.26**	-0.47***	-0.34***	-0.37***
	[0.06]	[0.14]	[0.12]	[0.11]	[0.15]	[0.08]	[0.07]
Number of countries	45	23	22	26	19	29	16
R^2	0.53	0.004	0.63	0.17	0.60	0.29	0.67
Observation Period	**Panel (B): Schooling 1960-2000, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.81***	-0.27	-0.70***	-0.58***	-0.71**	-0.69***	-0.51***
	[0.08]	[0.22]	[0.24]	[0.16]	[0.29]	[0.12]	[0.13]
Number of countries	45	23	22	26	19	29	16
R^2	0.63	0.05	0.56	0.29	0.53	0.42	0.58
Observation Period	**Panel (C): Schooling 1960-2000, Life Expectancy 1940-2000**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.73***	-0.46***	-0.69***	-0.62***	-0.68**	-0.67***	-0.50***
	[0.06]	[0.16]	[0.22]	[0.09]	[0.26]	[0.08]	[0.11]
Number of countries	45	23	22	26	19	29	16
R^2	0.72	0.19	0.57	0.45	0.54	0.55	0.59

Results from OLS regressions, the dependent variable is the percentage of the population aged 15 or over without schooling. Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country. Panel (A) displays results for changes in the share without schooling 1960-1980 on changes in life expectancy 1940-1980; panel (B) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-1980; Panel (C) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-2000. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 8: Causal Effect of Life Expectancy on Population Share Without Schooling

Observation Period	**Panel (A): Schooling 1960-1980, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.46***	0.63	-0.65***	-0.17	-0.68***	-0.36*	-0.49***
	[0.11]	[1.04]	[0.13]	[0.33]	[0.14]	[0.21]	[0.09]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (B): Schooling 1960-2000, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.95***	-0.46	-1.03***	-0.80**	-1.07***	-0.92***	-0.70***
	[0.13]	[1.01]	[0.25]	[0.35]	[0.28]	[0.22]	[0.15]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (C): Schooling 1960-2000, Life Expectancy 1940-2000**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.75***	-0.22	-0.94***	-0.54**	-0.97***	-0.68***	-0.63***
	[0.085]	[0.46]	[0.24]	[0.22]	[0.27]	[0.15]	[0.11]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.56	0.14	0.41	0.30	0.39	0.43	0.33
First Stage F-Stat.	54.1	3.4	6.5	8.8	5.8	19.8	4.3

Results from 2SLS regressions, the dependent variable is the percentage of the population aged 15 or over without schooling, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country. Panel (A) displays results for changes in the share without schooling 1960-1980 on changes in life expectancy 1940-1980; panel (B) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-1980; Panel (C) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-2000. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 9: Causal Effect of Life Expectancy on Log GDP Per Capita: Intermediate Countries

Observation Period	Panel (A): Observations 1940-1980, Criteria 1940-1980											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	2.285***	-5.342		2.285***	-7.897	-2.020	2.285***	-1.685	-20.51	2.234***	-2.489	-2.02
	[0.665]	[5.460]		[0.665]	[10.73]	[1.304]	[0.665]	[0.887]	[84.65]	[0.736]	[1.632]	[1.304]
Number of countries	22	24		22	20	5	22	8	17	19	23	5
Shea Partial R^2	0.37	0.05		0.37	0.03	0.60	0.37	0.32	0.004	0.35	0.21	0.60
First Stage F-Stat.	5.49	1.14		5.49	0.63	8.69	5.49	3.84	0.06	4.85	4.75	8.69

Observation Period	Panel (B): Observations 1940-2000, Criteria 1940-1980											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	2.742***	-5.273		2.742***	-7.415*	-0.484	2.742***	-7.958*	-3.461	2.642***	-3.670*	-0.484
	[0.747]	[3.247]		[0.747]	[4.100]	[0.502]	[0.747]	[3.706]	[4.401]	[0.866]	[1.929]	[0.502]
Number of countries	22	24		22	20	5	22	8	17	19	23	5
Shea Partial R^2	0.41	0.21		0.41	0.25	0.70	0.41	0.35	0.13	0.39	0.43	0.70
First Stage F-Stat.	6.48	5.64		6.48	5.19	6.54	6.48	5.96	1.93	5.82	10.17	6.54

Observation Period	Panel (C): Observations 1940-2000, Criteria 1940-2000											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	2.742***	-5.276		2.742***	-5.276		2.742***	-5.149***	2.837	2.642***	-3.139*	
	[0.747]	[3.192]		[0.747]	[3.192]		[0.747]	[1.581]	[47.93]	[0.866]	[1.622]	
Number of countries	22	25		22	25		22	20	5	19	28	
Shea Partial R^2	0.41	0.20		0.41	0.20		0.41	0.49	0.002	0.39	0.37	
First Stage F-Stat.	6.48	5.66		6.48	5.66		6.48	34.43	0.01	5.82	10.90	

Results from 2SLS regressions, the dependent variable is log GDP per capita, $\ln y$, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panels (B) and (C), respectively. All specifications include a full set of year and country fixed effects. Classification criteria are applied in 1940 and 1980 for panels (A) and (B), and in 1940 and 2000 in panel (C). Classification of Post-Transitional in 1940 in columns (1) to (9) is according to criteria 1, 2, and 3 (life expectancy at birth above 50, sustained fertility drop, crude birth rate below 30/1000) as discussed in the text. Intermediate countries are defined as passing the respective criterion (criterion 1, life expectancy at birth above 50 in column (2), criterion 2, sustained fertility drop in column (4), and criterion 3, crude birth rate below 30/1000 in column (6)) by 1980 (panels A and B) or 2000 (panel C). Columns (10)-(12) include comparable results for re-coding three countries concerning the sustained fertility drop (criterion 2a). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 10: Causal Effect of Life Expectancy on Log Population: Intermediate Countries

Observation Period	Panel (A): Observations 1940-1980, Criteria 1940-1980											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	-1.143*	-0.025		-1.143*	0.276	-0.197	-1.143*	1.606	-6.868	-1.088	1.556	-0.197
	[0.569]	[1.775]		[0.569]	[2.368]	[1.019]	[0.569]	[1.490]	[27.55]	[0.629]	[1.036]	[1.019]
Number of countries	22	24		22	20	5	22	8	17	19	23	5
Shea Partial R^2	0.37	0.05		0.37	0.03	0.60	0.37	0.32	0.004	0.35	0.21	0.60
First Stage F-Stat.	5.49	1.14		5.49	0.63	8.69	5.49	3.84	0.06	4.85	4.75	8.69

Observation Period	Panel (B): Observations 1940-2000, Criteria 1940-1980											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	-1.615**	0.553		-1.615**	1.095	-0.247	-1.615**	2.854	-1.105	-1.583*	1.822**	-0.247
	[0.747]	[1.151]		[0.747]	[1.293]	[0.934]	[0.747]	[1.653]	[1.154]	[0.814]	[0.848]	[0.934]
Number of countries	22	24		22	20	5	22	8	17	19	23	5
Shea Partial R^2	0.41	0.21		0.41	0.25	0.70	0.41	0.35	0.13	0.39	0.43	0.70
First Stage F-Stat.	6.48	5.64		6.48	5.19	6.54	6.48	5.96	1.93	5.82	10.17	6.54

Observation Period	Panel (C): Observations 1940-2000, Criteria 1940-2000											
Criterion	1: LEB > 50			2: Sustained Fert. Drop			3: CBR<30/1000			2a: Sustained Fert. Drop		
Sample	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log life expectancy	-1.615**	0.539		-1.615**	0.539		-1.615**	0.634	2.008	-1.583*	1.511*	
	[0.747]	[1.121]		[0.747]	[1.121]		[0.747]	[0.824]	[22.08]	[0.814]	[0.761]	
Number of countries	22	25		22	25		22	20	5	19	28	
Shea Partial R^2	0.41	0.20		0.41	0.20		0.41	0.49	0.002	0.39	0.37	
First Stage F-Stat.	6.48	5.66		6.48	5.66		6.48	34.43	0.01	5.82	10.90	

Results from 2SLS regressions, the dependent variable is log population, $\ln N$, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panels (B) and (C), respectively. All specifications include a full set of year and country fixed effects. Classification criteria are applied in 1940 and 1980 for panels (A) and (B), and in 1940 and 2000 in panel (C). Classification of Post-Transitional in 1940 in columns (1) to (9) is according to criteria 1, 2, and 3 (life expectancy at birth above 50, sustained fertility drop, crude birth rate below 30/1000) as discussed in the text. Intermediate countries are defined as passing the respective criterion (criterion 1, life expectancy at birth above 50 in column (2), criterion 2, sustained fertility drop in column (4), and criterion 3, crude birth rate below 30/1000 in column (6)) by 1980 (panels A and B) or 2000 (panel C). Columns (10)-(12) include comparable results for re-coding three countries concerning the sustained fertility drop (criterion 2a). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 11: Effect of Life Expectancy on the Probability of Entering the Demographic Transition

Observation Period	Panel (A): 1940-1980				
Criterion	LEB > 50 (1)	Fert. Drop (2)	CBR< $\frac{30}{1000}$ (3)	Sust.Fert.Drop (4)	CBR< $\frac{25}{1000}$ (5)
Log life expectancy	2.637*** [0.345]	2.409*** [0.447]	0.602 [0.421]	2.103*** [0.466]	-0.086 [0.295]
Number of countries	47	47	47	47	47
Number of transitions 0/1	24	20	8	23	3
Shea Partial R^2	0.50	0.50	0.50	0.50	0.50
First Stage F-Stat.	47.3	47.3	47.3	47.3	47.3

Observation Period	Panel (B): 1940-2000				
Criterion	LEB > 50 (1)	Fert. Drop (2)	CBR< $\frac{30}{1000}$ (3)	Sust.Fert.Drop (4)	CBR< $\frac{25}{1000}$ (5)
Log life expectancy	2.204*** [0.241]	2.204*** [0.241]	1.768*** [0.285]	1.960*** [0.279]	0.41 [0.335]
Number of countries	47	47	47	47	47
Number of transitions 0/1	25	25	20	28	10
Shea Partial R^2	0.60	0.60	0.60	0.60	0.60
First Stage F-Stat.	60.2	60.2	60.2	60.2	60.2

Results from 2SLS regressions, the dependent variable is 1 if a country is satisfies the classification for a post-transitional country and 0 if it does not satisfy the criterion; the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country, for 1940 and 1980 in panel (A), and for 1940 and 2000 in panel (B), respectively. All specifications include a full set of year and country fixed effects. Classification of Pre-Transitional and Post-Transitional countries in columns (1), (2), (3) is according to criteria 1 (life expectancy at birth above 50), 2 (sustained fertility drop), and 3 (crude birth rate below 30/1000), respectively. Classification in column (4) corresponds to criterion 2a (alternative coding of 3 countries); see also notes to Table 4. Classification in column (4) corresponds to a pre-transitional country according to criteria 1, 2, and 3 that makes a substantial fertility transition (a drop of the crude birth rate below 25/1000). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 12: List of Countries and their Classification

Post-Transitional according to:		Criteria 1, 2, 3 (1)	Criteria 1, 2a, 3 (2)	Criteria 1, 2, 3a (3)	Rich (4)
Argentina	ARG	1	1	0	0
Australia	AUS	1	1	1	1
Austria	AUT	1	1	1	0
Belgium	BEL	1	1	1	1
Bangladesh	BGD	0	0	0	0
Brazil	BRA	0	0	0	0
Canada	CAN	1	1	0	1
Switzerland	CHE	1	1	1	1
Chile	CHL	0	0	0	0
China	CHN	0	0	0	0
Colombia	COL	0	0	0	0
Costa Rica	CRI	0	0	0	0
Germany	DEU	1	1	1	1
Denmark	DNK	1	1	1	1
Ecuador	ECU	0	0	0	0
Spain	ESP	1	1	1	0
Finland	FIN	1	1	0	0
France	FRA	1	1	1	0
United Kingdom	GBR	1	1	1	1
Greece	GRC	0	1	1	0
Guatemala	GTM	0	0	0	0
Honduras	HND	0	0	0	0
Indonesia	IDN	0	0	0	0
India	IND	0	0	0	0
Ireland	IRL	0	1	1	0
Italy	ITA	1	1	1	0
Korea Republic	KOR	0	0	0	0
Sri Lanka	LKA	0	0	0	0
Mexico	MEX	0	0	0	0
Myanmar	MMR	0	0	0	0
Malaysia	MYS	0	0	0	0
Nicaragua	NIC	0	0	0	0
Netherlands	NLD	1	1	0	1
Norway	NOR	1	1	1	0
New Zealand	NZL	0	1	0	1
Pakistan	PAK	0	0	0	0
Panama	PAN	0	0	0	0
Peru	PER	0	0	0	0
Philippines	PHL	0	0	0	0
Portugal	PRT	1	1	0	0
Paraguay	PRY	0	0	0	0
El Salvador	SLV	0	0	0	0
Sweden	SWE	1	1	1	1
Thailand	THA	0	0	0	0
Uruguay	URY	1	1	1	0
United States	USA	1	1	1	1
Venezuela	VEN	0	0	0	0

List of 47 countries that represent the baseline sample in Acemoglu and Johnson (2007). "1" indicates if a country is coded as post-transitional according to the respective criteria, "0" corresponds to pre-transitional countries. Criteria 1, 2, 3 correspond to life expectancy at birth > 50, sustainded fertility drop and a crude birth rate $< \frac{30}{1000}$, respectively, by 1940. Criterion 2a codes Greece, Ireland and New Zealand as pre-transitional due to the unclear onset of their fertility drop. Criterion 3a considers a crude birth rate $< \frac{25}{1000}$ rather than $< \frac{30}{1000}$. "Rich" uses the classification proposed by Acemoglu and Johnson (2007). See also main text for description of the classification criteria.

Table 13: List of Countries and their Classification (Including Intermediate Countries)

		LE> 50			Sust. Fert. Drop			CBR< $\frac{30}{1000}$		
		Post	Intermediate	Pre	Post	Intermediate	Pre	Post	Intermediate	Pre
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Argentina	ARG	1	0	0	1	0	0	0	1	0
Australia	AUS	1	0	0	1	0	0	1	0	0
Austria	AUT	1	0	0	1	0	0	1	0	0
Belgium	BEL	1	0	0	1	0	0	1	0	0
Bangladesh	BGD	0	0	1	0	0	1	0	0	1
Brazil	BRA	0	0	1	0	1	0	0	0	1
Canada	CAN	1	0	0	1	0	0	0	1	0
Switzerland	CHE	1	0	0	1	0	0	1	0	0
Chile	CHL	0	1	0	0	1	0	0	1	0
China	CHN	0	1	0	0	1	0	0	1	0
Colombia	COL	0	1	0	0	1	0	0	0	1
Costa Rica	CRI	0	1	0	0	1	0	0	0	1
Germany	DEU	1	0	0	1	0	0	1	0	0
Denmark	DNK	1	0	0	1	0	0	1	0	0
Ecuador	ECU	0	0	1	0	1	0	0	0	1
Spain	ESP	1	0	0	1	0	0	1	0	0
Finland	FIN	1	0	0	1	0	0	0	1	0
France	FRA	1	0	0	1	0	0	1	0	0
United Kingdom	GBR	1	0	0	1	0	0	1	0	0
Greece	GRC	1	0	0	1	0	0	1	0	0
Guatemala	GTM	0	0	1	0	0	1	0	0	1
Honduras	HND	0	0	1	0	0	1	0	0	1
Indonesia	IDN	0	0	1	0	1	0	0	0	1
India	IND	0	0	1	0	1	0	0	0	1
Ireland	IRL	1	0	0	1	0	0	1	0	0
Italy	ITA	1	0	0	1	0	0	1	0	0
Korea Republic	KOR	0	1	0	0	1	0	0	1	0
Sri Lanka	LKA	0	1	0	0	1	0	0	0	1
Mexico	MEX	0	0	1	0	1	0	0	0	1
Myanmar	MMR	0	0	1	0	1	0	0	0	1
Malaysia	MYS	0	0	1	0	1	0	0	0	1
Nicaragua	NIC	0	0	1	0	0	1	0	0	1
Netherlands	NLD	1	0	0	1	0	0	0	1	0
Norway	NOR	1	0	0	1	0	0	1	0	0
New Zealand	NZL	1	0	0	1	0	0	0	1	0
Pakistan	PAK	0	1	0	0	1	0	0	0	1
Panama	PAN	0	0	1	0	1	0	0	0	1
Peru	PER	0	1	0	0	1	0	0	0	1
Philippines	PHL	0	0	1	0	1	0	0	0	1
Portugal	PRT	1	0	0	1	0	0	0	1	0
Paraguay	PRY	0	0	1	0	0	1	0	0	1
El Salvador	SLV	0	0	1	0	1	0	0	0	1
Sweden	SWE	1	0	0	1	0	0	1	0	0
Thailand	THA	0	0	1	0	1	0	0	0	1
Uruguay	URY	1	0	0	1	0	0	1	0	0
United States	USA	1	0	0	1	0	0	1	0	0
Venezuela	VEN	0	0	1	0	1	0	0	0	1

List of 47 countries that represent the baseline sample in Acemoglu and Johnson (2007). Classification according to criterion 1, LE> 50, in 1940 and in 1980 in column (1), LE< 50 in 1940 and LE> 50 in 1980 in column (2), and LE< 50 in 1940 and in 1980 in column (3). Classification according to criterion 2, sustained fertility drop, in 1940 and in 1980 in column (4), no sustained fertility drop in 1940 but sustained fertility drop in 1980 in column (5), and no sustained fertility drop in 1940 and in 1980 in column (6). Classification according to criterion 3, CBR< $\frac{30}{1000}$, in 1940 and in 1980 in column (1), CBR> $\frac{30}{1000}$ in 1940 and CBR< $\frac{30}{1000}$ in 1980 in column (2), and CBR> $\frac{30}{1000}$ in 1940 and in 1980 in column (3). See also main text for description of the classification criteria.

Table 14: Effect of Life Expectancy on Population Share Without Schooling

Observation Period	Panel (A): Schooling 1960-1980, Life Expectancy 1940-1980						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.33***	0.07	-0.51***	-0.15	-0.51***	-0.24**	-0.46***
	[0.06]	[0.19]	[0.10]	[0.13]	[0.12]	[0.10]	[0.08]
Number of countries	45	23	22	26	19	29	16
R^2	0.37	0.01	0.67	0.05	0.63	0.15	0.68

Observation Period	Panel (B): Schooling 1960-2000, Life Expectancy 1940-1980						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.76***	-0.01	-0.83***	-0.44**	-0.83**	-0.59***	-0.65***
	[0.08]	[0.19]	[0.24]	[0.18]	[0.30]	[0.14]	[0.15]
Number of countries	45	23	22	26	19	29	16
R^2	0.56	0.001	0.60	0.18	0.56	0.31	0.60

Observation Period	Panel (C): Schooling 1960-2000, Life Expectancy 1940-2000						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.68***	-0.16	-0.81***	-0.46***	-0.80***	-0.56***	-0.64***
	[0.07]	[0.19]	[0.22]	[0.14]	[0.26]	[0.11]	[0.13]
Number of countries	45	23	22	26	19	29	16
R^2	0.62	0.03	0.61	0.26	0.57	0.40	0.61

Results from OLS regressions, the dependent variable is the percentage of the population aged 25 or over without schooling. Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country. Panel (A) displays results for changes in the share without schooling 1960-1980 on changes in life expectancy 1940-1980; panel (B) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-1980; Panel (C) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-2000. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 15: Causal Effect of Life Expectancy on Population Share Without Schooling

Observation Period	**Panel (A): Schooling 1960-1980, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.34***	0.96	-0.71***	0.01	-0.73***	-0.22	-0.62***
	[0.12]	[1.00]	[0.10]	[0.37]	[0.11]	[0.23]	[0.12]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (B): Schooling 1960-2000, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.87***	0.57	-1.20***	-0.47	-1.24***	-0.75**	-0.89***
	[0.17]	[1.24]	[0.24]	[0.50]	[0.28]	[0.31]	[0.18]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (C): Schooling 1960-2000, Life Expectancy 1940-2000**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-0.69***	0.27	-1.10***	-0.32	-1.12***	-0.55**	-0.80***
	[0.12]	[0.58]	[0.22]	[0.33]	[0.26]	[0.22]	[0.14]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.56	0.14	0.41	0.30	0.39	0.43	0.33
First Stage F-Stat.	54.1	3.4	6.5	8.8	5.8	19.8	4.3

Results from 2SLS regressions, the dependent variable is the percentage of the population aged 25 or over without schooling, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country. Panel (A) displays results for changes in the share without schooling 1960-1980 on changes in life expectancy 1940-1980; panel (B) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-1980; Panel (C) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-2000. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Table 16: Causal Effect of Life Expectancy on Average Years of Schooling

Observation Period	**Panel (A): Schooling 1960-1980, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	-1.72**	-12.9	-0.41	-3.54	-0.19	-2.58	-1.70
	[0.64]	[14.1]	[1.31]	[3.14]	[1.36]	[1.60]	[1.57]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (B): Schooling 1960-2000, Life Expectancy 1940-1980**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	0.85	-20.8	7.47**	-4.62	8.10*	-2.04	10.1*
	[1.24]	[22.7]	[3.34]	[5.35]	[3.88]	[2.88]	[5.01]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.48	0.04	0.47	0.19	0.28	0.32	0.37
First Stage F-Stat.	43.5	0.8	5.5	5.8	4.8	13.2	3.4

Observation Period	**Panel (C): Schooling 1960-2000, Life Expectancy 1940-2000**						
Classification Criterion		Criteria 1, 2, 3		Criteria 1, 2a, 3		Criteria 1, 2, 3a	
Sample	All	Pre	Post	Pre	Post	Pre	Post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log life expectancy	0.67	-9.82	6.87**	-3.14	7.33**	-1.51	9.13**
	[0.97]	[7.80]	[2.86]	[3.56]	[3.23]	[2.13]	[4.06]
Number of countries	45	23	22	26	19	29	16
Shea Partial R^2	0.56	0.14	0.41	0.30	0.39	0.43	0.33
First Stage F-Stat.	54.1	3.4	6.5	8.8	5.8	19.8	4.3

Results from 2SLS regressions, the dependent variable is the average years of schooling in the population aged 15-64 that is not in education, the instrument is predicted mortality change (see text). Robust, small sample corrected standard errors are in brackets. All regressions are in long-difference specifications with two observations per country. Panel (A) displays results for changes in the share without schooling 1960-1980 on changes in life expectancy 1940-1980; panel (B) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-1980; Panel (C) displays results for changes in the share without schooling 1960-2000 on changes in life expectancy 1940-2000. Classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (2) and (3) is according to a country satisfying the three classification criteria 1 (life expectancy at birth in 1940 being above 50), 2 (sustained fertility drop by 1935) and 3 (crude birth rate in 1940 being below 30/1000) at the same time; the classification criterion 2 regarding the onset of the sustained fertility decline being prior to 1935 follows the classification of Reher (2004) in non-forerunner countries and forerunner countries, respectively. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (4) and (5) is according to criteria 1, 2a (same as 2 with Greece, Ireland and New Zealand coded as pre-transitional) and 3. The classification of Pre-Transitional in 1940 and Post-Transitional in 1940 in columns (6) and (7) is according to criteria 1, 2, and 3a (crude birth rate in 1940 being below 25/1000). First stage F-tests correspond to the partial F test of the instrument. ***, **,* indicate significance at 1-, 5-, and 10-percent level, respectively.

Figure 2: Demographic Transition: Crude Birth Rates

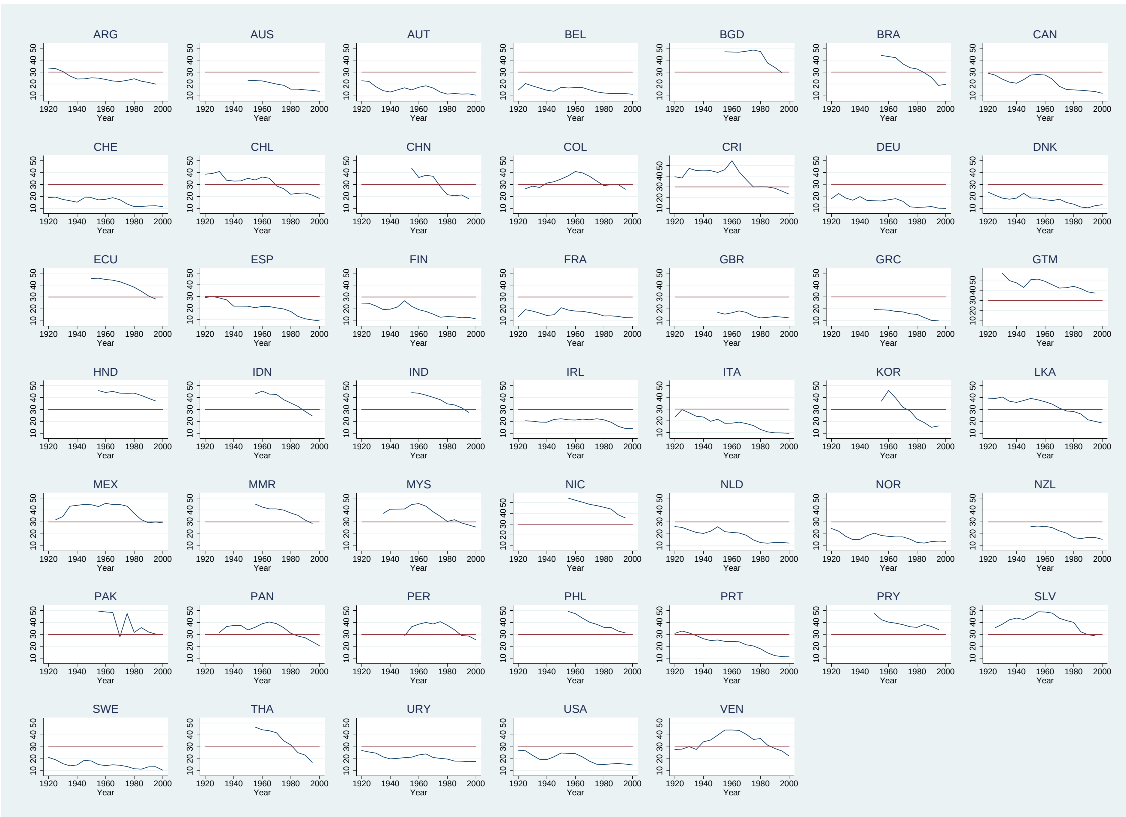
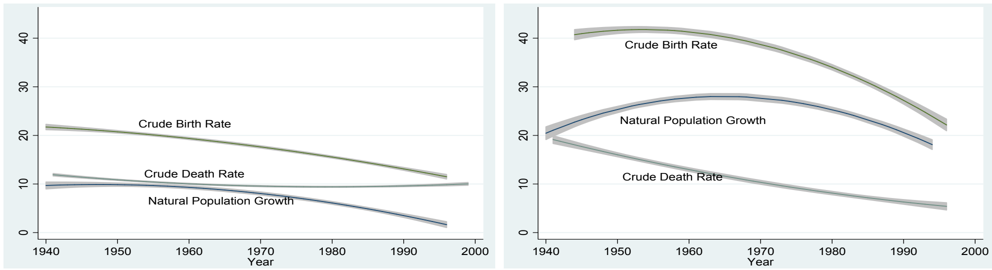


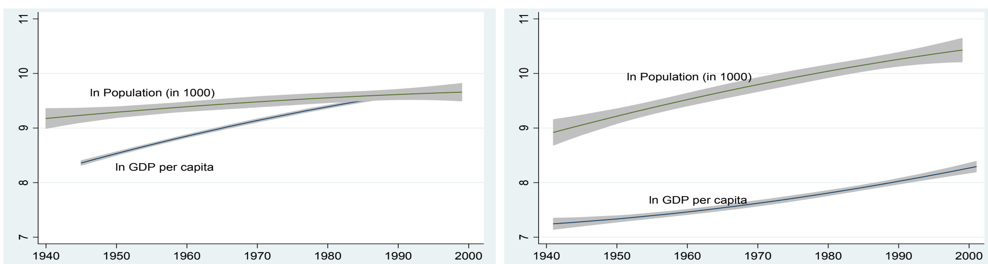
Figure 3: Demographic Dynamics in Pre-Transitional and Post-Transitional Countries



(a) Post-Transitional Countries (b) Pre-Transitional Countries

Classification according to criteria 1, 2, 3, see Table 12 and main text for detailed description of the classification criteria.

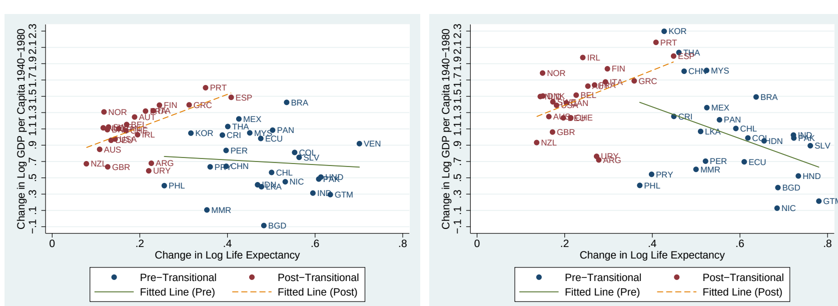
Figure 4: Income and Population Dynamics in Pre-Transitional and Post-Transitional Countries



(a) Post-Transitional Countries (b) Pre-Transitional Countries

Classification according to criteria 1, 2, 3, see Table 12 and main text for detailed description of the classification criteria.

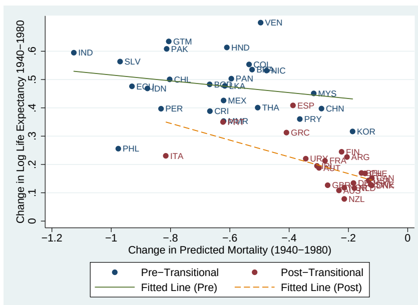
Figure 5: The Consequences of the Demographic Transition for Development



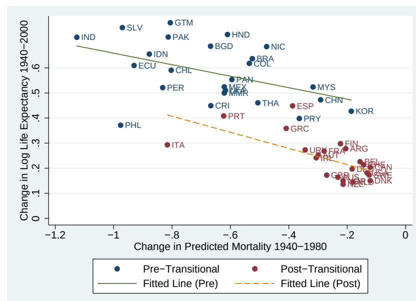
(a) Change in log Life Expectancy and Change in log GDP per Capita 1940-1980 (b) Change in log Life Expectancy and Change in log GDP per Capita 1940-2000

Classification according to criteria 1, 2, 3, see Table 12 and main text for detailed description of the classification criteria.

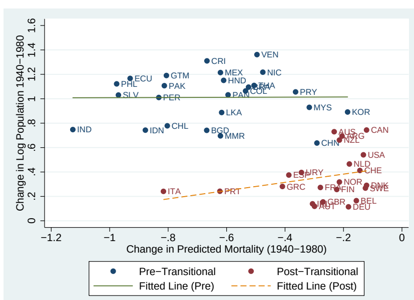
Figure 6: The Consequences of the Demographic Transition for Development



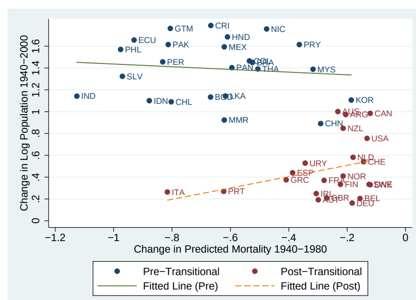
(a) Predicted Mortality Change and Change in Life Expectancy 1940-1980



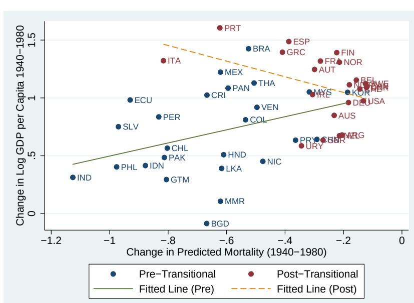
(b) Predicted Mortality Change and Change in Life Expectancy 1940-2000



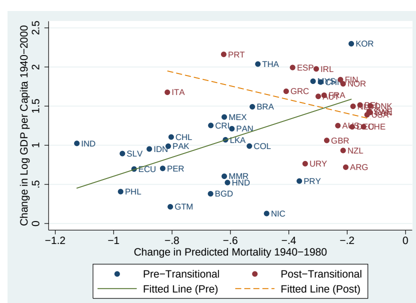
(c) Predicted Mortality Change and Change in log Population 1940-1980



(d) Predicted Mortality Change and Change in log Population 1940-2000



(e) Predicted Mortality Change and Change in log GDP per Capita 1940-1980



(f) Predicted Mortality Change and Change in log GDP per Capita 1940-2000

Classification according to criteria 1, 2, 3, see Table 12 and main text for detailed description of the classification criteria.