LONG-TERM DETERMINANTS OF THE DEMOGRAPHIC TRANSITION, 1870–2000

Fabrice Murtin*

Abstract—This paper analyzes the long-term economic determinants of the demographic transition using a large panel of countries since 1870. A simple theoretical framework accounts for the possibly nonmonotonic variations of fertility in the course of economic development. As predicted by unified growth theory, I find that primary schooling, rather than income or health-related variables, is the most robust determinant of the fertility transition. As regards the health transition, both education and income are significant determinants of mortality rates, but education alone accounts for the bulk of their time variation over the twentieth century. Thus, education can be viewed as the main long-term determinant of the demographic transition.

I. Introduction

THE demographic transition swept the world in the course of the nineteenth and twentieth centuries, bringing about a significant reduction in mortality, fertility, and ultimately population growth in almost all regions of the world (Chesnais, 1986). According to unified growth theory (Galor & Weil, 1999, 2000; Galor, 2005, 2011), the demographic transition played a crucial role in the economic development of nations, as it facilitated the shift from a Malthusian world with stagnating income to a modern growth era with sustained technological progress. Indeed, it fueled the growth process by higher concentration of the stock of capital and land, better human capital and health, as well as a temporary increase in the size of the labor force relative to the population.[1]

The causes of the demographic transition and, more specifically, of the decline in fertility, have been much debated. Unified growth theory attributes fertility's decline to the rise in the demand for education. Along this line, the growing complexity of industrial machinery raised the demand for skills at the onset of the second industrial revolution (Bairoch, 1997), which triggered a simultaneous reduction in fertility and an increase in schooling enrolment. However, other theories underline the role played by different factors such as income per capita or health standards. What do the data say on the nature of economic forces that have initiated the decline in fertility and, more generally, the demographic transition?

This paper seeks to identify the factors that contributed to the demographic transition using a large panel of countries since 1870. Because a demographic transition is classically composed of a first phase during which mortality declines, soon followed by a decrease in fertility, this paper examines both aspects and finds in both cases strong empirical evidence of the crucial role of education, and primary education in particular. Overall, this paper suggests that education has been the main socioeconomic determinant of the demographic transition, confirming the predictions made by unified growth theory.

This study complements an important theoretical, empirical, and historical literature. To start with, three competing explanations of the health transition (the long-term reduction in mortality rates) have been proposed: the increase in nutrition and caloric intakes associated with higher height, body mass index, and lower morbidity at any age (McKeown, 1976, Fogel, 2004); the role of medicine, health technology, and the development of public health infrastructures such as water sanitation and hospitals (Mackenbach et al., 1988, Cutler, Deaton, & Lleras-Muney, 2006); and the diffusion of good health practices and improved hygiene, which has been facilitated by increased literacy and educational attainment (Lleras-Muney, 2005). Generally, the decline in mortality can be viewed as the consequence of a modernization process in which better health technology, higher wealth, and education have had roles to play. An empirical investigation is necessary to assess which of these factors has been the most effective.

The decline in fertility is the second chapter of the demographic transition. Competing theories aiming to uncover the causes of this decline can be divided into two main strands. First, a demographic version of the modernization hypothesis states that fertility should decline as a consequence of economic development.[2] Second, a health hypothesis views health improvement as the main cause of the fall in fertility.

The first family of theories, which encompasses unified growth theory, describes several economic aspects that have contributed to make fertility relatively more costly with respect to investments in child education in the context of rapid technological progress. For instance, technological change may have decreased the comparative advantage of males in physically intensive tasks, raised the demand for female labor, and therefore increased the opportunity cost of fertility (Galor & Weil, 1996); technological change may have raised the return to education, hence fostered investments in child education while simultaneously reducing fertility (Becker, Murphy, & Tamura, 1990; Tamura,

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* OECD.

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[1] Weil and Wilde (2009) assess the influence of the Malthusian factor today. Lorentzen, McMillan, and Wacziarg (2008) and Aghion, Howitt, and Murtin (2011) demonstrate empirically the positive impact of higher life expectancy on growth in GDP per capita. Bloom and Williamson (1998) assess the role of the demographic dividend in emerging Asia.

[2] In the field of political science, Lipset (1960) argued that democracy standards should increase as a result of growth in income or educational attainment.

1996; Galor & Weil, 2000); and the implementation of laws restricting or abolishing child labor may have increased the opportunity cost of fertility by reducing the monetary benefits that parents could reap from child work (Hazan & Berdugo, 2002; Doepke, 2004; Doepke & Zilibotti, 2005). By contrast, the Beckerian theory emphasizes the role of rising income rather than education and the entailed substitution between quantity and quality of children if parents are naturally inclined toward quality (Becker, 1981).

The second family of theories aiming to explain the decline of fertility decline focuses on the interaction between mortality and fertility. Assume that each household has a certain target level of surviving offspring. Then the higher the child mortality, the higher the fertility. This theory, originally developed by Nerlove (1974) and furthered by Ehrlich and Lui (1991), Kalemli-Ozcan, Ryder, and Weil (2000), Kalemli-Ozcan (2002), and Soares (2005), can be easily extended to the case where parents care not only about surviving children but also about the survival of their lineage: total mortality then becomes the key determinant of the decline of fertility.

As a first contribution, this paper proposes a simple model of fertility transition that embeds the latter two explanations: the modernization and health hypothesis. Indeed, the model shows that fertility may decline either because the cost of fertility is rising in modernizing societies or because child mortality is falling. Interestingly, the model captures the possibly nonmonotonic time variations in fertility, which has historically followed an inverted U-shape curve in several countries. A simple explanation of this phenomenom is provided. In early stages of economic development, risk-averse households do not invest in expensive child education, and increases in wealth have a positive Malthusian income effect on fertility. Then a second phase begins where parents start investing in child education, and fertility starts decreasing from a substitution effect.

As a second and main contribution, the paper assesses the major long-term determinants of the fertility transition, borrowing explanatory variables from both the modernization and health hypothesis. In practice, I regress the log birthrate on log GDP per capita and average years of schooling among the adult population, which are convenient proxies for economic development, as well as on infant and total mortality rates, demographic factors, and time effects. Using alternatively OLS, panel fixed effects, and GMM techniques with education lagged thirty and forty years as instruments addressing the endogeneity of income, education, and health variables, I find some empirical support for both hypotheses, but the most robust determinant of fertility's decline turns out to be average education—more precisely, average years of primary schooling among the adult population. When average years of primary schooling grow from 0 to 6 years, fertility should decrease by about 40% to 80%. This suggests that the modernization hypothesis, and more precisely the theories that emphasize the role of education such as unified growth theory, receive wide empirical support from long-term historical data.

As a third and last contribution, I look at the determinants of the health transition. I regress mortality rates and log life expectancy on log GDP per capita, average schooling of the adult population, their square, time, and country fixed effects. Using again lagged education as instruments in a GMM setting to tackle the reverse causality between health and development, I find that both income and education are significant determinants of the decline of mortality, but that the magnitude of education's effect dwarfs that of income. In sum, education was the main engine of both fertility and health transitions over the twentieth century.

Section II summarizes historical evidence on the demographic transition since 1870. Section III proposes a simple model of nonmonotonic fertility transitions. Section IV describes the data and presents the empirical results. The final section concludes.

II. Historical Evidence on the Demographic Transition, 1870–2000

This paper introduces an original database that gathers much of the available statistical information on population, health, income, and education for a large panel of countries since 1870. Selected variables are average years of schooling in the population older than 15 years and its decomposition into years of primary, secondary, and tertiary schooling as taken from Morrisson-Murtin (2009);[3] GDP per capita taken from Maddison (2001); the crude birthrate (total number of births per thousand individuals); the crude mortality rate (total number of deaths per thousand individuals); and the infant mortality rate (total number of deaths of children younger than one year per thousand births). The three latter demographic variables are available in Chesnais (1986) and are complemented by United Nations (2006) from 1950 onward, together with Mitchell (2003a, 2003b, 2003c) for age pyramids. As an alternative to mortality rates, life expectancy calculated by Acemoglu and Johnson (2007) and the United Nations (2006) is available from 1930 onward.[4] Data span from 1870 to 2000, sixteen countries display balanced panel data since 1870, and 70 countries in total span all continents.[5] Based on the former variables, a few historical facts are now recalled, choosing 1870 as the starting point of the analysis.

A. *Wealth*

The divergence of GDP per capita at a global level is one of the best-known historical facts. As quantified by

[3] This data set is downloadable from www.pse.ens.fr/data/.

[4] Crude death rates are not fully comparable across countries, which display different age pyramids. However, this variable is available early in time, in any case earlier than life expectancy that requires more information to be calculated (mortality by age). Similarly, crude birthrates are available early in time relative to fertility rates.

[5] The sixteen countries are Argentina, Australia, Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Ireland, New Zealand, Norway, Spain, Sweden, Switzerland, and the United Kingdom.

FIGURE 1.—CRUDE DEATH RATE FOR A SAMPLE OF COUNTRIES, 1870–2000

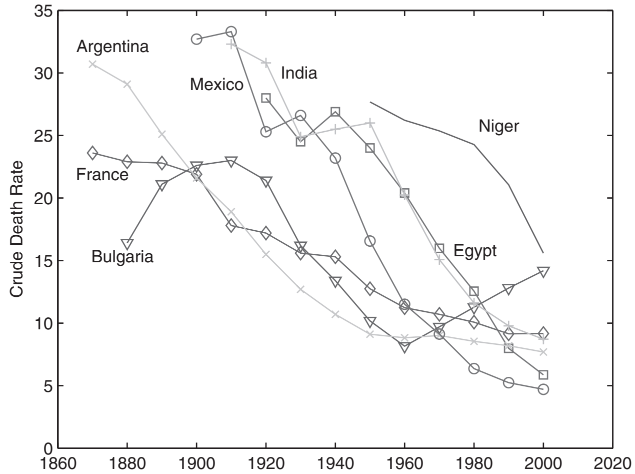
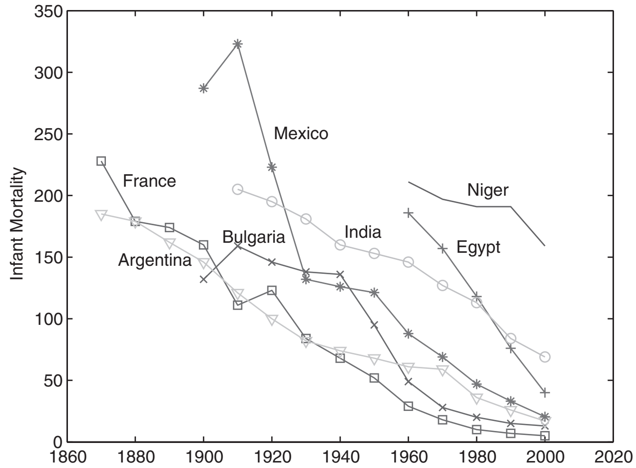


FIGURE 2.—INFANT MORTALITY FOR A SAMPLE OF COUNTRIES, 1870–2000



Maddison (2001) and Bourguignon and Morrisson (2002), Western Europe and prosperous Western offshoots (Australia, Canada, New Zealand, and the United States) have witnessed unprecedented income growth since the industrial revolution, with other countries lagging behind. During the first modern globalization era, a period roughly between 1870 and 1914, a group of advanced countries experienced sustained economic growth with respect to other countries, while at the same time reducing income differences and ultimately forming a convergence club (O'Rourke & Williamson, 1999). Educational attainment also converged among this club, as shown by Morrisson and Murtin (2009, 2013). After World War II, a comparable phenomenom occurred.

B. *Mortality*

As Chesnais (1986) and Lee (2003) noted, the decline in overall mortality first happened around 1800 in France, Czechoslovakia, and the Scandinavian countries; it was slow in the early nineteenth century, but accelerated at the onset of the first globalization around 1870 and involved most European countries. Figure 1 shows that France has witnessed a continuous decrease in overall mortality since 1870, which was particularly intense at the turn of the twentieth century. Large developing countries such as India and Mexico acknowledged a sudden decline in mortality in the interwar period, which accelerated and spread to other developing countries in the postwar period.[6]

Furthermore, infant mortality decreased steadily in northern Europe after 1800 and in northwestern and southern Europe after 1870. As shown in figure 2, this decline was rapid after 1900 and slowed after 1960. This health transition took place Latin and South America in the first quarter of the twentieth century. In Mexico, for instance, the fall in infant mortality was astonishing: rates were slashed by 50%, from more than 300 infant deaths per 1,000 live births in 1910 to fewer than 150 in 1930. Today, infant mortality remains high only in sub-Saharan Africa and in some Central Asian countries such as Afghanistan.

C. *Fertility*

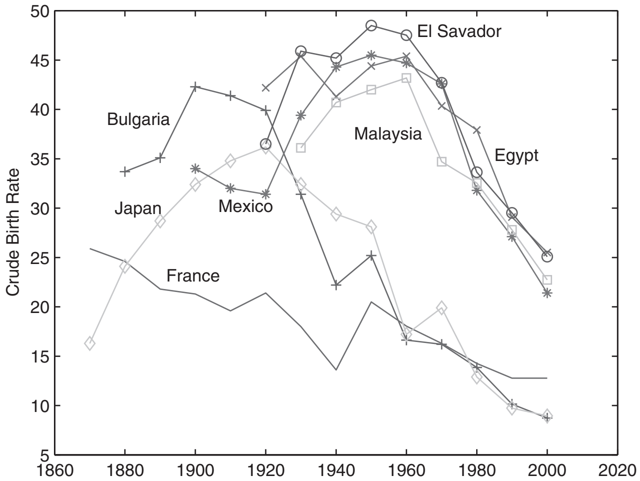
Fertility started to fall in France, the Czech countries, and the United States from 1750–1800 and then spread gradually to the rest of the world over the next two centuries.[7] The majority of European countries (Scandinavian countries and those in northwestern and central Europe) experienced a dramatic decline in fertility at the onset of the first globalization period, soon followed by northeastern Europe (Poland and Russia), southern and eastern Europe (Spain, Portugal, Bulgaria, Romania, and Yugoslavia), and some South American countries (Argentina, Chile, and Uruguay) in the first quarter of the twentieth century. Many developing countries experienced a decline in fertility in 1960s or 1970s, with the notable exceptions of the Middle East and sub-Saharan Africa.

Importantly, several countries experienced a transitory rise in fertility before an almost continuous decrease. As several country studies of the European fertility project (Coale & Watkins, 1986) have noted, fertility first increased in many western European countries at the onset of the globalization era. This phenomenon has been observed in other countries at different times. Figure 3 shows that variations in crude birthrates have been nonmonotonic in Bulgaria, El Salvador, Japan, Mexico, Malaysia, and Egypt, with tipping points occurring in the early stages of economic development. The next section proposes a simple framework that aims to capture the potential nonmonotonicity of fertility variations in the course of economic development.

[6] In contrast with global trends, Eastern European countries such as Bulgaria in figure 1 witnessed an increase in mortality rates in the postwar period, associated with a slight increase in average life expectancy or even a decrease in the case of Russia.

[7] According to Haines (1992), greater control of marital fertility in late-nineteenth-century France likely reflected new values emphasizing individual choice and education.

FIGURE 3.—CRUDE BIRTHRATE FOR A SAMPLE OF COUNTRIES, 1870–2000



III. A Simple Model of Fertility Transition

A. Basic Framework

The model belongs to a large family of frameworks where parents trade between quantity and quality of children (Becker, 1981; Barro & Becker, 1989; Galor & Weil, 2000; De la Croix & Doepke, 2003). Parents care about lifetime consumption and the total bequest they leave to surviving children in the form of human capital. An alternative explanation is that parents transfer human capital to their a children in exchange for a pension during retirement.[8] Parents choose their level of consumption, the number of children, and the educational level of their children. Children are assumed to be identical and receive the same level of education. Bequests take the form of human capital transmission, abstracting from monetary intergenerational transfers as in Galor and Moav (2004) or Moav (2005). Let c denote parental consumption and y parental income, s the surviving probability of children, n the number of births, and h children human capital. The program is:

$$\operatorname*{Max}_{c,n,h} V = u(c) + \beta u(snh), \tag{1}$$

$$\text{s.c. } c + \phi sn + \tau esn = y, \tag{2}$$

where $u(.)$ is the utility function, β weighs the altruistic motive, ϕ is the marginal cost of raising a surviving child, and τ is the marginal cost of each year of schooling e paid to each surviving child. The production function of human capital has decreasing returns,

$$h = (1+e)^{\eta}, \eta < 1, \tag{3}$$

which provides one unit of human capital to children not attending school and is a concave function of schooling. The first-order condition yields

$$\frac{\partial V}{\partial n} \Big/ \frac{\partial V}{\partial e} = \frac{1+e}{\eta n} = \frac{\phi + \tau e}{\tau n} \tag{4}$$

or, after some basic manipulations,

$$e^* = -\frac{1}{1-\eta} + \frac{\eta}{1-\eta}\frac{\phi}{\tau}. \tag{5}$$

This simple expression links child education e^* to the relative cost of fertility relative to education $\frac{\phi}{\tau}$: the higher the latter cost, the higher the educational attainment of children.

There are two regimes in the model. In the first one, parents invest in child education. The former expression of e^* is positive (the relative cost of education is smaller than the elasticity of education $\tau/\phi < \eta$), and e^* represents the level of education that children complete. In the second regime, parents do not invest into their children's education, which is constrained to 0, and the latter program has no interior solution.

In order to derive an explicit expression for n, a functional form for the utility function is chosen. One considers a CRRA utility function with a relative degree of risk aversion greather than or equal to 1.[9] Proposition 1 follows.

Proposition 1. *Determinants of Fertility.*

i. In any regime, fertility is a decreasing function of the survival probability of children.
ii. In the regime where parents invest in child education, fertility is a decreasing function of the relative cost of fertility relative to education (ϕ/τ).

The first part of the proposition (demonstrated in the appendix) illustrates the replacement effect: when child mortality is high, parents have more children to hold net fertility constant, net fertility being equal to the product of fertility by child survival probability. As Doepke (2005), demonstrated the decline in child mortality is sufficient to generate a decrease in total fertility in this kind of model but not a decrease in net fertility, as observed historically. Doepke (2005) concludes that the health hypothesis is unable to account for the entire fertility transition. Similarly, Galor (2005) has challenged the latter hypothesis because child mortality and fertility have displayed inconsistent trends in some European countries such as England in the eighteenth and nineteenth centuries.

Therefore, the fertility transition needs a complementary explanation, which is provided by the second part of the proposition. Along this line, fertility hinges on the relative cost of fertility relatively to child education ϕ/τ. How

[8] See Caldwell (1976) for an interpretation of the demographic transition, as well as Ehrlich and Lui (1991).

[9] Formally, $u(c) = \frac{1}{1-\epsilon}c^{1-\epsilon}$ with $\epsilon > 1$, or $u(c) = \log(c)$ in the particular case where $\epsilon = 1$.

TABLE 1.—DESCRIPTIVE STATISTICS: SAMPLE AVERAGES

	Balanced Panel				Other Countries			
	1870	1910	1960	2000	1870	1910	1960	2000
Crude birthrate	35.0	28.0	19.0	11.8	–	34.6	42.3	26.5
Crude death rate	22.8	16.2	10.3	9.3	–	23.0	16.6	9.4
Infant mortality rate	173.9	116.9	30.4	5.9	–	179.8	120.4	49.0
Average years of schooling	3.5	5.7	7.8	11.6	–	2.9	2.7	6.4
GDP per capita	1,972	3,386	7,224	18,783	–	1,788	2,390	5,330
Number of countries	16	16	16	16	0	9	54	54

that ratio evolves in the course of economic development is investigated below.

B. *Dynamics of Fertility*

We make two assumptions:

A1. The cost of raising children is the sum of a fixed cost and a time cost proportional to parental income,

$$\phi(y) = \alpha + \theta y, \text{ with } \theta > 0. \tag{6}$$

A2. The relative cost of fertility relatively to education $\phi(y)/\tau(y)$ increases with income y. This is equivalent to assuming from equation (5) that child education increases with parental income, which an obvious historical fact.

The former two assumptions deserve a quick discussion. First, assumption A1 decomposes the cost of fertility into two components: the cost of giving birth, which is constant, and the cost of child rearing, which can be viewed as a fixed proportion of household's time. According to Haveman and Wolfe (1995), raising a child costs about 15% of a household's total time, hence income. Assumption A1 is standard and used in many theoretical frameworks.

Assumption A2 relies on the fact that observed enrollments in primary, secondary, and tertiary schools have risen alongside economic development in all countries from 1850 onward, wartime periods excepted. Historically, this fact likely reflects the gradual transition from elite private schooling to universal, tax-based public schooling (Lindert, 2004). Indeed, the provision of mass education has lowered the opportunity cost of education of the median household and has constituted a form of income redistribution.[10] In contrast, the cost incurred for child rearing has largely remained private over time. In sum, the production of child education acknowledged economies of scale through public schooling contrary to child rearing, so that the cost of fertility relative to education has presumably increased in the course of economic development. From those two assumptions, proposition 2 follows:

Proposition 2. *Fertility Variations Relative to Income.*

i. *In the phase of zero investment in child education, fertility increases with parental income y if $\epsilon > 1$ or $\epsilon = 1$ and $\alpha > 0$.*
ii. *When households invest in child education and the fixed cost of fertility is negligible relative to its time cost, fertility decreases with parental income y.*

The first part of the proposition, demonstrated in the appendix, shows that some degree of relative risk aversion is sufficient to generate increasing fertility in the first regime.[11] The second part of the proposition is a straightforward deduction from point ii of proposition 1 and assumption A2. It requires that the fixed cost of fertility α be small relative to its time cost θy, a condition that is verified once income standards have reached sufficiently high levels.

This simplistic model contains the most salient ideas of the literature on fertility transition and explains its nonmonotonic variations over time. It shows that (a) child and adult mortality are positive determinants of fertility, (b) there exists another determinant of fertility, the relative cost of fertility relatively to education; (c) fertility increases with income in a regime where risk-averse parents do not invest in child education (possibly because education is too expensive); and (d) once the process of educational investment is engaged, fertility starts decreasing while child education increases.[12] The next section details the empirical strategy.

IV. Empirical Framework

A. *Descriptive Statistics*

The full sample is composed of 70 countries that enter the panel at different dates. A balanced panel of 16 advanced countries is available since 1870, and 25 countries are available in 1910, 29 in 1930, 37 in 1950, and 69 in 1960. Table 1 reports the average of the main economic variables for the balanced panel and the set of other countries—developing countries in a large majority of cases. Descriptive statistics

[10] Improvements in school enrollment accelerated in western Europe on the eve of the second industrial revolution (Bairoch, 1997). Murtin and Wacziarg (2011) find that the diffusion of literacy is largely explained by economic growth.

[11] In the first regime, fertility is constant if households have a logarithmic utility function and the fixed cost of fertility is null ($\alpha = 0$ and $\epsilon = 1$). This case is envisaged in De la Croix-Doepke (2003).

[12] Some countries never experienced increases in fertility, possibly because they never experienced episodes of income growth combined with null investment in child education.

TABLE 2.—CORRELATION MATRICES

	All Countries				Balanced Panel			
	Log Birthrate	Log Death Rate	Log Infant Mortality	Average Schooling	Log Birthrate	Log Death Rate	Log Infant Mortality	Average Schooling
Log death rate	0.52				0.75			
Log infant mortality	0.76	0.72			0.82	0.79		
Average schooling	−0.85	−0.56	−0.84		−0.83	−0.71	−0.86	
Log GDP per capita	−0.8	−0.57	−0.82	0.86	−0.8	−0.79	−0.93	0.9

FIGURE 4.—LOG BIRTHRATE AND AVERAGE SCHOOLING, 1870–2000

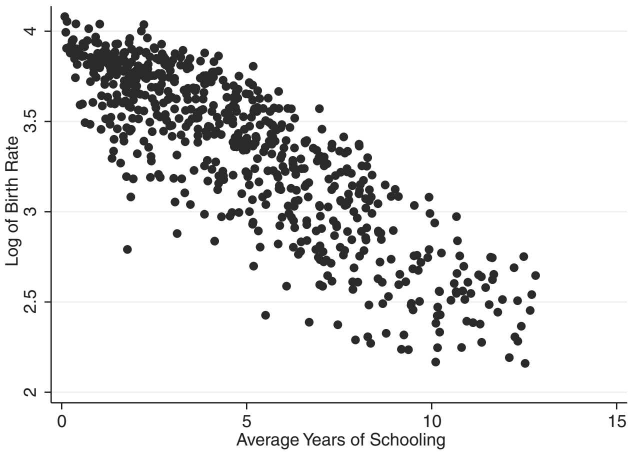


FIGURE 6.—LOG BIRTHRATE AND LOG INFANT MORTALITY, 1870–2000

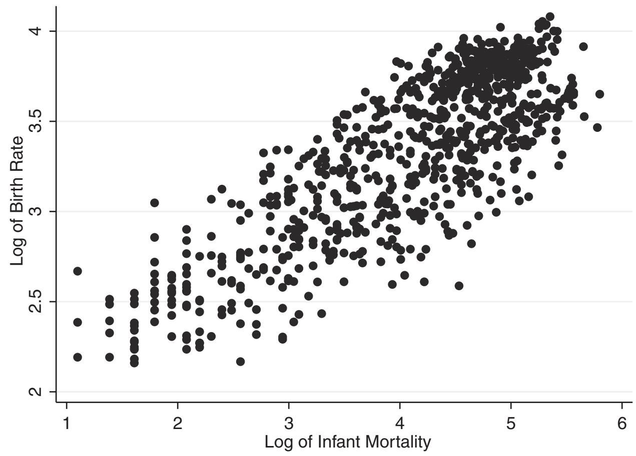


FIGURE 5.—LOG BIRTHRATE AND LOG GDP PER CAPITA, 1870–2000

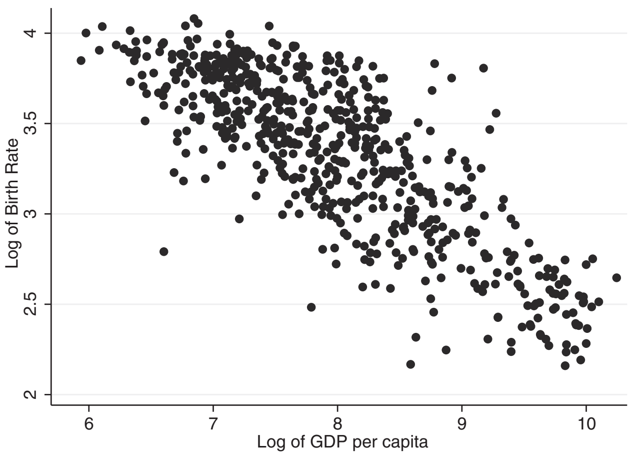
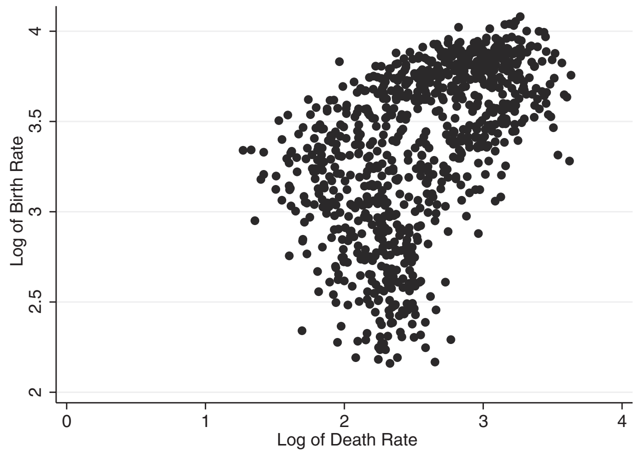


FIGURE 7.—LOG BIRTHRATE AND LOG DEATH RATE, 1870–2000



pertaining to the balanced sample of advanced countries illustrate the qualitative facts already noted: between 1870 and 2000, the birthrate has been divided by three, the death rate by two, infant mortality has been dwarfed to 6 deaths per 1,000 births versus 174 deaths in 1870, and average years of schooling and income have grown continuously, and at an especially marked pace after 1960.[13] Interestingly, table 1 shows that in 2000, the group of developing countries displayed health standards comparable to those of developed countries in the interwar period.

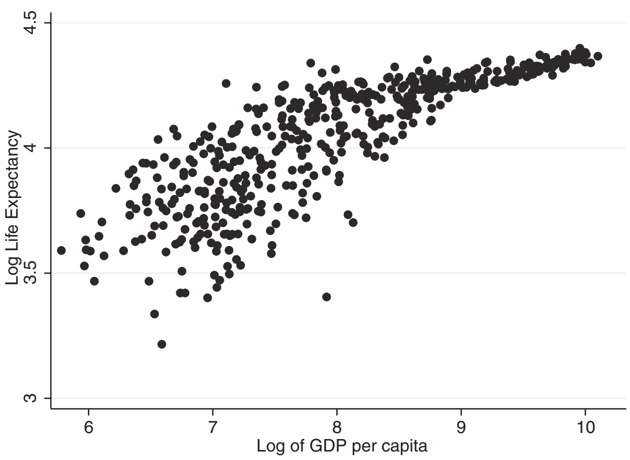
Table 2 offers a quick look at the correlations of our main variables. Among the potential determinants of fertility, average years of schooling and income are the most correlated with the crude birthrate. These two variables are also significantly correlated with mortality rate, and are themselves highly correlated. Figures 4 to 8 depict the scatter plots of the main variables over the entire period. The econometric analysis will determine whether the latter correlations are robust.

B. *Determinants of Fertility*

Econometric model. From the theoretical section, fertility is the outcome of two separate economic forces: a health effect arising from increased survival probabilities s and a modernization effect stemming from a growing relative cost

[13] Most of this decrease occurred between 1870 and 1960.

FIGURE 8.—LOG LIFE EXPECTANCY AND LOG GDP PER CAPITA, 1930–2000



of fertility ϕ/τ. As an illustration, fertility is equal in the second regime to the following expression obtained with a logarithmic utility function:

$$n = \frac{(1-\eta)}{(1+1/\beta)\theta}\frac{1}{s}\left(1+\frac{1}{\phi/\tau-1}\right), \tag{7}$$

showing that fertility is a decreasing function of the child and adult survival probability s and the cost of fertility relative to education ϕ/τ. A log linearization of equation 7 yields[14]

$$\log n \approx a - \log(s) - \log(\phi/\tau), \tag{8}$$

where a is a constant.

In the econometric framework, the health effect is proxied by an index of child mortality, denoted as $M^I_{i,t}$, and total mortality $M^T_{i,t}$, where i (resp. t) is the country (resp. time) index:

$$\log(s_{i,t}) = -(\gamma \log M^I_{i,t} + \delta \log M^T_{i,t}). \tag{9}$$

Conversely, proposition 2 shows that the relative cost of fertility is possibly an inverted U-shape curve of the level of economic development. After testing several functional forms, I retain a cubic function of income y combined with a linear function of average education S and time effects to account for the modernization effect:

$$\log(\phi/\tau)_{i,t} = -(b_t + \alpha S_{i,t} + \beta_1 \log y_{i,t} + \beta_2(\log y_{i,t})^2 + \beta_3(\log y_{i,t})^3). \tag{10}$$

Combining equations (8), (9), and (10) yields the following econometric model:

$$\log n_{i,t} = a_i + b_t + \alpha S_{i,t} + \beta_1 \log y_{i,t} + \beta_2(\log y_{i,t})^2 + \beta_3(\log y_{i,t})^3 + \gamma \log M^I_{i,t} + \delta \log M^T_{i,t} + \pi X_{i,t} + u_{i,t}. \tag{11}$$

In practice, the log birthrate $n_{i,t}$ is regressed over average years of schooling among the population older than 15 years, $S_{i,t}$, a cubic in log GDP per working-age adult $y_{i,t}$ that captures the nonlinear effect of economic development on fertility,[15] the log of infant mortality rate $M^I_{i,t}$, the log of total mortality rate $M^T_{i,t}$, time-specific effects b_t, country-specific effects a_i, and demographic controls $X_{i,t}$ as the birthrate obviously depends on the shape of pyramid's age.[16]

This set of explanatory variables allows testing for the health hypothesis that emphasizes the decline in child mortality (Nerlove, 1974) or in total mortality (Soares, 2005), as well as for the modernization hypothesis based on either the rise in education (unified growth theory by Galor & Weil, 2000) or income growth (Becker, 1981).

The results. Table 3 proposes pooled OLS regressions (dropping specific effects a_i) that mainly reflect the negative correlation between education and fertility, as well as the positive correlation between fertility and child mortality. Columns I to IV show that all variables, except the log death rate, are significantly correlated with the log birthrate; in particular, introducing a cubic in income is statistically relevant. Provided that a cubic in income is introduced as in column VI, all explanatory variables are significant. As expected, education is negatively related to fertility, whereas infant mortality displays a positive association. The total death rate, however, has a significant negative sign in the last column, suggesting that adult and infant mortality have opposite effects on fertility. Finally, the magnitude of the coefficients corresponding to the cubic in income, together with the range of values of log GDP per working-age adult, indicate a positive association between fertility and income until GDP per working-age adult reaches about 2000 \$US and a flat or slightly negative association afterward.[17] Thus, the nonmonotonicity described earlier receives partial empirical support in pooled regressions. Interestingly, controlling for other determinants of fertility undermines the negative canonical correlation between income and fertility.

Table 4 introduces fixed effects in all regressions. Coefficients are marginally modified except for total mortality, which is no longer significant. Also, income is now only positively associated with fertility, as shown in column V. As a preliminary conclusion, the decrease in fertility is significantly associated with educational development, and income displays a positive, rather than negative, correlation with fertility.

The magnitude of the coefficients can be better discussed using table 5, which reproduces the fixed-effects estimation

[14] Assuming by convenience that ϕ is much larger than τ.

[15] The adult population of reference is the population between 20 and 59 years. The use of GDP per capita has been avoided as it would be influenced directly by fertility, introducing some reverse causality inside the regressions. Besides, nonlinearities in other factors such as education have been tested and rejected empirically.

[16] As it depends more particularly on the share of females aged 15 to 45 in the total population, I introduce the shares of population respectively aged between 20 and 30 years and between 30 and 40 years as convenient proxies.

[17] In 1990 Geary-Khamis dollars.

TABLE 3.—LONG-TERM DETERMINANTS OF THE LOG BIRTHRATE, OLS POOLED: REGRESSIONS ON ALL COUNTRIES, 1870–2000

	I	II	III	IV	V	VI
Schooling	−0.10***				−0.05***	−0.04***
	(0.00)				(0.01)	(0.01)
Log infant mortality		0.40***			0.27***	0.33***
		(0.02)			(0.02)	(0.02)
Log death rate		−0.01			−0.04	−0.16***
		(0.03)			(0.03)	(0.03)
Log GDP per working-age adult			−0.32***	11.29***	−0.01	10.93***
			(0.01)	(2.90)	(0.02)	(2.22)
Log of GDP per working-age adult^2				−1.30***		−1.31***
				(0.33)		(0.25)
Log of GDP per working-age adult^3				0.048***		0.052***
				(0.012)		(0.010)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	No	No	No	No	No	No
N	572	572	572	572	572	572
N countries	70	70	70	70	70	70
R^2	0.78	0.81	0.72	0.73	0.83	0.85

TABLE 4.—LONG-TERM DETERMINANTS OF THE LOG BIRTHRATE, PANEL FIXED EFFECTS: REGRESSIONS ON ALL COUNTRIES, 1870–2000

	I	II	III	IV	V	VI
Schooling	−0.08***				−0.05***	−0.05***
	(0.01)				(0.01)	(0.01)
Log infant mortality		0.27***			0.28***	0.31***
		(0.03)			(0.03)	(0.03)
Log death rate		0.07**			0.05*	−0.03
		(0.03)			(0.03)	(0.03)
Log GDP per working-age adult			−0.04	12.22***	0.10***	7.80***
			(0.03)	(2.31)	(0.03)	(2.08)
Log of GDP per working-age adult^2				−1.38***		−0.91***
				(0.26)		(0.23)
Log of GDP per working-age adult^3				0.051***		0.036***
				(0.010)		(0.009)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	572	572	572	572	572	572
N countries	70	70	70	70	70	70
R^2	0.65	0.69	0.18	0.23	0.80	0.81

on the balanced panel of sixteen advanced countries. As before, education displays a negative coefficient, and infant and total mortality positive ones, and income displays a positive association with fertility in column V and no significant association in column VI. In quantitative terms, average years of schooling have gone from 3.5 years in 1870 (meaning that about 60% of the population attended six years of primary schooling) to 5.7 years in 1910 (almost the entire population attended primary schooling) in those countries. Retaining column VI as a benchmark, the schooling coefficient is equal to −0.04, which represents a decrease of $0.04 \times (5.7 - 3.5) = 8.8\%$ in the fertility rate. In the meantime, infant mortality has declined by 38%, implying a fall in $0.38 \times 0.27 = 10.3$ percentage points in fertility. Adult mortality decreased by 33%, entailing a 6% decline in fertility, while GDP per working-age adult had no significant effect. The sum of the later effects amounts to a decrease of about 25% in the birthrate, which compares well with the 22% decrease observed historically. In other words, among the convergence club of the first globalization, health improvements might have explained about two-thirds of the decline in fertility and education the remaining third. These calculations, based on estimates that do not necessarily reflect causality, provide a lower bound on the effect of education.

In table 6, I decompose education into two components: average years of primary schooling and average years of secondary and tertiary schooling among the population older than 15 years.[18] To account for heterogeneity across countries, several samples are examined: the full sample, OECD countries, nonOECD countries, and the balanced panel. OLS and panel fixed effects are used alternatively. The following conclusions emerge: (a) in all regressions but one, primary schooling is significantly and negatively associated with fertility; (b) in all regressions, the secondary and tertiary schooling variable is significant as well; (c) infant mortality is significantly and positively associated with fertility, whereas

[18] As tertiary schooling has small values and tiny variations, it is probably more affected by measurement errors than primary and secondary schooling, and it has consequently been added to secondary schooling.

TABLE 5.—LONG-TERM DETERMINANTS OF THE LOG BIRTHRATE, PANEL FIXED EFFECTS: REGRESSIONS ON BALANCED PANEL, 1870–2000

	I	II	III	IV	V	VI
Schooling	−0.04***				−0.04***	−0.04***
	(0.01)				(0.01)	(0.01)
Log infant mortality		0.23***			0.31***	0.30***
		(0.04)			(0.05)	(0.05)
Log death rate		0.18***			0.20***	0.17**
		(0.06)			(0.06)	(0.06)
Log GDP per working-age adult			−0.00	18.24***	0.21***	7.39
			(0.05)	(6.79)	(0.05)	(6.21)
Log of GDP per working-age adult^2				−2.04***		−0.82
				(0.74)		(0.68)
Log of GDP per working-age adult^3				0.08***		0.031
				(0.03)		(0.024)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	224	224	224	224	224	224
N countries	16	16	16	16	16	16
R^2	0.85	0.81	0.82	0.82	0.82	0.82

TABLE 6.—LONG-TERM DETERMINANTS OF THE LOG BIRTHRATE, VARIOUS SAMPLES

	All Countries		OECD		Non-OECD		Balanced Panel	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
Primary schooling	−0.05***	−0.04***	−0.03**	−0.03*	−0.01	−0.06**	−0.05***	−0.03**
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.02)
Secondary and	−0.03***	−0.07***	−0.03***	−0.05**	−0.11***	−0.12***	−0.04***	−0.06***
tertiary schooling	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.02)
Log infant mortality	0.32***	0.30***	0.26***	0.32***	0.19***	0.17***	0.19***	0.29***
	(0.02)	(0.03)	(0.03)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)
Log death rate	−0.16***	−0.02	−0.22***	0.07	0.06	−0.01	−0.22***	0.17**
	(0.03)	(0.03)	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)
Log GDP per	10.25***	8.76***	15.29**	13.71**	11.17***	12.19***	8.29	7.97
working-age adult	(2.29)	(2.20)	(6.27)	(5.75)	(3.70)	(3.39)	(7.16)	(6.26)
Log of GDP per	−1.22***	−1.03***	−1.77***	−1.55**	−1.35***	−1.49***	−0.94	−0.89
working-age adult^2	(0.26)	(0.25)	(0.68)	(0.63)	(0.44)	(0.40)	(0.78)	(0.68)
Log of GDP per	0.048***	0.040***	0.068***	0.058**	0.054***	0.060***	0.040	0.034
working-age adult^3	(0.010)	(0.009)	(0.025)	(0.023)	(0.017)	(0.016)	(0.028)	(0.025)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
N	572	572	292	292	280	280	224	224
N countries	70	70	24	24	46	46	16	16
R^2	0.85	0.81	0.83	0.80	0.80	0.76	0.88	0.82

total mortality displays mixed results; and (d) with the notable exception of the balanced panel, income displays a significant association with fertility, which is positive below a threshold of about 2000 US$ and flat above it. In particular, there is no evidence that income is negatively associated with fertility.

Instrumenting and accounting for persistence. Next, I use an instrumentation procedure and also account for time persistence in the dependent variable. Under the assumption of weak exogeneity of explanatory variables and zero autocorrelation of residuals, our procedure allows a causal interpretation of estimates. Echoing the microeconomic literature that uses grandparents' characteristics as an instrument for parental background variables (Maurin, 2002), I use long-distant lags of explanatory variables as instruments (for example, education lagged thirty and fourty years).

In practice, I introduce the first lag (a ten year time span) of the log birthrate inside the regression. Rationales for doing so include the persistence of cultural factors or social norms or imitation of parental behavior.[19] The econometric model becomes

$$\log n_{i,t} = a_i + b_t + \rho \log n_{i,t-1} + \alpha S_{i,t} + \beta_1 \log y_{i,t} + \beta_2 (\log y_{i,t})^2 + \beta_3 (\log y_{i,t})^3 + \gamma \log M^I_{i,t} + \delta \log M^T_{i,t} + \pi X_{i,t} + u_{i,t}. \quad (12)$$

This model is estimated by state-of-the-art Blundell-Bond (1998) SYS-GMM techniques. The use of such a procedure is submitted to several robustness and specification tests, as it is well known that the choice of instruments, and in particular their number, can have adverse effects on the

[19] Haines (1992) invokes imitative behavior of the elite by the middle class when describing the onset of the fertility transition in late nineteenth-century France.

TABLE 7.—GMM ESTIMATION OF LOG FERTILITY DETERMINANTS, 1870–2000: ALL COUNTRIES

	I	II	III	IV	V	VI
Lagged log fertility	0.59***	0.64***	0.54***	0.46***	0.68***	0.60***
	(0.14)	(0.13)	(0.18)	(0.14)	(0.13)	(0.14)
Schooling	−0.11**		−0.04*		−0.05**	
	(0.04)		(0.02)		(0.02)	
Primary schooling		−0.13**		−0.07**		−0.09**
		(0.05)		(0.03)		(0.04)
Secondary and tertiary schooling		−0.01		0.00		0.01
		(0.08)		(0.06)		(0.06)
Log infant mortality	−0.01	−0.01	0.21**	0.20***	0.12	0.08
	(0.08)	(0.11)	(0.10)	(0.08)	(0.08)	(0.09)
Log death rate	0.02	0.02	0.07	0.05	0.16*	0.09
	(0.13)	(0.11)	(0.10)	(0.09)	(0.09)	(0.10)
Log GDP per working-age adult	−1.81	−8.61	0.55	13.33	2.91	5.42
	(10.40)	(13.35)	(0.50)	(8.67)	(7.92)	(7.56)
Log of GDP per working-age adult^2	0.18	0.96	−0.12	−1.48	−0.35	−0.58
	(1.16)	(1.50)	(0.10)	(0.95)	(0.89)	(0.86)
Log of GDP per working-age adult^3	−0.005	−0.035	0.007	0.054	0.015	0.021
	(0.042)	(0.056)	(0.005)	(0.034)	(0.033)	(0.772)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
N	519	519	519	519	519	519
N countries	70	70	70	70	70	70
N instruments	69	69	77	77	77	77
AB AR(1) *p*-value	0.00	0.00	0.00	0.00	0.00	0.00
AB AR(2) *p*-value	0.85	0.84	0.91	0.99	0.83	0.91
Hansen *J*-test *p*-value	0.99	0.99	0.35	0.95	0.95	0.99

Columns I and II: lags 3 to 7 of log birthrate. Columns III and IV: third and fourth lags of log birthrate and schooling. Columns V and VI: third and fourth lags of log birthrate and log infant mortality.

estimates, particularly on the Hansen *J*-test of overidentifying restrictions.[20]

Table 7 reports the results for several sets of instruments and shows that education—primary education, more precisely—is the only robust determinant of fertility, together with the lagged level of the log birthrate.[21] The coefficient of primary education is higher but consistent with former estimates: one additional year of primary education diminishes fertility by about 7% to 13%. This means that in the course of economic development, when average primary schooling goes from zero to six years, fertility declines by 40% to 80%. Importantly, all other determinants, including infant mortality, are in most cases insignificant.[22]

In sum, these results display empirical support for two theories of the decline of fertility and is inconsistent with the third one. Both growth in education and the fall in infant mortality are significantly associated with the decline of fertility in most OLS and panel fixed-effects regressions, with consistent estimates across the various regressions. However, instrumentation techniques show that primary years of schooling are the only robust determinant of fertility when controlling for lagged fertility. The magnitude of the coefficient also indicates that education explains the bulk of the decline of fertility over time, from 40% to 80%. In contrast, the Beckerian theory emphasizing the role of income growth is not supported by the data, as income is positively, rather than negatively, associated with the birthrate in the early stages of economic development. This suggests that the initial increase in fertility observed in many countries at various periods is a consequence of growth in income standards, whereas the subsequent decline in fertility is the consequence of growth in educational attainment. Finally, these empirical findings constitute a strong validation of predictions made by unified growth theory: education, rather than income or child mortality, explains the decline in (net) fertility over time.

C. *Determinants of Health*

Econometric model. We now turn to the determinants of health variables: mortality rates and life expectancy. The literature has gravitated to three potential explanations for

[20] See Roodman (2009). I used the xtabond2 Stata version of SYS-GMM provided by Roodman (2006), who advises as a practical rule of thumb not using more instruments than there are countries. In practice, I applied the two-step procedures that correct for a nontrivial covariance matrix and used the Windmeijer (2005) correction of downward-biased standard errors in finite samples. A Blundell-Bond (1998) estimator was preferred to an Arellano-Bond (1991) DIF-GMM estimator, which often suffers from weak instruments problems.

[21] All regressions pass the Arellano-Bond tests of residuals' zero autocorrelation, with an expected rejection when testing the null hypothesis of zero first-order autocorrelation of differenced residuals, and acceptance when testing the null hypothesis of zero second-order autocorrelation; regressions also pass the Hansen test of joint exogeneity of instruments.

[22] Using a panel of seventy countries observed between 1960 and 2000, I found that the previous results are largely unchanged when replacing the log birthrate by the log total fertility rate. More specifically, I find that (a) education is highly significant and negatively related to the log fertility rate in OLS, panel fixed effects, and GMM regressions, a result mostly explained by primary schooling that is robust to the use of GMM, unlike secondary and tertiary schooling; (b) when income is significant, it is positively related to log fertility until reaching a threshold of about \$2,000 to \$3,000, after which it displays a flat profile; and (c) log infant mortality is also highly significant, contrary to total mortality. These results were expected as the birthrate regressions control for the share of population aged 20 to 29 and 30 to 39, ensuring that the birthrate conditional on the number of females is more or less equivalent to the total fertility rate.

TABLE 8.—ESTIMATION OF LOG INFANT MORTALITY DETERMINANTS, 1870–2000

	Balanced Panel				All Countries					
	OLS		Fixed Effects		OLS		Fixed Effects		GMM	
Schooling	−0.03*		−0.00		−0.15***		−0.07***		−0.19***	
	(0.02)		(0.02)		(0.01)		(0.02)		(0.03)	
Primary schooling		−0.06**		0.02		−0.15***		0.02		−0.12***
		(0.02)		(0.02)		(0.02)		(0.02)		(0.04)
Secondary and tertiary schooling		0.00		−0.04		−0.14***		−0.23***		−0.28***
		(0.03)		(0.03)		(0.02)		(0.02)		(0.04)
Log GDP per working-age adult	−0.56***	−0.58***	−0.60***	−0.58***	−0.43***	−0.43***	−0.43***	−0.37***	−0.37***	−0.32***
	(0.08)	(0.08)	(0.07)	(0.07)	(0.03)	(0.03)	(0.04)	(0.04)	(0.10)	(0.10)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	224	224	224	224	572	572	572	572	572	572
N countries	16	16	16	16	70	70	70	70	70	70
R^2	0.94	0.94	0.93	0.93	0.87	0.88	0.81	0.79	–	–
N instruments									86	86
AB AR(1) p-value									0.00	0.03
AB AR(2) p-value									0.27	0.52
Hansen J-test p-value									0.79	0.81

In GMM instruments: schooling and log GDP per working-age adult lagged 60, 80, and 100 years.

global improvements in health over the twentieth century: health technology, public health infrastructures, and changes in health practices and hygiene. The first effect refers to health-related technological progress embodied in drugs, vaccines, and medical equipment, which can be captured by country- and time-specific effects. The second set of factors captures improvements in health infrastructures such as water sanitation and hospitals, the implementation of a public health care system, all factors that have been related to growing health expenditures and better living standards. Finally, information-related effects can be proxied by the level of education in the population.

Reverse causality is a major issue when regressing health variables on average education or log GDP per capita. For instance, Aghion et al. (2011) show that life expectancy has a positive and significant causal impact on per capita GDP growth, using various sets of instruments for health variables. Similarly, several studies have argued that longer life expectancy should increase educational investments. However, this argument relies on the assumption that lifetime labor supply increases alongside life expectancy, an assumption not supported empirically in the case of the United States (Hazan, 2009).

As before, I select very long lags of explanatory variables as instruments in a GMM setting, such as education and income lagged 60, 80, and 100 years. Such variables are still sufficiently correlated with their contemporary values to avoid weak instrumentation problems and most likely do not have any direct impact on health variables.[23]

Infant mortality is investigated first. Because no pattern of convexity in income or schooling has been detected, the following model is estimated:

$$\log M^I_{i,t} = a_i + b_t + \alpha_1 \log y_{i,t} + \beta S_{i,t} + u_{i,t}. \quad (13)$$

[23] It cannot be fully excluded that fertility has a reverse causality effect on both infant and adult (female) mortality, but previous GMM estimates show that this is not likely to be the case because their statistical association is not significant. Therefore, fertility is excluded from all regressions.

The results. Table 8 depicts the results pertaining to both the balanced and full samples using, alternatively, OLS, panel fixed effects, and SYS-GMM.[24] Overall, average schooling is significant and negatively signed in four cases over five, but the relative importance of primary schooling, and secondary and tertiary schooling, is difficult to determine. Income is significant and negatively associated with infant mortality. But in terms of magnitude, the effect of education appears to be larger than that of income, provided that the last column, which uses GMM, reflects causal effects: with average schooling rising from three years to twelve as in advanced countries between 1870 and 2000, infant mortality would be divided by a factor of $\exp(3 \times 0.12 + 6 \times 0.28) = 7.7$; by contrast, with average income rising from \$2,000 to \$20,000, infant mortality would be divided by $\exp(0.32 \times \log(10)) = 2.1$. Thus, the effect of education on infant mortality would be three times as large as that of income.

Turning to the determinants of the crude death rate and life expectancy, decreasing returns in the health production function have been detected empirically, so I add squared log GDP per working-age adult and squared schooling as explanatory variables.[25] Intuitively, education might have a stronger impact when the population becomes more lliterate and a weaker impact afterward, and similarly, escaping from the subsistence level could have huge health benefits, which might then decrease at the margin. As mirrored by figures 8 and 9, which plot log life expectancy with respect to income and schooling over the period 1930 to 2000, decreasing returns in both income and education constitute a plausible hypothesis.

[24] GMM are presented only for the full sample as this econometric technique is designed for "small T, large N." Consequently it comes as no surprise that the balanced panel of sixteen countries delivers inaccurate results.

[25] When looking at total mortality as a dependent variable, one also adds the age structure of the population that relates to differential mortality across age groups (shares of 10–19 years, 20–29,…,50–59 years and the share of population older than 59)

TABLE 9.—ESTIMATION OF LOG DEATH RATE DETERMINANTS, 1870–2000

	Balanced Panel				All Countries					
	OLS		Fixed Effects		OLS		Fixed Effects		GMM	
Schooling	0.00 (0.01)	0.00 (0.03)	0.01 (0.01)	−0.07*** (0.02)	−0.04*** (0.01)	−0.15*** (0.02)	−0.04*** (0.02)	−0.16*** (0.02)	−0.09*** (0.03)	−0.20*** (0.04)
Schooling^2		−0.000 (0.002)		0.008*** (0.002)		0.010*** (0.002)		0.011*** (0.001)		0.012*** (0.003)
Log GDP per working-age adult	−0.31*** (0.05)	−2.66*** (0.76)	−0.11** (0.05)	−0.57 (0.61)	−0.23*** (0.02)	−1.35*** (0.31)	−0.05 (0.04)	−1.10*** (0.32)	−0.171* (0.093)	−1.44** (0.72)
Log GDP per working-age adult^2		0.129*** (0.042)		0.024 (0.033)		0.064*** (0.018)		0.058*** (0.018)		0.073* (0.040)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	224	224	224	224	572	572	572	572	572	572
N countries	16	16	16	16	70	70	70	70	70	70
R^2	0.72	0.76	0.70	0.66	0.68	0.75	0.56	0.66	–	–
N instruments									86	86
AB AR(1) *p*-value									0.21	0.12
AB AR(2) *p*-value									0.77	0.98
Hansen *J*-test *p*-value									0.51	0.91

In GMM, instruments are schooling and log GDP per working-age adult lagged 60, 80, and 100 years.

FIGURE 9.—LOG LIFE EXPECTANCY AND EDUCATION, 1930–2000

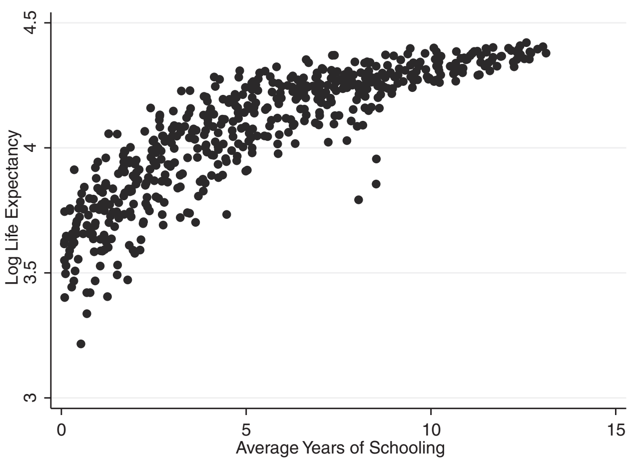


Table 9 and 10, respectively, look at the crude death rate since 1870 and life expectancy since 1930 as dependent variables. Overall, results are consistent across both analyses, even if regressions pertaining to life expectancy seem to perform a bit better. In particular, there is clear evidence of decreasing returns to schooling and, to a lesser extent, income. If GMM estimates displayed in the last two columns reflect causality, then education again displays the larger influence on the crude death rate and life expectancy. Indeed, in the transition from a developing economy (three years of education and GDP per capita of $2,000) to a developed economy (twelve years of schooling and an average income of $20,000), gains in education would increase life expectancy by 122%, while gains in income would entail a 27% increase. Education, rather than income, therefore explains the bulk of the rise in life expectancy over the twentieth century.[26]

D. Limitations and Implications

A first limitation to the analysis relates to the small number of explanatory variables. It was not possible to extend data collection beyond a handful of dimensions. As a result, the exact channels through which education operates on fertility and mortality are absent from the analysis, which has adopted a macroeconomic and historical viewpoint. Thus, the effects associated with education should be viewed as reduced-form results, as education of the adult population correlates with several other dimensions. For instance, Doepke, Hazan, and Maoz (2007) find that female labor demand was a key determinant of U.S. fertility variations in the immediate postwar period. It is clear that increases in female labor demand and female level of education are determined simultaneously. More generally, untangling the effect of education from other simultaneous changes such as the evolution of preferences and social norms is beyond the scope of this study.

In terms of public policy implications, universal primary education displays several benefits. There is, of course, a direct productivity effect of literacy, but declining fertility would also have a Malthusian positive effect on per capita GDP growth if some fixed factor such as land enters the production function. Moreover, this paper suggests that policies that aim to diminish the opportunity cost of education (such as the building of infrastructures, monetary transfers to parents of scholarized pupils, mandatory and free primary schooling) should be complemented by policies that would increase the

[26] Several robustness tests have been conducted but are not reported for conciseness. This involves, first, the introduction of the lagged dependent variable in GMM regressions. As autocorrelation is often large, especially for infant mortality, and estimates are sometimes less accurate and display larger standard errors, which dampens significance. This might stem from residuals that are close to a random walk, perhaps because of large and persistent deviations from world mean outcomes, as for African countries. Thus, GMM was run using first-differenced variables to purge the data from nearly integrated processes. Resulting estimates are very close to the original ones. I have also tested the existence of lagged effects in education and income by introducing a twenty-year lag together with contemporary variables. I found evidence of a lagged effect of a education with infant mortality, but weaker evidence in other regressions.

TABLE 10.—ESTIMATION OF LOG LIFE EXPECTANCY DETERMINANTS, 1930–2000

	Balanced Panel				All Countries					
	OLS		Fixed Effects		OLS		Fixed Effects		GMM	
Schooling	0.01***	0.03***	0.00	0.02*	0.03***	0.09***	0.01	0.06***	0.05***	0.09***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Schooling^2		−0.001**		−1.4e−3**		−0.005***		−0.005***		−0.004***
		(0.000)		(0.6e − 3)		(0.001)		(0.000)		(0.001)
Log GDP per working-age adult	0.07***	0.68***	0.04**	0.98***	0.09***	0.36***	−0.02	0.30***	0.03	0.54*
	(0.01)	(0.22)	(0.02)	(0.22)	(0.01)	(0.11)	(0.01)	(0.10)	(0.04)	(0.29)
Log GDP per working-age adult^2		−0.032***		−0.050***		−0.015**		−0.016***		−0.025
		(0.012)		(0.011)		(0.006)		(0.006)		(0.017)
Demographic controls	No	No	No	No	No	No	No	No	No	No
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	128	128	128	128	414	414	414	414	414	414
N countries	16	16	16	16	66	66	66	66	66	66
R^2	0.88	0.90	0.85	0.83	0.78	0.87	0.15	0.38	–	–
N instruments									78	78
AB AR(1) p-value									0.00	0.00
AB AR(2) p-value									0.02	0.25
Hansen J-test p-value									0.64	0.83

In GMM, instruments are schooling and log GDP per working-age adult lagged 60, 80, and 100 years.

cost of fertility (family planning), as the key policy variable is the relative cost of fertility relatively to education.

V. Conclusion

This paper analyzes the economic determinants of the demographic transition in a large panel of countries since 1870. From a theoretical point of view, I present a simple framework that captures the effects of both modernization and health improvements on the level of fertility. This model captures the nonlinear effect of economic development on fertility, as it accounts for the Malthusian income effect on fertility in early stages of development and the substitution effect with respect to child education in a later stage.

As a main empirical contribution, I find that average years of primary schooling among the adult population, rather than income standards, child mortality, or total mortality rates, drive fertility down by about 40% to 80% when those years grow from zero (no illiteracy) to six years (full literacy). This result is robust to a variety of specifications, samples, and econometric models, including a GMM instrumental approach.

As for the health transition, both average schooling and income are significant determinants of infant mortality, total mortality, and life expectancy, but education alone can account for the bulk of health improvements since 1870.

Overall, these empirical findings suggest that education was the main engine of the demographic transition in the twentieth century as predicted by unified growth theory.

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APPENDIX

Proofs

Proof of Proposition 1. We examine the case where parents invest in education, namely when $e^* \geq 0$. As noticed in the main text, first-order conditions provide

$$e^* = -\frac{1}{1-\eta} + \frac{\eta}{1-\eta}\frac{\phi}{\tau} \tag{A1}$$

or, equivalently,

$$\phi + \tau e^* = \frac{\phi - \tau}{1-\eta}. \tag{A2}$$

The second first-order condition is

$$\frac{\partial V}{\partial c} \Big/ \frac{\partial V}{\partial e} = \frac{1}{\beta snh'}\left(\frac{snh}{c}\right)^{\epsilon} = \frac{1}{\tau sn}, \tag{A3}$$

with

$$h' = \frac{\partial h}{\partial e} = \eta \frac{h}{1+e}. \tag{A4}$$

Then equation (A3) becomes

$$\frac{c}{n} = sh\left(\frac{\tau}{\beta h'}\right)^{1/\epsilon}. \tag{A5}$$

The budget constraint can be rewritten as

$$\frac{c}{n} = \frac{y}{n} - s(\phi + \tau e). \tag{A6}$$

Equations (A6 and A7) lead to

$$\frac{y}{n} = s\left[h\left(\frac{\tau}{\beta h'}\right)^{1/\epsilon} + \phi + \tau e\right]. \tag{A7}$$

To ease notations, we introduce a linear function of the relative fertility cost relative to education:

$$x := \frac{1}{1-\eta}\frac{\phi - \tau}{\tau}. \tag{A8}$$

Given that $e^* \geq 0$, one has $x > 0$. Then, simple algebra based on equations (A1) and (A8) leads to

$$h = (1+e)^{\eta} = (\eta x)^{\eta}, \tag{A9}$$

and by equation (A4),

$$h' = \eta h/(\eta x) = \eta^{\eta} x^{\eta - 1}. \tag{A10}$$

Consequently, after some elementary algebric manipulations, equation (A7) becomes, with equations (A2), (A9), and (A10),

$$\frac{y}{n} = s\left[\beta^{-1/\epsilon}\eta^{\eta-\eta/\epsilon}\tau^{1/\epsilon}x^{\eta+(1-\eta)/\epsilon} + \tau x\right], \tag{A11}$$

from which one deduces easily that

$$n = \frac{y}{s}g(\tau, x), \tag{A12}$$

where g is a decreasing function of τ and x as $g(\tau, x) = 1/[\beta^{-1/\epsilon}\eta^{\eta-\eta/\epsilon}\tau^{1/\epsilon}x^{\eta+(1-\eta)/\epsilon} + \tau x]$.

Let us examine the simpler case where there is no interior solution ($e = 0$). Then agents maximize

$$\underset{c,n,h}{\text{Max}}\ V = u(c) + \beta u(sn), \tag{A13}$$

$$\text{s.c. } c + \phi sn = y. \tag{A14}$$

The budget constraint rewrites

$$\frac{c}{n} = \frac{y}{n} - \phi s. \tag{A15}$$

Similarly, first-order conditions provide

$$\frac{\partial V}{\partial c} \Big/ \frac{\partial V}{\partial n} = \frac{1}{\beta s}\left(\frac{sn}{c}\right)^{\epsilon} = \frac{1}{\phi s}. \tag{A16}$$

It leads to

$$\frac{c}{n} = \frac{\phi}{\beta}^{1/\epsilon} s. \tag{A17}$$

Using equations (A15) and (A17) yields

$$\frac{y}{n} = s\left(\phi + \phi^{1/\epsilon}\beta^{-1/\epsilon}\right). \tag{A18}$$

Consequently,

$$n = \frac{y}{s}g_0(\phi), \tag{A19}$$

where g_0 is a decreasing function of ϕ, $g_0(\phi) = 1/[\phi + \phi^{1/\epsilon}\beta^{-1/\epsilon}]$.

Proof of proposition 1 immediately follows. From equations (A12) and (A19), it is clear that fertility is an inverse function of children survival probability. This result is independant of risk aversion and stems from the inclusion of s in the utility function. This proves point i of the proposition. Then, point ii follows directly from equation (A12) and the sense of variation of function g.

Proof of Proposition 2. First, we examine point i of the proposition. In the first regime, equation (A19) shows that the derivative of fertility with respect to y is of the same sign as $\alpha + \beta^{-1/\epsilon}\phi^{1/\epsilon-1}(\alpha + \theta y(1 - 1/\epsilon)) > 0$ when $\epsilon > 1$. When $\epsilon = 1$ (logarithmic utility function), fertility equals

$$n = \frac{y}{s(1 + 1/\beta)\phi} = \frac{y}{s(1 + 1/\beta)(\alpha + \theta y)}. \tag{A20}$$

Its derivative has the same sign as α, hence is strictly positive when $\alpha > 0$. This demonstrates point i.

Point ii can be seen by considering, without loss of generality, the case where agents have logarithmic utility, namely, $\epsilon = 1$. This simplification is valid as asymptotically, when y is large enough, the function $g(\tau, x) \approx \tau x$ as $\eta + (1 - \eta)/\epsilon < 1$. So one can consider the log utility case as a benchmark. In that case,

$$n = \frac{y}{s(1 + 1/\beta)\tau x} = \frac{y(1 - \eta)}{s(1 + 1/\beta)}\frac{1}{\phi - \tau}. \tag{A21}$$

This expression can be rewritten as

$$n = \frac{y(1 - \eta)}{s(1 + 1/\beta)\phi}\left(1 + \frac{1}{\phi/\tau - 1}\right). \tag{A22}$$

When countries are enough developed, any fertility fixed cost is negligeable with respect to income y, and $y/\phi \approx 1/\theta$ constant. Then, under the assumption A2 that the relative cost of fertility relatively to education ϕ/τ increases with income, it is clear that fertility decreases.