When Did Modern Economic Growth Really Start?[1]

The Empirics of Malthus to Solow

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Abstract

This chapter argues that, in spite of slow economic growth, the Industrial Revolution was a period in which there was a discontinuity in the driving forces of modern economic growth. Nevertheless, empirical evidence indicates that temporary growth spurts occurred in several pre-industrial economies. Micro and macro data also suggest that there was another discontinuity in the driving forces of the demographic transition and modern economic growth, involving a change in fertility decisions. Cross-country regressions indicate that improvements in human capital were fundamental for the emergence of modern economic growth.

JEL Classification: N10, O11, O14
Keywords: Malthus to Solow, stylized facts, modern economic growth

[1] I am grateful to Cliff Bekar, Brian Krauth, Oded Galor, Richard Lipsey, Peter Meyer, Clyde Reed, Jean-Laurent Rosenthal and participants in the American Social Sciences Association meetings in Washington D.C. and at the Lisbon conference of the Portuguese Society for Economics Research (SPiE), as well in seminars at the University of British Columbia, Simon Fraser University, Wilfrid Laurier University, Brock University, and Ryerson University for valuable comments in different drafts of this paper. All errors are mine.

1. Introduction

Following the developments of endogenous growth theory in the 1990s, the macroeconomics literature has recently focused on the transition from "Malthus to Solow" (Artrouni and Komlos 1985, Goodfriend and McDermott 1995, Hansen and Prescott 1999, Galor and Weil 2000, Galor and Moav 2002, Carlaw and Lipsey 2001), as well on the Industrial Revolution (Lucas 2002, Jones 2001). This literature emphasizes that there are fundamental differences between Malthusian and modern economies, and the Industrial Revolution is seen as a watershed in world economic development after which sustained growth started. This renewed interest in the transition from Malthus to Solow was mainly caused by the lingering inconsistencies between the Malthusian and the neoclassical theories of economic development. Although the Malthusian theory accounts relatively well for most of pre-industrial history and the modern growth theory can explain many features of modern economic development, there was no unifying theory linking both theories until the recent literature on the transition Malthus to Solow (Lucas 2002).

This interest of macroeconomists in the process of long-term economic growth has coincided with the revisionist movement in economic history, which has reconsidered long-held views on world development. An "old" perspective maintained that the first Industrial Revolution marked a brave new era, after which diminishing returns and the Malthusian checking forces were finally defeated and growth triumphed. In this view, the advent of industrialization unleashed the forces of modern economic growth (Kuznets 1966), which then allowed for a massive increase in population and urbanization at the same time that income and consumption per capita trended sharply upwards (Deane and Cole 1969).

More recently, several studies have cast doubt on some of the premises of this traditional view. It is now clear that the Industrial Revolution was much less sudden and less dramatic than previously thought (Harley 1982, Crafts 1985, Crafts and Harley 1992, Clark 2001). Due to the slow rates of both GDP and per capita GDP growth[2], the Industrial Revolution has been depicted as a mere growth spurt, not very different from others in the past (Clark 2001, Goldstone 2002). In addition, there is also a growing debate on whether or not the Industrial Revolution was really necessary for the emergence of modern economic growth. For instance, de Vries and Woulde (1997) have argued that the 17th century Dutch economy had many features of a "modern" economy, such as high urbanization (around 35 percent by 1650), and relatively high income per capita. Since international trade and secure property rights were the main sources of growth during this Dutch "golden age", de Vries (2001) contends that industrialization was not the sole path to modern economic growth. In overview, the revisionists argue that the Industrial Revolution should be seen as an episode, albeit important, in the trajectory of world economic development, but not as a marked discontinuity.

In sum, after years of neglect, macroeconomists have renewed their interest in the Industrial Revolution and the transition from Malthus to Solow, whereas mainstream economic historians have increasingly downplayed the role of the Industrial Revolution, preferring to emphasize continuity instead of structural breaks in the process of world economic development.

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[2] GDP per capita grew at an average rate of less than 1 per cent per year from 1760 to 1830.

This chapter attempts to bridge the gap between the two literatures by providing some empirical evidence on the transition from Malthus to Solow. The empirical results support the view that modern economic growth started with the Industrial Revolution. Namely, the results indicate that permanent “symptoms of modernity” emerged during this period. The chapter also argues that although the results of the growth process in countries such as Britain exhibit a certain continuity (as Crafts and Harley (1992) have shown), the Industrial Revolution entailed a discontinuity in the driving forces of the same growth process. Thus, although the aggregate indices do not seem to indicate a sharp discontinuity in the evolution of GDP and per capita GDP, the underlying forces of modern economic growth were already in full swing during this period. However, as many have argued before[3], the emergence of modern economic growth during the Industrial Revolution does not imply that intensive growth was nonexistent in the previous centuries. Indeed, the empirical results of this chapter also suggest that growth spurts occurred in several pre-industrial economies, indicating that the latter were much more dynamic than suggested by the traditional modeling of Malthusian economies.

This chapter also presents additional evidence that there were discontinuities in other driving forces typically associated with modern economic growth as well as with the demographic transition. Namely, the micro data for some early European developers suggests that there was a change in fertility decisions in the early 19th century (as suggested by many “Malthus to Solow” models). Nevertheless, the empirical evidence also indicates the fall in birth rates is highly correlated with the decline in mortality rates, which decreased due to improvements in health technology.

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[3] See, for instance, Jones (1988), Snooks (1994), de Vries (2001).

Finally, the empirical results from several macro cross-country regressions suggest that: 1) literacy was highly correlated with economic development in the 19th century, 2) the average number of children was negatively correlated with per capita GDP growth as well as literacy rates, 3) Protestantism and urbanization were positively correlated with literacy, and 4) there was a strong negative relationship between mortality rates and literacy rates.

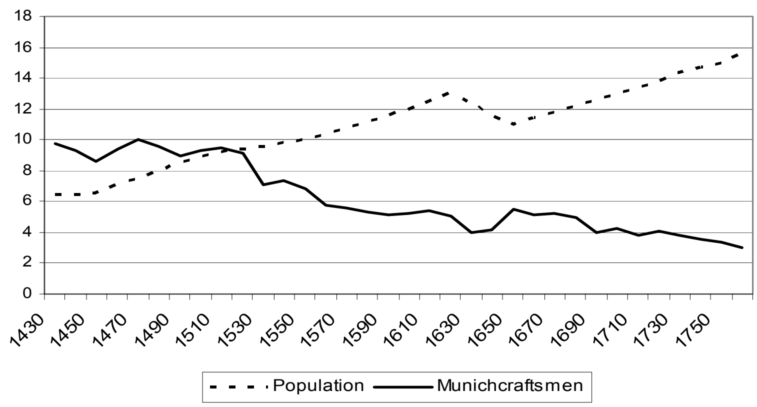
The chapter proceeds as follows. The next section describes the three main features of the Malthus to Solow literature: intensive versus extensive growth, the relationship between real wages and population, and the child quantity-quality trade-off. The following subsections present empirical evidence on each of these features. The last section concludes.

2. From Malthus to Solow

The Malthus to Solow models contain three central ideas. First, in Malthusian economies, income gains were mainly translated into additional population. Consequently, income per capita was almost constant (Galor and Weil 2000). In contrast, in modern economies, productivity improvements sustained by technical change enabled population and standards of living to increase simultaneously.

Second, since technical change was largely absent in Malthusian economies, labour supply shocks were much more common than labour demand shocks. Typically, increases in population led to a rise in the labour supply, putting downward pressure on real wages. Since the shift in labour supply was not matched by a shift in labour demand, population increases were associated with a decrease in real wages. By the same token, wages increased during periods of population decline (e.g. after the Black Death in the 14th century). Figure 1 presents a typical example of the inverse relationship between real wages (in grams of silver) and population (in millions) in pre-industrial economies. In modern economies, wages and population are no longer inversely related, due to sustained improvements in labour productivity, which offset increases in the labour supply. Therefore, one "symptom" that an economy is no longer Malthusian is a *permanent* disappearance of the inverse relationship between wages and population.

Figure 1_ Munich Craftsmen Real Wages Vs German Population, 1460-1750



Source: real wages from Allen (2001), population from McEvedy and Jones (1978)

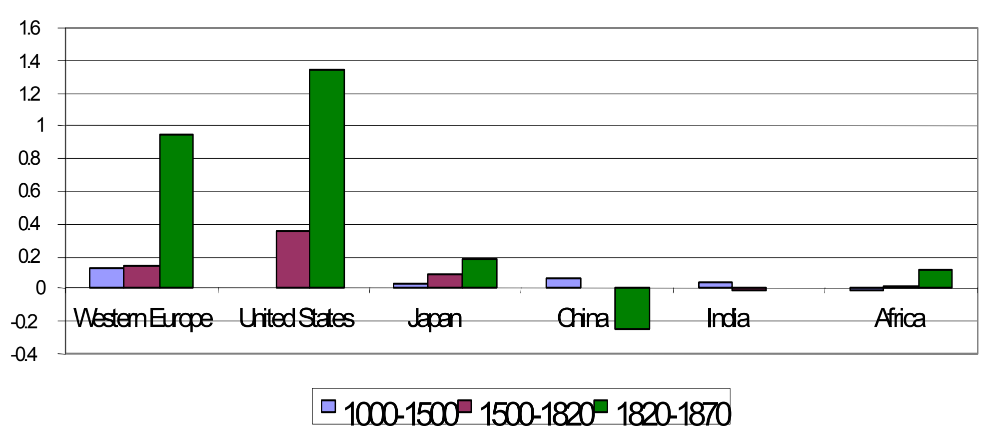
Third, the decline in fertility initiated sometime in the late 18th century was chiefly caused by parents' preferences over their children's education. According to Becker, Murphy and Tamura (1990), Galor and Weil (2000) and Lucas (2002), the returns to education were low in the mostly-agricultural Malthusian economies, and hence parents preferred to invest in child quantity. Over time, technology raised the returns to human capital, and parents started investing in the quality of their children, initiating a demographic transition.

These three characteristics of the transition from Malthus to Solow allow us to observe the process of economic development by looking at "symptoms of modernity" in terms of intensive versus extensive growth, the relationship between real wages and population, and the child quality-quantity trade-off. The next sections present some empirical evidence on these "symptoms of modernity".

Extensive Versus Intensive Growth

The greatest difference between modern and pre-modern economies was not the existence of growth, but the nature of growth. In pre-industrial economies intensive growth (GDP per capita growth) was almost negligible (figure 2). Although average standards of living in pre-industrial economies showed little trend (Hansen and Prescott 1999), many pre-industrial economies sporadically experienced periods of relatively fast growth, such as in Sung China (Jones 1988), 14th century Italy (Clark 2001), or 17th century Holland (de Vries and Woulde 1997). However, these growth episodes were then mostly reflected into a higher population, an expansion of urbanization, or an improvement in the living standards of the ruling elites.

Figure 2 _ Per Capita GDP growth rates: 1000-1870



Source: Maddison (2001)

Furthermore, not only was intensive growth rather uneventful in pre-industrial economies, but also extensive growth was not impressive by today's standards (Livi-Bacci 1989). In contrast, in the last 200 years both intensive and extensive growth accelerated considerably. In spite of a dramatic rise in population, output per person has also increased at an unprecedented pace, increasing by more than a factor of 13 in the most developed countries (Lucas 2002).

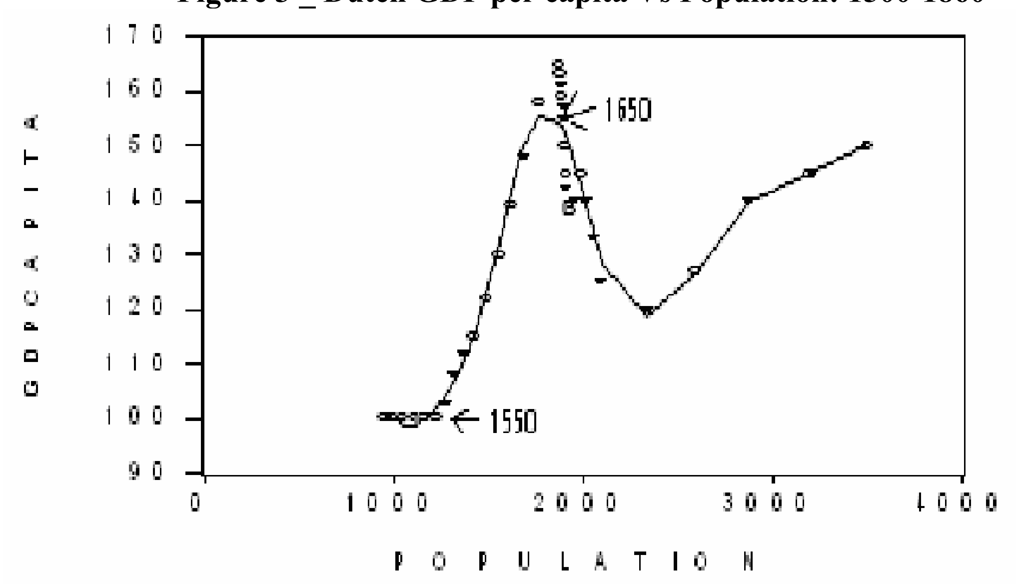
Other features of the transition from Malthus to Solow can also be observed from cross-country data, although before 1800 the data are often made of rough guess-estimates (and thus are subject to significant measurement error). GDP and GDP per capita figures from Maddison (2001) for a sample of 23 countries and territories[4] show that, by the year 1000, GDP per capita was remarkably similar for the great majority of the countries and territories, since most of them were still at the subsistence level of $400 (1990 international dollars). Between 1000 and 1800, the level of income per capita increased for most countries and territories in the sample. Namely, by 1800, most countries and territories in the sample were in a better position than 300 years earlier. Although these rates of GDP per capita growth are small by today's standards, from 1500 onwards there was already an important difference between Western Europe and most other countries: the former was growing at about 0.1 percent per year whereas the latter grew on average at 0.01 percent. At these rates European living standards doubled each 700 years, whereas for the rest of the world it would take about 7,000 years to double income. Thus, these small rates were sufficient to open up a sizeable gap between Europe and the rest of the world in a few centuries.

The impact of intensive growth can also be grasped in individual countries, although the scarcity of high-frequency data raises several difficulties to cross-country

[4] The countries and territories include Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, United Kingdom, Portugal, Spain, Eastern Europe, Russia, the United States, Mexico, Japan, China, India, Other Asia, and Africa.

comparisons. Most data start only in the 18th or 19th centuries, and often the existing figures are incomplete and unreliable. Nevertheless, we do have some data for some of the most advanced countries in Europe, and some scattered data for many of the other countries of different regions. More importantly, we have data for the two early developers in Western Europe, Holland and England, which allows us to compare the development trajectory of these two countries. Data on the Dutch population data are from McEvedy and Jones (1978) and de Vries and Woude (1997). The GDP data were obtained from de Vries (2000) and from de Vries and Woude (1997). Figure 3 shows the relationship between Dutch GDP per capita (in 1720-44 guilders) and the Dutch population (in thousands) from 1500 to 1900, adjusted by an Epanechnikov Kernel fit[5].

Figure 3 _ Dutch GDP per capita Vs Population: 1500-1860



[5] The Epanechnikov Kernel was used due to its versatility and optimality in comparison to other parametric and nonparametric approaches. According to Härdle (1990), there are four main advantages of the nonparametric kernel-fit approach to estimating a regression curve: 1) versatility of exploring a relationship between two variables, 2) prediction of observations without having to use a fixed parametric model, 3) it is a tool for finding spurious observations, 4) it is a method for interpolating or substituting for missing values

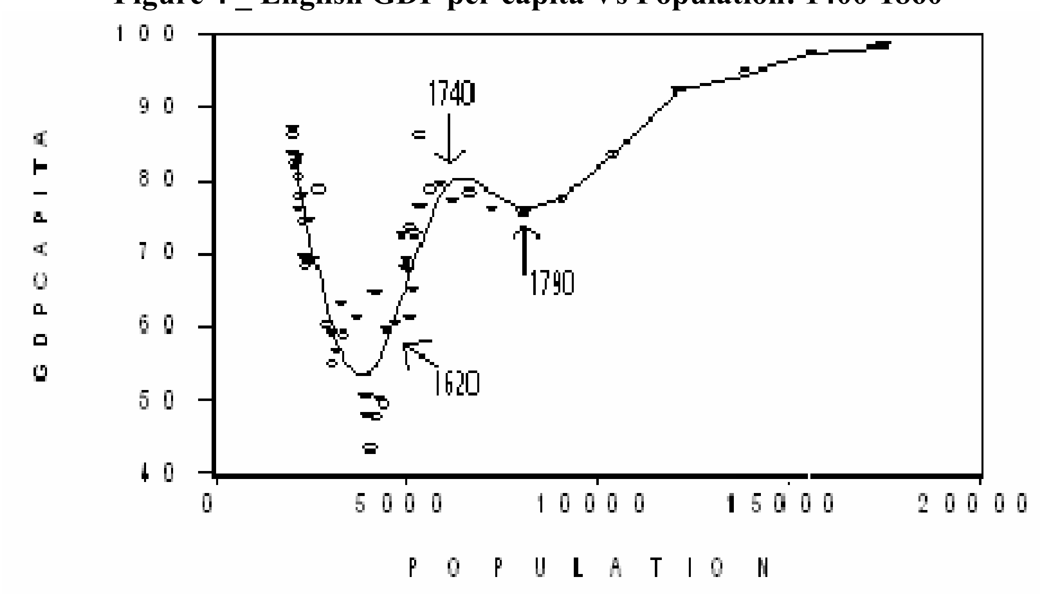
During the period 1550-1650, the Dutch economy exhibited some "symptoms of modernity", as de Vries and Woude (1997) claim. During this Dutch "golden age", trade-based or Smithian growth fuelled GDP per capita and enabled a considerable increase in population. However, these signs of modernity were only temporary. After 1650, population growth stagnated, and GDP per capita fell. Consequently, the Kernel fit polynomial relating both variables becomes negatively sloped. Only after 1800 did both population and GDP per capita increase simultaneously once again. The wage data in the next section also suggests the same pattern of development. Since the increases in both standards of living and population did not become permanent or self-sustaining, the Dutch Golden Age should be seen more as a growth spurt rather than the start of the modern economic growth, as Goldstone (2002) argues.

For England, I obtained data on GDP per capita from Clark (2001), as well as population data from Hatcher (1977) and Wrigley and Schofield (1981). Figure 4 plots an index of English GDP per capita against population (in thousands). The figure shows that GDP per capita was inversely related to population until around the 17th century[6]. From about 1620 until around 1740, there is an increase in both population and GDP per capita, which indicates that the English economy was experiencing an intensive growth spurt. North and Thomas (1973) attribute much of the significant income gains during this period to the establishment of well-defined property rights (North and Thomas 1973) as well as gains from international trade. However, this growth spurt did not become self-sustaining because it was based on Smithian growth, which, according to Mokyr (1990),

[6] The considerable decrease in GDP per capita observed in the Clark (2001) data was a consequence of rise in incomes to the survivors of the Black Death. The sharp fall in population in the 14th century led to a considerable rise in real wages as well as capital per capita. Per capita GDP fell in the following centuries due to the increase in population.

is subject to diminishing returns. Between 1740 and 1790, population continued to expand considerably, but GDP per capita declined slightly. Consequently, during this period both variables became temporarily inversely related. After 1790, and in spite of an unprecedented increase in population, the productivity improvements associated with the Industrial Revolution allowed for both GDP per capita and population to clearly trend upwards. Contrary to previous growth spurts, growth from the Industrial Revolution did not peter out, because it was largely based on sustained technological and organizational change or Schumpeterian growth (Mokyr 1990).

Figure 4 _ English GDP per capita Vs Population: 1400-1860



Source: Clark (2001), Hatcher (1977), Wrigley and Schofielld (1981)

In short, by comparing the two most developed countries in the world after the 16th century we can see that pre-industrial economies were much more dynamic than suggested by the models of the transition from Malthus to Solow. The data show that pre-industrial economies underwent *temporary* growth spurts, in which both population and GDP per capita grew. These findings are consistent with the recent historical literature (de

Vries and Woulde 1997, de Vries 2000, Clark 2001, Goldstone 2002), which emphasize temporary growth episodes in some pre-industrial economies. Nevertheless, the data also suggest that *permanent* increases occurring simultaneously in both population and GDP per capita happened only after the Industrial Revolution. Thus, whereas in previous periods growth petered out, the technological and organizational changes of the Industrial Revolution allowed for the emergence of modern economic growth. In this sense, and in spite of slow per capita GDP growth, the Industrial Revolution was indeed a discontinuity in the process of world development (which is consistent with the Malthus to Solow literature). The same conclusions are obtained by analyzing the relationship between real wages and population.

Real Wages and Population

As mentioned above, wages and population are inversely related in Malthusian economies, whereas in modern economies sustained productivity improvements enable simultaneous increases of wages and population. This section analyzes the wage-population relationship for some European countries (Austria, Belgium, England, France, Germany, Italy, the Netherlands, Poland and Spain). Most population data are from McEvedy and Jones (1978). Whenever possible, these data are complemented by other sources, such as Hatcher (1977), Wrigley and Schofield (1981), de Vries and Woulde (1997), and de Vries (2000). The existing wage data are for representative professions (chiefly labourers and craftsmen) that can proxy for the behaviour of overall real wages. Since most of the wage data are for urban professions, a great percentage of the population is not accounted for in the analysis. Nevertheless, Clark (2001) provides evidence that for England at least, urban wages provide a good proxy for the general wage trend during the period analyzed since his real wages for farm labourer's are highly correlated with both craftsmen's and labourer's wages. Most data on real wages are from Allen (2001). Allen provides an invaluable collection of annual data for series of nominal wages, consumer prices indexes, real wages and welfare ratios for several European cities in a uniform measure, grams of silver[7]. English real wage data was also obtained from Clark (2001). The data are mostly from 1400 to 1900[8]. Figures 5-8 present the wage-population relationship adjusted by an Epanechnikov Kernel fit of a polynomial of degree 2. As expected, for most countries, there is a strong inverse relationship between real wages and population until the 19th century. After the mid-14th century, real wages became relatively high throughout Europe after a plethora of plagues (such as the notorious Black Death), wars and famines. After that shock to population, real wages gradually declined with the recovery of the European population.

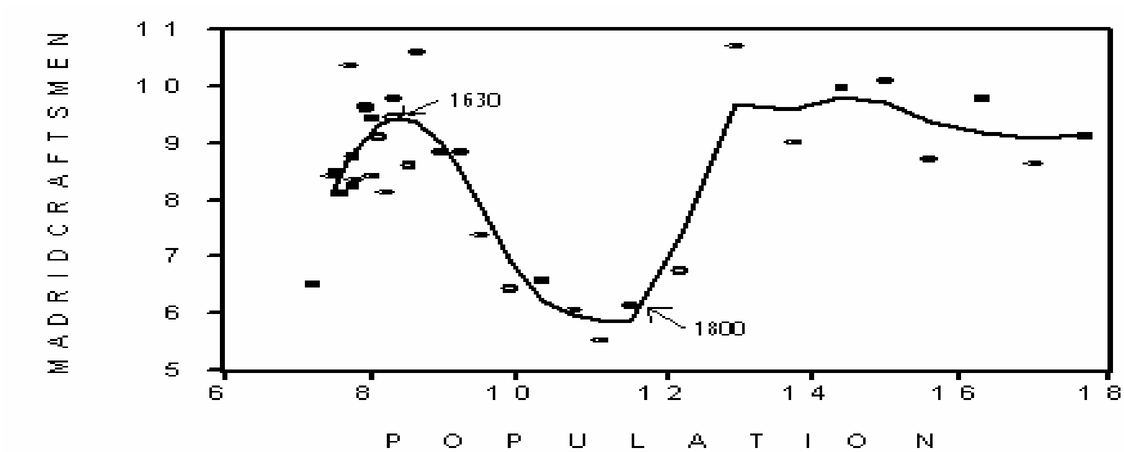
However, as argued before, pre-industrial economies were by no means static. Several European economies underwent temporary growth spurts throughout the period. In Spain, the revenues from the empire and the gains from international trade enabled real wages to grow at the same time as population during the early 16th century (figure 5). The wage data for Valencia craftsmen and labourers also show that the Spanish growth spurt was experienced in other regions outside Madrid (figure 8h). Nevertheless, after 1630, the relationship between real wages and population became once again negative until early in

[7] The data are available in the website: www.econ.ox.ac.uk/Members/robert.allen

[8] The Allen data used are the following: Austria (Vienna from 1400 to 1800), Belgium (Antwerp: 1400-1900), England (London and Oxford, 1400-1900), France (Paris and Strasbourg: from 1395 to 1900, with missing observations from 1790 to 1840), Germany (Munich 1430-1760, Leipzig 1600-1800, and Augsburg 1500-1770), Holland (Amsterdam: 1400 to 1900), Italy (Florence 1340-1900, and Milan 1600-1900), Poland (Krakow and Warsaw: 1400-1900), Spain (Madrid: 1550-1900, and Valencia: 1410 to 1790).

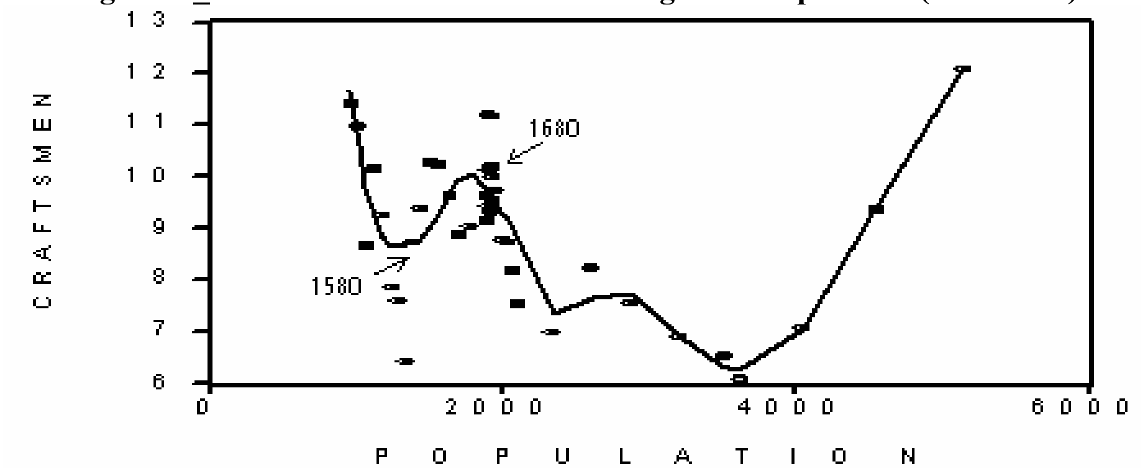
the 19th century. All in all, a growth spurt fuelled by Smithian growth enabled the Spanish economy to temporarily experience simultaneous increases in real wages and population. However, after the growth spurt ended, real wages and population reverted to their previous inverse relationship.

Figure 5 _ Madrid Craftsmen Real Wages vs. Population (1550-1900)



As the previous section indicated, an important growth spurt also occurred in the Netherlands from around the mid 16th century until about 1670. The Dutch and Belgium graphs (figures 6, 8b and 8c) show that during the so-called Dutch golden age real wages and population were no longer inversely related. During this period, there were simultaneous increases in population and real wages (for craftsmen and labourers). This is consistent with de Vries and Woude (1997), who asserted that the Dutch economy exhibited some signs of "modernity" during this period. Thus, the Golden Age allowed the Dutch economy to *temporarily* escape the traditional negative relationship between real wages and population. Nevertheless, after this growth spurt ended, the inverse relationship between wages and population emerged once again, persisting until the 19th century.

Figure 6 _ Amsterdam Craftsmen Real Wages Vs. Population (1400-1900)



There is also evidence suggesting the existence of growth spurts in England before the Industrial Revolution. The wage-population data indicate that, between 1620 and the early decades of the 18th century, the English economy started exhibiting some symptoms of modernity. The 17th century growth spurt enabled both population and real wages to trend upwards. However, this growth spurt in the English economy was not self-sustaining, since by 1720 real wages declined whereas population continued to increase. This trend persisted until the start of the Industrial Revolution, after which the relationship between real wages and population became *permanently* positive. Both the data from Allen (2001) and from Clark (2001) support the findings.

Figure 7 _ London Craftsmen Real Wages vs. Population (1300-1900)

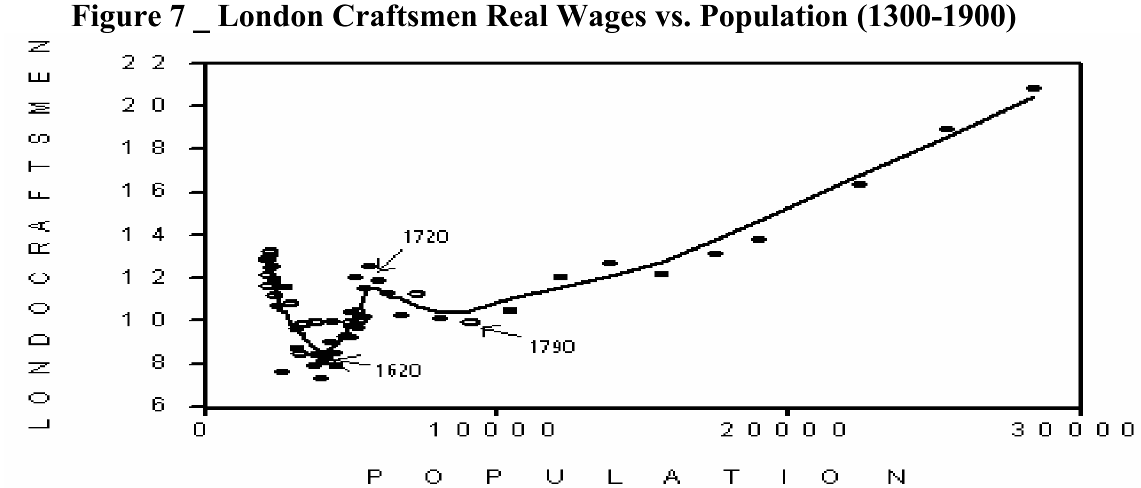
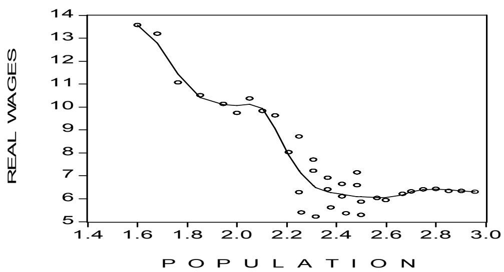


Figure 8 _ Wages Vs Population in Europe

Figure 8a _ AUSTRIA

Vienna Craftsmen 1490-1800



Vienna Labourer 1490-1800

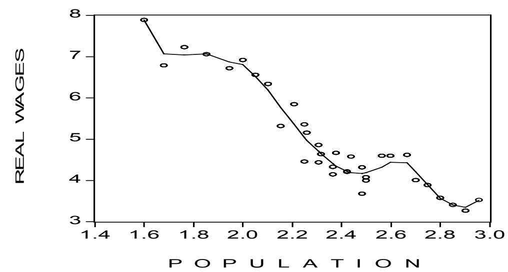
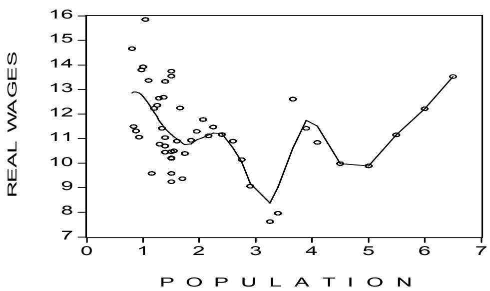


Figure 8b _*BELGIUM*

Antwerp Craftsmen 1400-1900



Antwerp Labourer 1400-1900

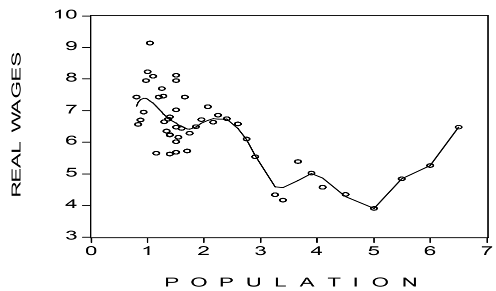


Figure 8c _ *NETHERLANDS*

Amsterdam Labourer 1400-1900

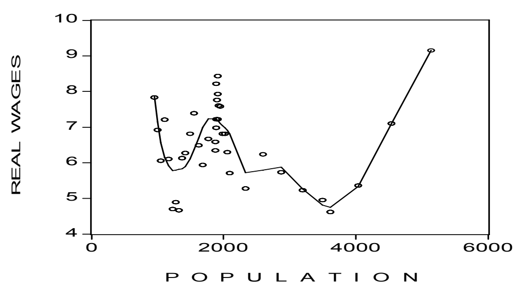
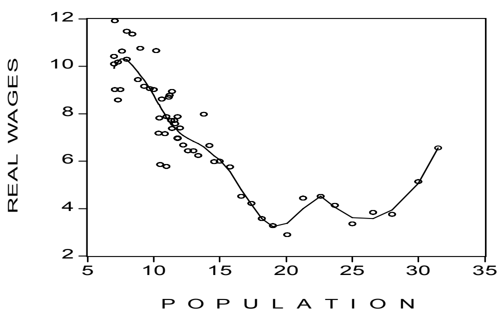


Figure 8d _*ITALY*

Florence Craftsmen 1340-1900



Milan Labourer 1600-1900

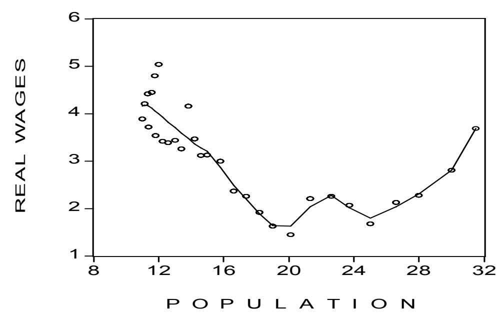
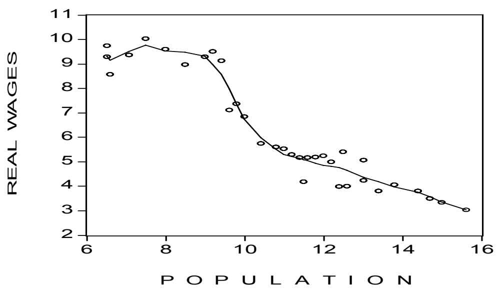


Figure 8e _*GERMANY*

Munich Craftsmen 1430-1760



Leipzig Labourer 1600-1800

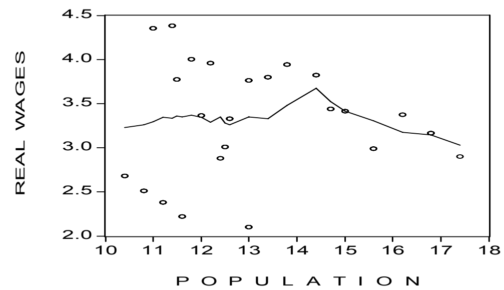
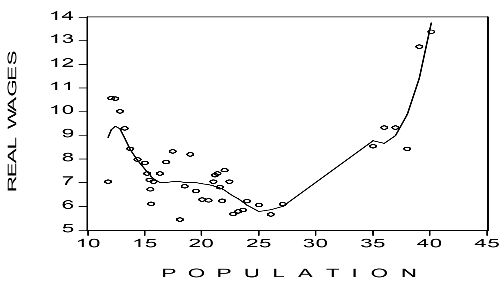
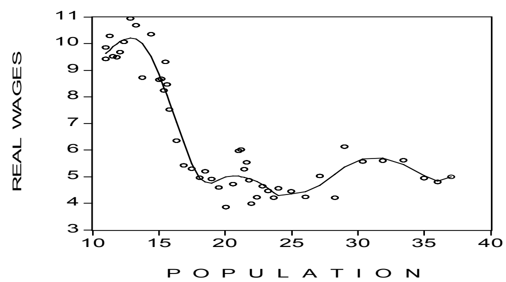


Figure 8f _*FRANCE*

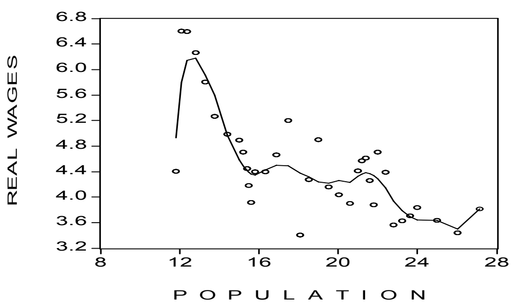
Paris Craftsmen 1390-1870



Strasbourg Craftsmen 1390-1860



Paris Labourer 1430-1790



Strasbourg Labourer 1390-1860

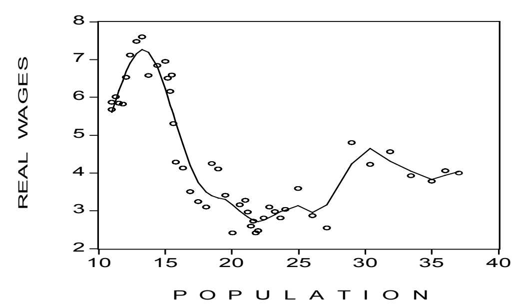
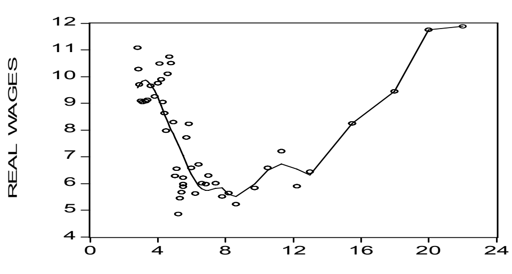


Figure 8g _*POLAND*

Krakow craftsmen 1410-1900



Krakow labourer 1410-1900

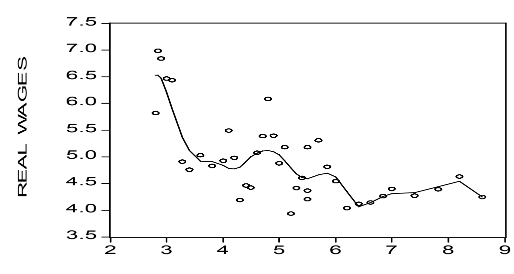
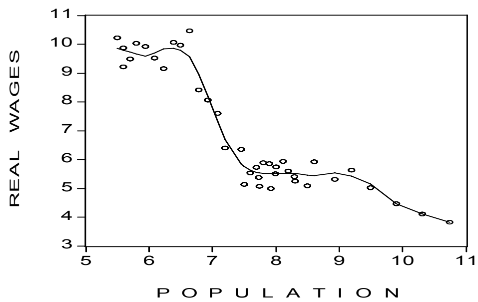


Figure 8h _*SPAIN*

Valencia craftsmen 1410-1790



Valencia labourer 1410-1790

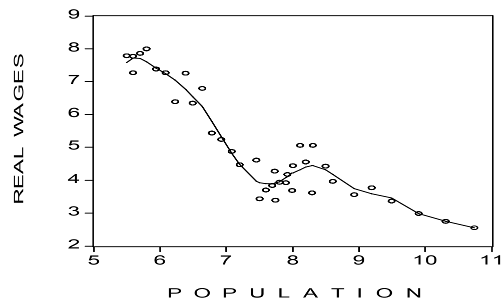
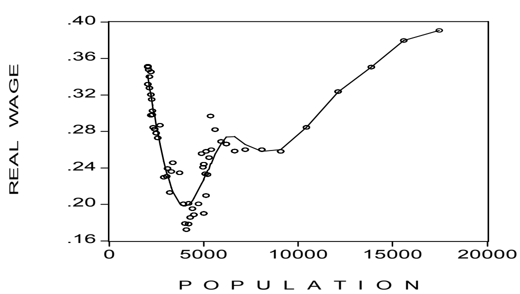
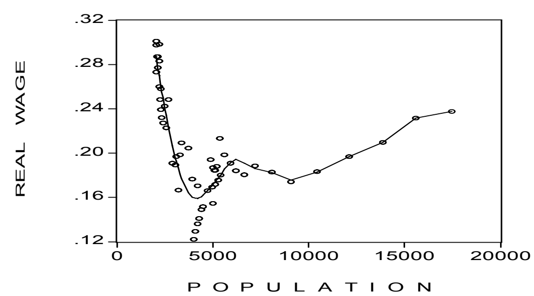


Figure 8i _*ENGLAND*[9]
Clark data

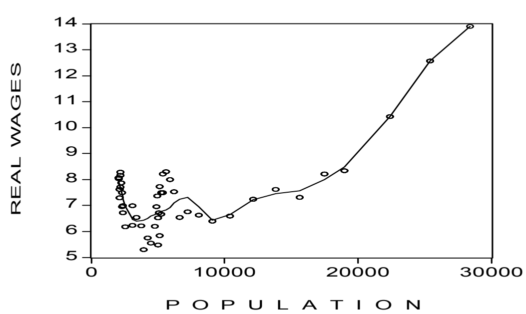
Overall Wage Vs Population 1400-1860



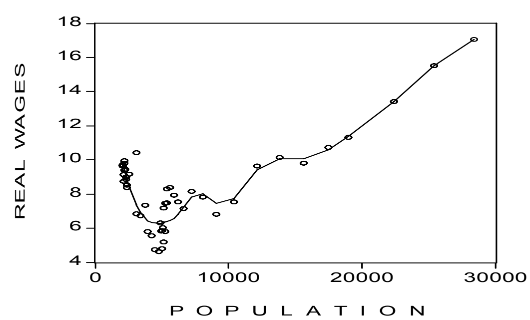
Farmer's Real Wage 1400-1860



London Labourers Vs Population 1541-1850



Oxford Craftsmen Vs Population 1541-1850



[9] It could be argued that the temporary negative relationship between real wages and population from about 1720 until 1790 is due to the measurement error inherent to these historical data. Nevertheless, the magnitude of the increases in population and real wages after the Industrial Revolution suggest that there was indeed a discontinuity in the wage-population relationship during this period.

All in all, there is evidence that growth spurts occurred in some European economies before 1800, allowing for a temporary inversion of the typical negative relationship between wages and population that was typical in pre-industrial societies. However, it is only after the Industrial Revolution that the relationship between real wages and population becomes positive in a *permanent* basis, a clear "symptom" of modern economic growth. Therefore, the findings on the wages-population indicate not only that pre-industrial economies were much more dynamic than suggested by a simple division "Malthus to Solow", but also there is strong evidence that the Industrial Revolution was indeed a discontinuity in the process of world economic development. The difference between the Industrial Revolution and previous growth spurts might have been a question of degree, but the irreversibility of events show that, as Mokyr (1999) emphasizes, "degree was everything".

Shocks to Wages and Population: a VAR approach

The findings in this section suggest that the Industrial Revolution also induced very different types of shocks to wages and population from those of the pre-industrial period. Contrary to previous growth spurts, after 1770, the negative response of population to shocks in real wages suggests that the Industrial Revolution induced parents to alter their fertility decisions.

The dynamic relationship between real wages and population can be further observed by estimating a vector autoregression (VAR) and calculating impulse response functions. Namely, the following VAR of order q was estimated:

$$W_t = \beta_{10} + \gamma_{1j} \sum_{j=1}^{q} W_{t-q} + \gamma_{1j} \sum_{j=1}^{q} POP_{t-q} + e_{1t} \qquad (1)$$

$$POP_t = \beta_{20} + \gamma_{2j} \sum_{j=1}^{q} W_{t-q} + \gamma_{2j} \sum_{j=1}^{q} POP_{t-q} + e_{2t} \qquad (2)$$

where W represents real wages and POP denotes population, and it is assumed that both disturbances are white noise with standard deviations of σ_W and σ_{POP}. In more compact notation, a multivariate VAR of order q can be written as:

$$x_t = A_o + A_1 x_{t-1} + A_2 x_{t-2} + \dots + A_q x_{t-q} + e_t \qquad (3)$$

where x_t is an (n x 1) vector of variables, A_0 is an (n x 1) vector of intercept terms, A_i is a (n x n) matrix of coefficients and e_t is an (n x 1) vector of error terms.

The order of the VAR was determined by the usual lag selection criteria. Since the coefficients of the estimated VARs often alternate in sign and are difficult to interpret, I follow the usual procedure of estimating impulse response functions. The latter provide the response of the dependent variable to shocks in the error terms (also known as innovations or impulses). In terms of the transition to modern economic growth, we should expect the following results from the impulse response functions: 1) in traditional Malthusian economies, population should increase after a shock to real wages, and 2) after modern growth emerges, population should respond negatively to a positive shock in real wages since higher incomes are associated with lower fertility. Formally, the impulse responses can be obtained from the vector-moving average representation of (3):

$$x_t = \mu + \sum_{j=0}^{\infty} \phi_i \varepsilon_{t-j} \qquad (4)$$ [10]

[10] e_i are the white-noise disturbances for a VAR in standard form, whereas ε_I are the errors terms for a structural VAR. Chapter 2 presents the formal relationship between them for a VAR of order 1.

For instance, in a VAR of order 1, we have:

$$\begin{bmatrix} W_t \\ POP_t \end{bmatrix} = \begin{bmatrix} \overline{W} \\ \overline{POP} \end{bmatrix} + \sum_{j=0}^{\infty} \begin{bmatrix} \phi_{11}^{(i)} & \phi_{12}^{(i)} \\ \phi_{21}^{(i)} & \phi_{22}^{(i)} \end{bmatrix} \begin{bmatrix} \varepsilon_{Wt-j} \\ \varepsilon_{POPt-j} \end{bmatrix} \quad (5)$$

where $\phi_{11}^{(i)}$ is the expected one-period response of a one-unit change in ε_{Wt-1} on real wages W, and $\phi_{12}^{(i)}$ is the expected one-period response of a one-unit change in ε_{Wt} on POP. $\phi_{21}^{(i)}$ and $\phi_{22}^{(i)}$ denote the responses to ε_{POPt} shocks.

Due to the correlation between the error terms ε_{Wt-j} and ε_{POPt-j} in (5), it is likely that if ε_{Wt-j} changes then ε_{POPt-j} will be affected, and hence POP_t will also be altered. Therefore, we need to undertake orthogonalization, in which $e_{1t} = \varepsilon_{Wt} - b_{12}\varepsilon_{POPt}$, and $e_{2t}=\varepsilon_{POPt}$. Assuming that the structural disturbances have a recursive structure, the structural parameters are recovered using the Choleski decomposition of the reduced form covariance matrix, which constrains the system such that there are no contemporaneous effects of W_t on POP_t. Impulse response functions were then estimated for combinations of real wages and population for all the countries described above[11]. Figures 9a-9e report the impulse response functions for the two early European developers, England and Holland in several periods. In the figures 9a-9e, the horizontal axis represents the number of years after the shock took place, whereas the vertical axis shows the magnitude of the shock on different variables.

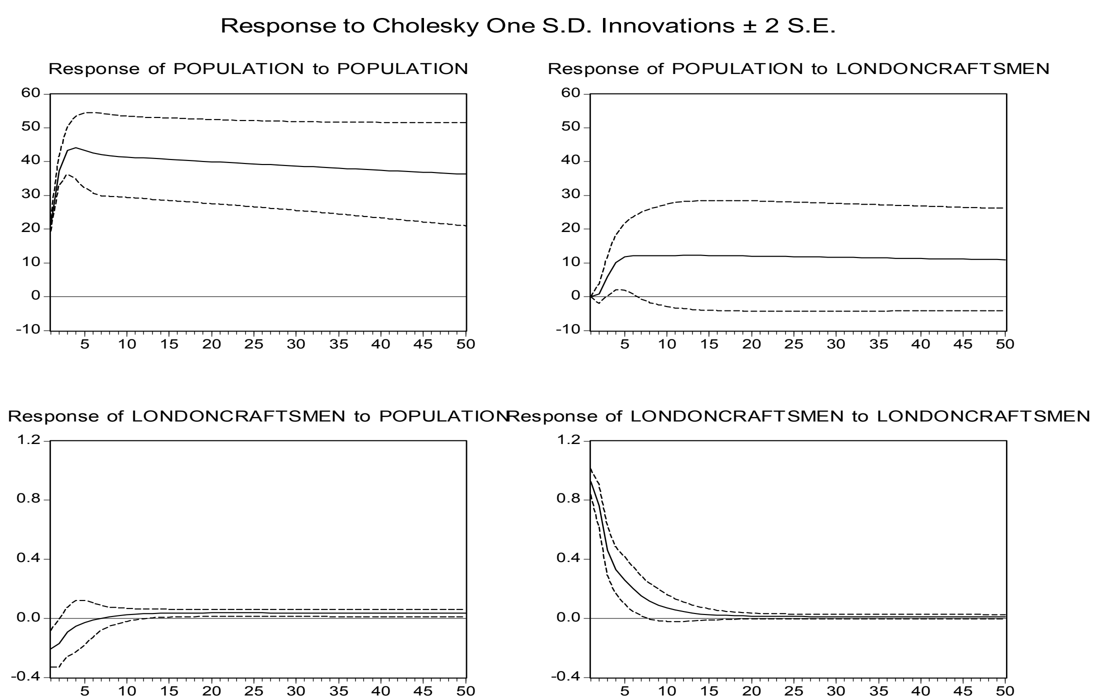
For England, the model above was estimated for two broad periods: before the Industrial Revolution (1541-1770) and after (1770-1850)[12]. As we can see in Figure 9a,

[11] Due to data limitations, for most countries, the data are decennial. For England, we also have annual data for both real wages and population after 1541. In addition, following Sims (1982) methodology, the data used for the estimation of the VARs are raw or untreated data

[12] Allen's data in decennial form as well as Clark's data provided similar results.

during the period up to the 1770, a shock in ε_{Wt} of one standard deviation leads to an increase of population of about 10 thousand people in the first decade after the shock. The impact of the shock persists for a long period of time. Thus, as expected, before the Industrial Revolution, population responded positively to an increase in real wages. The response of craftsmen's real wages to its own shock leads to a temporary increase of real wages of about 10 percent (the average real wage for the period was about 10 grams of silver), but the effect of the shock also swiftly dies down in less than 10 years. In turn, a ε_{POP} shock has a long and persistent effect on population, which lasts for more than 50 years, although it gradually decreases over time. Real wages initially decrease after a ε_{POP} shock, but return to their equilibrium values in about two decades.

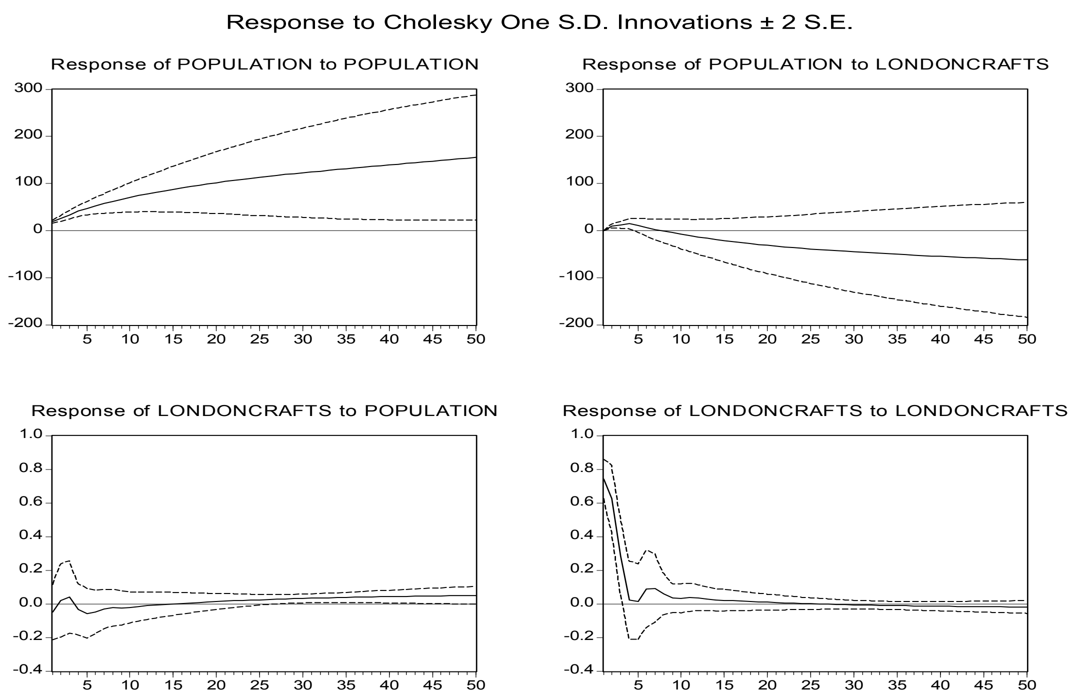
Figure 9a: London Craftsmen 1541-1770



After 1770, the impact of the shocks changes substantially (figure 9b). On the one hand, the effect of idiosyncratic shocks to population gradually increases over time.

Population shocks have a very small and temporary positive effect on real wages. On the other hand, in contrast to period pre-1770, shocks to real wages lead to a substantial decrease of population. Thus, during the Industrial Revolution, increases in real wages were followed by decreases in population, which suggests that parents were indeed making fertility decisions that varied according to their level of income[13]. Since the effects of the shocks to real wages and population were substantially distinct for the period pre- and after 1700, the results suggest that the Industrial Revolution induced a discontinuity in the relationship between wages and population.

Figure 9b: London Craftsmen 1770-1850



[13] Clearly, the changes in population depend on the behavior of both birth and death rates. The results of impulse response functions estimated from bivariate VARs relating birth rates and real wages suggest that birth rates fall after a shock to real wages, which is consistent with the estimation above. The interactions between these birth and death rates are further discussed in the sections below.

For Holland, a VAR and its respective impulse response functions were estimated for three broad periods: 1500-1650 (the Dutch Golden Age), 1650-1800 (the stagnation period), and 1800-1900 (the recovery and industrialization period). During the Dutch Golden Age, the results from the estimation of impulse response functions suggest that the effect of the idiosyncratic shocks increase over time, and that a shock to population has a small but not statistically significant positive effect on real wages. Furthermore, it is noticeable that during the Dutch Golden Age, and in contrast to what happened during the Industrial Revolution, population does not respond negatively to shocks to craftsmen real wages. During the period 1650-1800, the same tendency is observed. In contrast, during the period between 1800 and 1900, ε_{Wt} shocks lead to decreases in population (although the confidence interval widens considerably with time), suggesting that parents responded to shocks in real wages by having a lower number of children.

Figure 9c: Amsterdam Craftsmen 1500-1660

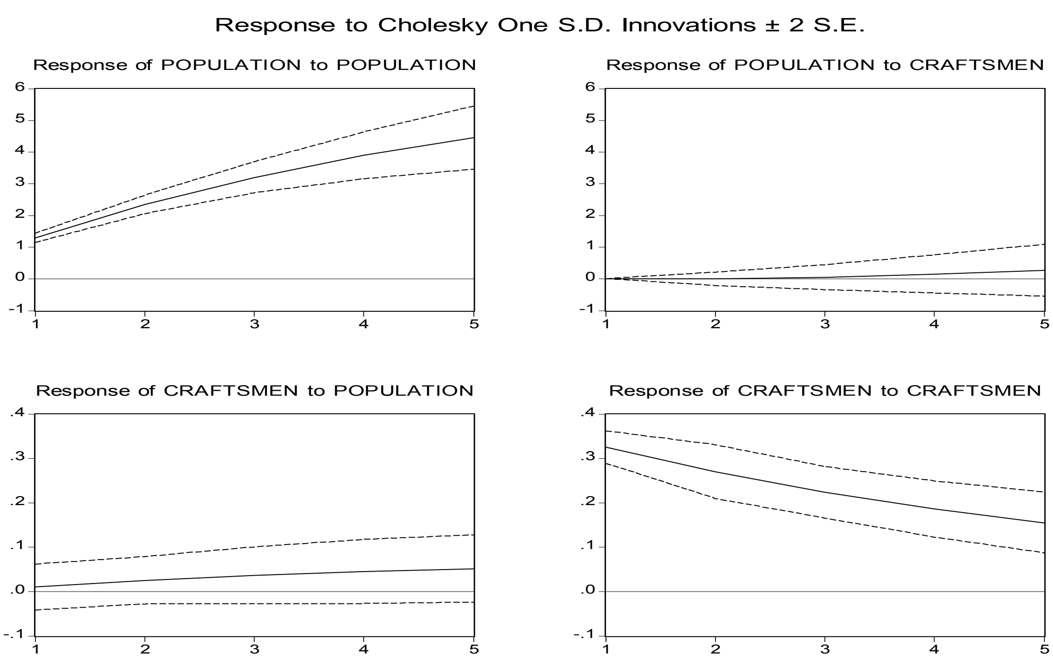


Figure 9d: Amsterdam Craftsmen 1650-1800

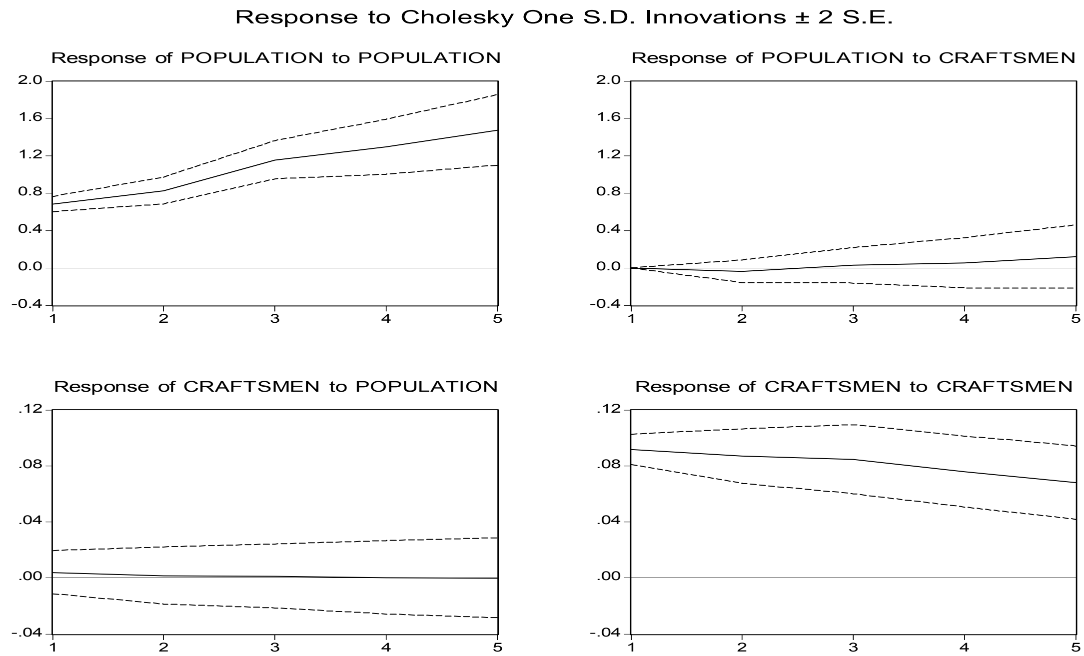
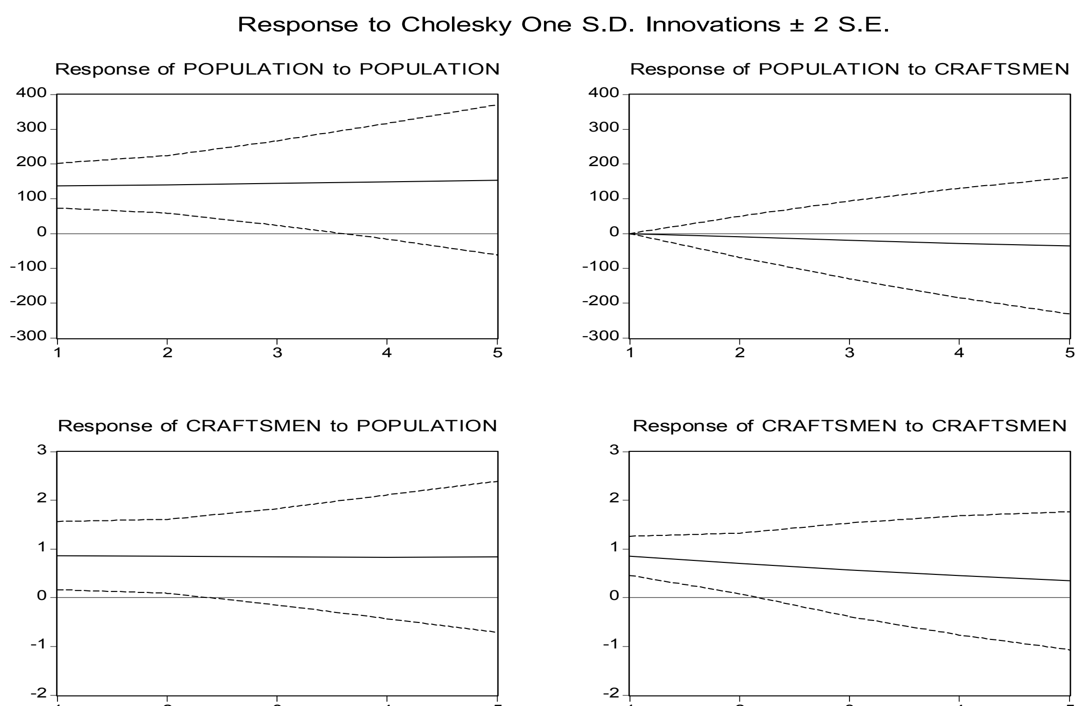


Figure 9e: Amsterdam Craftsmen 1800-1900



Comparing the two early European developers we can conclude that: 1) the English impulse responses relating wages and population change considerably after the mid-18th century, 2) population starts responding negatively to real wages shocks after the Industrial Revolution, and 3) the Dutch impulse responses indicate that during the Dutch Golden Age, wage shocks did not have a considerable effect on population. All in all, the empirical results in this section seem to indicate once again that the Industrial Revolution involved a discontinuity in the driving forces of the growth process. Thus, although the aggregate output indices suggest a certain continuity of the British process, the symptoms of modern economic growth seem to have started with the Industrial Revolution, and not at an earlier period.

Child Quantity versus Child Quality

This section argues that in the 19th century there was another discontinuity in the driving forces of the demographic transition (i.e. fertility decisions), which in turn interacted with the emergence of modern economic growth. In the Malthus to Solow literature, parents' fertility decisions change during the Industrial Revolution due to the acceleration of technical change, which increases the returns to human capital and induces parents to substitute child quality for child quantity. Consequently, the demographic transition ensues. Thus, in this literature, the emergence of modern economic growth is closely interrelated with the demographic transition, and human capital plays a crucial role in both phenomena.

In stark contrast, the prevailing view in the historical literature on the Industrial Revolution dismisses a prominent role for human capital, not only because Britain did not have any special kind of advantage in terms of formal education (Mitch 1999, Crafts

1995), but also because male literacy stagnated during the first three decades of the Industrial Revolution (Cressy 1980). Therefore, the historical literature seems to be at odds with the one of the central tenets of the "Malthus to Solow" models. However, if we take a long run view, the picture that emerges is less contradictory. By 1800, in the most advanced countries in Western Europe the number of brides and grooms that could sign their names was at least four times higher than in 1500[14]. This suggests that human capital improved during and after the Renaissance and the Enlightment[15]. The Chinese and, especially, the Japanese literacy rates also improved during this period. This worldwide increase in literacy rates seems to support Cipolla's (1969) assertion that there was a strong correlation between education levels and the levels of economic development. The rest of this section presents empirical evidence on the improvement of human capital in the 19th century and its impact on the child quantity-quality trade-off.

As mentioned above, in the "Malthus to Solow" literature there is an important relationship between literacy and fertility: if children are normal goods, then fertility decisions can be seen as an additional component of the consumption plans of households. Children generate benefits but also costs, such as education, food, as well as an opportunity cost in terms of income foregone (Becker 1960). Time devoted to child

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[14] For the European countries, literacy rates are often proxied by the percentage of brides and grooms that could sign their names. See Schofield (1973), one of the authorities in pre-industrial human capital, for a survey on why this is the most adequate proxy for human capital in pre-19th century Europe. Schofield advocates the use of signatures as a proxy for literacy because of the following reasons: objectivity, easiness to express quantitatively and their homogeneity across space and time.

[15] From the 16th century onwards, there is substantial evidence indicating that the quality of European human capital was also substantially enriched by the development of the scientific method and culture (Jacob 1997, Bekar and Lipsey 2001), by the diffusion of the printing press, and by the Protestant Reformation.

rearing decreases income earnings. Suppose we have a world with N households and two goods, "children" (*n*) and "other goods" (*x*). Households' total time endowment *T* can be spent either working, *l*, or on child rearing, *z*. The budget constraint faced by households can be written as:

$$c = w\,(T - z) + y \qquad (6)$$

where *c* is consumption of "other goods", *w* is wage income, and *y* is non-labour income. Assume also that households' preferences are "well-behaved", and hence indifference curves are convex to the origin. In this setting, increases in income will have distinct impacts on fertility rates depending on the source of income. On the one hand, non-wage income increases lead to a parallel shift of the budget constraint, which unambiguously raises fertility rates. On the other hand, if income rises due to an increase in wages, then the budget line will rotate, originating both a substitution effect and an income effect[16]. The income effect increases the number of children, since parents/households will be able to better afford them. However, an increase in wage income also gives rise to a substitution effect by raising the opportunity cost of child rearing, which reduces fertility rates. The net effect is ambiguous, depending on which effect dominates[17]. Based on the previous discussion, we should expect the income effect to dominate in Malthusian economies (implying that increases in income are translated into higher fertility), whereas the substitution effect should dominate in modern economies (and hence fertility declines

[16] Note that increases in wage income have a stronger impact on the decline of fertility rates than non-labor income increases (Ray 1998).

[17] This argument implies that workers during Industrial Revolution increase their hours, as Voth (2001) has shown recently.

after an income increase). There is thus a simple relationship between wages and fertility rates that we can observe empirically.

The available micro data restricts our analysis to some 19th century early European developers. Nevertheless, the findings suggest by these data are consistent with the literature on economic development. For England, data on fertility and mortality were obtained from Wrigley and Schofield (1981) and from Mitchell (1988). The other European fertility and mortality data are also from Mitchell (1988). As before, the wage data are from Allen (2001).

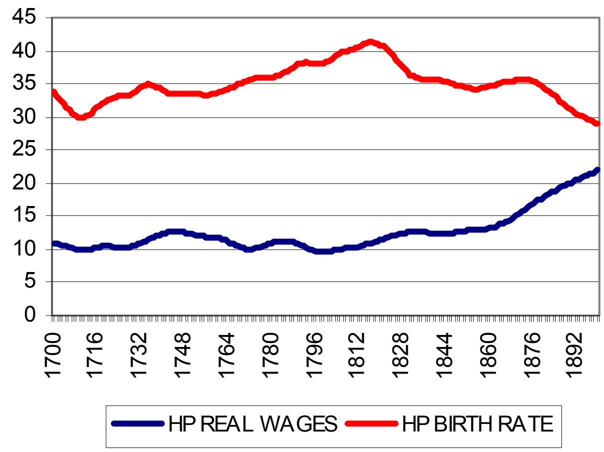
In terms of the English data, a simple scattered plot reveals that there is no clearly discernable pattern of the relationship between real wages and birth rates in the 18th century[18] (figures 10a and 10b). As we can see in figure 10b, birth rates were fairly constant until about the last quarter of the 18th century. Real wages also do not show any particular trend throughout the period.

Figure 10a_ Real Wages and Birth rates in England,

1700-1800 **1800-1900**

[18] In figure 10b, both series were smoothed by the Hodrick-Prescott filter in order to reduce yearly fluctuations.

Figure 10b_ Real Wages and Birth rates in England 1700-1900

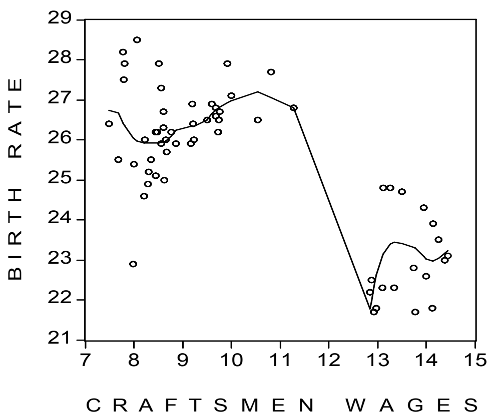


From the last quarter of the 18th century onwards until around 1820, birth rates increased, declining substantially afterwards. Since real wages are rising after the second decade of the 19th century, it seems plausible to argue that the substitution effect started to dominate the income effect, and fertility declined. Similar patterns can be found for both France and Belgium, although in these countries the change in fertility decisions described in the Malthus to Solow literature occurs later in the 19th century[19] (figure 11). All in all, the data from these early European developers suggests that the increase in income associated with the advent of 19th century industrialization led to a temporary rise in birth rates due to the income effect. However, the rise in real wages increased the opportunity cost of child rearing, enhancing the substitution effect, and hence birth rates declined.

[19] However, at the start of our period of analysis, French birth rates were lower than those in Britain.

Figure 11_ Real Wages and Birth rate, 1800-1900

France[20]



Belgium

In addition, in the Malthus to Solow literature, the change in parents' fertility decisions is highly correlated with an increase in literacy. The relationship between these two variables can also be observed for these early developers. For England, data on literacy were obtained from Cressy (1980), Schofield (1973) and Cipolla (1969). Crude birth rates are from Wrigley and Schofield (1981). As Figure 12 shows, from 1750 to about 1815, birth rates increased although literacy rates also rose. Since throughout the period increases in literacy are highly correlated with real wages, this fact suggests that the income effects still dominated, and hence fertility increased. From the second decade of the 19th century onwards, the continuing rise in literacy combined with the small but gradual increase in real wages seems to have had an effect on parents' fertility decisions, since birth rates in England steadily decline. This fact is consistent with the Malthus to Solow literature.

[20] Contrary to most of the data in this chapter, the Paris wage data are discontinuous from 1790 to 1840. However, the trend can still be observed in Figure 11, since the Epanechnikov Kernel fit allows us to interpolate for missing values.

Figure 12 _ Birth rate vs. Female literacy England, 1750-1900

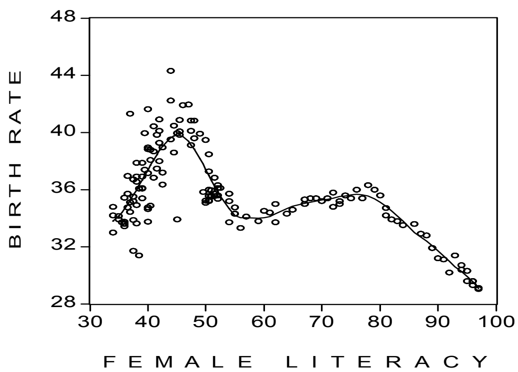
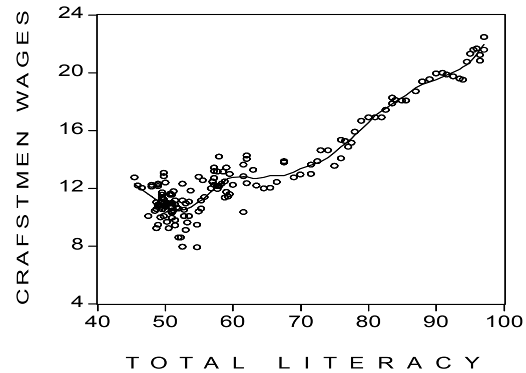


Figure 13 _ Literacy rates vs. real wages England, 1750-1900

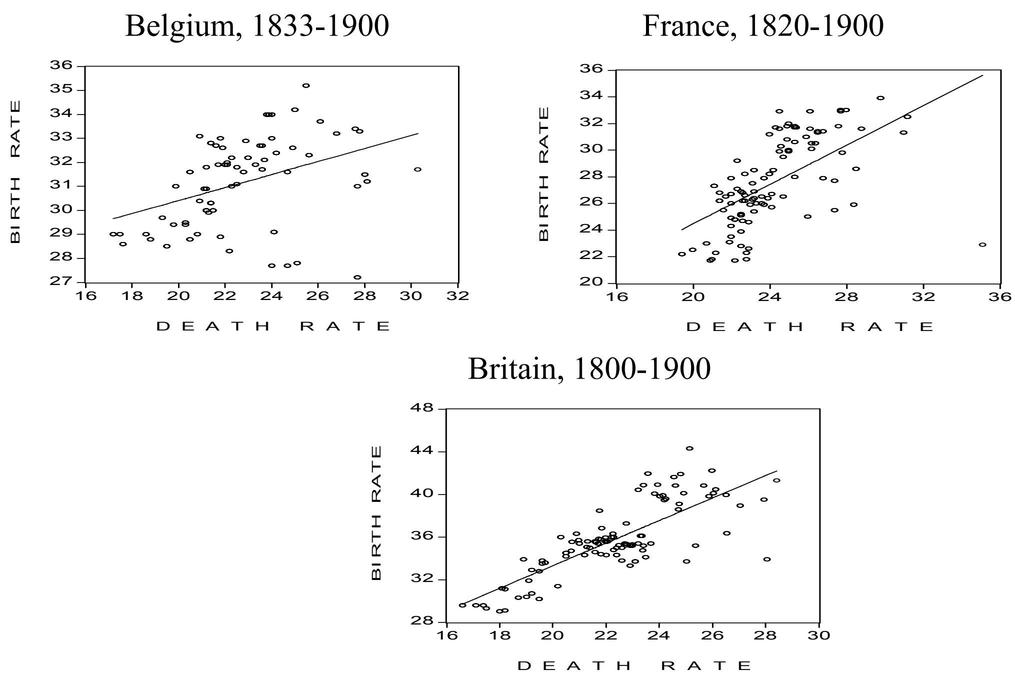


Nevertheless, the Malthus to Solow models are somewhat at odds with the historical records, which suggest that the change in fertility decisions was not the immediate cause of the demographic transition initiated in the 19th century. Throughout most Western Europe, the fall in mortality rates was the main cause of the rise in population from the late 18th century onwards (Easterlin 1996). Until the 18th century, mortality rates were high and very volatile due to frequent epidemics and famines. From the late 18th century onwards, there was a slow but steady improvement in the mortality figures throughout Western Europe. The wide fluctuations of mortality rates were also reduced. Death rates fell due to the gradual improvements in sanitary and hygienic conditions made possible by a higher investment in the health sector as well by an increase in the general public perception of the links between unsanitary conditions and disease (Mokyr 1993).

The decrease in European mortality rates preceding the decline in birth rates in the 19th century has some similarities with the demographic transition of the developing countries during the 20th century. As several microeconomic studies on fertility and mortality have shown for developing countries (McKeown 1977, Mensch, Lentzner and

Preston 1985, Shultz 1981, Schultz 1993), fertility decisions are not independent of mortality rates. Schultz (1981) argues that in general parents respond to a decrease in child mortality by choosing to reduce the number of births[21]. The high correlation between mortality rates and birth rates can also be observed historically for the Belgian, French, and British data[22] (figure 14).

Figure 14 _ Birth rates vs. death rates, 1800-1900



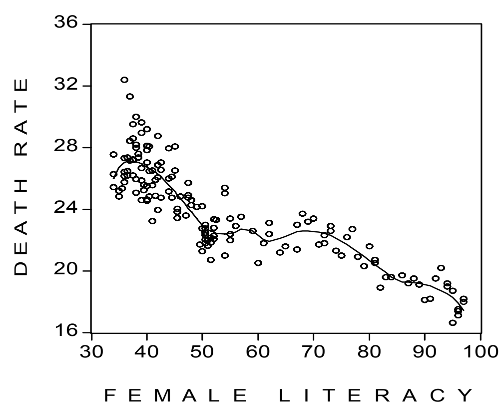
As mentioned above, the fall in mortality from mid-18th century onwards was caused by an improvement in health technology (Easterlin 1996, Mokyr 1993) as well as

[21] This proposition holds as long as there is price-inelasticity of parent demand for surviving children and the cost per surviving child declines in proportion to the rise in the survival rate.

[22] However, there are exceptions to this pattern. Namely, a scattered plot of German birth and death rates for the period 1830-1900 does not indicate any noticeable correlation. The lack of German wage data for the 19th century does not allow us to pursue this issue here, being the subject of future research. In addition, by the end of the 18th century, France had already lower birth rates than most other European countries. France was also one of the most literate countries in Europe.

by an increase in the knowledge of sanitary and hygienic conditions. The rise in literacy (especially female literacy) played an important role in the diffusion of this knowledge to most sections of society. It is thus not surprising that death rates fell with the rise in literacy (figure 15). This is also consistent with the macro data presented in the next section. Although the change in fertility decisions played an important role in the demographic transition (as the Malthus to Solow literature suggests), the behaviour of fertility was also a function of mortality rates. In turn, the rise in literacy was crucial for both the decline in fertility and the improvement in health-related knowledge.

Figure 15 _ Death rate and Female literacy England, 1750-1900



The same general conclusions are suggested by undertaking a regression analysis for individual countries. Due to data restrictions, the analysis was only performed for English data for the period between 1760 and 1900. In spite of this limitation, we should note that England is the typical example used in both the Malthus to Solow models and the historical literature on the emergence of modern economic growth.

In England, birth rates increased during the 18th century, chiefly due to the fall in marriage age (Wrigley and Schofield 1981). From the end of the 18th century onwards, mortality rates steadily declined, and their volatility also decreased. Birth rates started falling after the first decade of the 19th century. All in all, the reduction in mortality and the decline in the average marriage age were the main causes of the unprecedented population increase in Britain after the 18th century. Fertility decisions regarding the quantity of children become important in a second phase of the demographic transition, when urbanization accelerated and income per capita increased during the 19th century.

For the regression analysis, birth and death rates are from Mitchell (1988), craftsmen real wages are from Allen (2001), and the literacy figures are from Cipolla (1969), Schofield (1973), and Cressy (1980). Table 1 presents the matrix of correlations between these variables. As we can see, there are high correlations between all the variables, and all the correlations have the expected sign. As expected, birth rates are positive correlated with death rates, and negatively correlated with craftsmen real wages as well as with the different literacy figures. Death rates are negatively correlated with real wages and literacy. Male and female are also highly correlated.

Table 1 _ Correlation matrix

	BIRTH RATE	REAL WAGES	DEATH RATE	MALE LITERACY	FEMALE LITERACY	TOTAL LITERACY
BIRTH RATE	1	-0.6939	0.5073	-0.7306	-0.6727	-0.6967
REAL WAGES	-0.6939	1	-0.8049	0.9502	0.9410	0.9473
DEATH RATE	0.5073	-0.8049	1	-0.8094	-0.8568	-0.8412
MALE LITERACY	-0.7305	0.9502	-0.8094	1	0.9878	0.9953
FEMALE LITERACY	-0.6727	0.9410	-0.8568	0.9878	1	0.9982
TOTAL LITERACY	-0.6967	0.9473	-0.841	0.9953	0.9982	1

Following the discussion above, birth rates are regressed on literacy (female and total), on death rates, on real wages, on a time trend (TIME) that can proxy for improvements in health technology, and on a couple of dummy variables that take into account a possible structural break in the first decades of the 19th century (D1815 = 1 if t≥1815, zero otherwise and DT1815 = t $-T_{1815}$ if t > T_B, zero otherwise). The results are presented in table 2.

Table 2 _ OLS regression coefficients _ birth and death rates, Britain 1760-1900

Dependent Variable	*Birth rate*	*Birth rate*	*Birth rate*	*Death rate*	*Death rate*	*Death rate*
WAGES	-0.189 (0.252)	-0.139 (0.414)	0.034 (0.839)	-0.347 (0.0002)	-0.325 (0.004)	-0.342 (0.003)
FEMALE LITERACY	-0.191 (0.0001)	-0.223 (0.000)			-0.014 (0.732)	
TOTAL LITERACY			-0.317 (0.000)			-0.004 (0.939)
BIRTH RATE				0.142 (0.063)	0.144 (0.060)	0.142 (0.064)
DEATH RATE	0.0426 (0.740)	0.0298 (0.817)	0.064 (0.608)			
TIME	0.059 (0.0002)	0.078 (0.0006)	0.0842 (0.000)	-0.083 (0.000)	-0.081 (0.000)	-0.0826 (0.000)
D1815		-0.951 (0.237)	-1.398 (0.074)	-0.529 (0.251)	-0.618 (0.244)	-0.550 (0.310)
DT1815				0.0714 (0.007)	0.0763 (0.0115)	0.0728 (0.023)
CONSTANT	40.344 (0.000)	39.900 (0.000)	43.749 (0.000)	32.468 (0.000)	32.517 (0.000)	32.570 (0.000)
Prob(F-statistic)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R^2	0.551	0.555	0.587	0.833	0.833	0.833

(p-values in parentheses)

The empirical results suggest that literacy is an important explanatory variable of birth rates, which is consistent with the analysis above as well as with the literature on economic development. Namely, the results suggest that a one-percent increase in female literacy rates is associated with a 0.2 per cent decline in birth rates. In turn, an 1 percent increase in total literacy is associated with a decline in birth rates of 0.3 percent. Additionally, the coefficients on real wages and on death rates have the expected signs, but they are not statistically significant. In contrast, the coefficient on TIME (the proxy for improvements in health technology) is positive and significant.

The results for the death rate regressions are also consistent with the descriptive analysis above as well as with the historical literature. Birth rates are positively correlated with death rates. On average, a decrease of 1 percentage points in the birth rate is associated with a decline of 0.14 percent in death rates. Real wages are negatively correlated with death rates, suggesting that increases in income were associated with a decrease in the mortality statistics, probably due to improvements in hygienic and sanitary conditions. The coefficient on TIME is negative and statistically significant, which also suggests that death rates decline over time due to the improvements in health technology, as argued by Easterlin (1996) and Mokyr (1993).

The determinants of literacy were then observed by estimating a series of regressions on the same set of variables (table 3). Once again, birth rates and literacy rates are negatively correlated, suggesting that the increase in literacy was an important factor for the decline in fertility during and after the Industrial Revolution. This is especially true with respect to female literacy, as suggested by Schultz (1981) and by Rosenzweig and Evenson (1977). Wages are also an important explanatory variable of literacy, being positively correlated with both female and total literacy. Therefore, wage increases are associated with a rise in literacy, especially after the second decade of the 19^{th} century. In turn, the coefficient on TIME is positive and strongly significant. Since this variable can also be a proxy for technical change, the coefficient on TIME suggests that technical change and human capital were positively correlated, which is consistent with the Malthus to Solow models.

Table 3 _ OLS regression coefficients _ Literacy, Britain 1760-1900

Dependent Variable	*Female literacy*	*Female Literacy*	*Total Literacy*	*Total literacy*
WAGES	2.433	2.235	2.136	1.974
	(0.000)	(0.000)	(0.000)	(0.000)
BIRTH RATE	-0.595	-0.520	-0.631	-0.563
	(0.0001)	(0.000)	(0.000)	(0.000)
DEATH RATE		0.190		0.239
		(0.333)		(0.149)
TIME	0.229	0.332	0.161	0.255
	(0.000)	(0.000)	(0.000)	(0.000)
D1815		-7.163		-6.300
		(0.000)		(0.000)
CONSTANT	15.153	1.457	36.527	22.038
	(0.019)	(0.866)	(0.000)	(0.003)
Prob(F-statistic)	0.0000	0.0000	0.0000	0.0000
R^2	0.963	0.973	0.958	0.970

In short, the empirical results for the British economy in the period between 1760 and 1900 are consistent with the descriptive and graphical analysis presented in this section. The micro data for the early European developers suggests that the change in fertility decisions emphasized by “Malthus to Solow” literature was indeed occurring during the early 19th century. The empirical evidence does suggest that a rise in real wages increased the opportunity cost of child rearing, and parents responded by decreasing fertility. Nevertheless, the fall in birth rates is also highly correlated with the decline in mortality rates, which were decreasing due to improvements in health technology. The micro data for the three early European countries analyzed in this section thus suggests that our modeling of the transition to modern economic growth should take into account not only the change in fertility decisions but also the high correlation between birth and death rates. The next section presents some additional macro cross-country evidence for the period between 1500 and 1870.

Economic Growth and Literacy, 1500-1870

The findings of the sections above suggest that: (1) intensive growth replaced extensive growth during the transition to modern economic growth, (2) literacy was highly correlated with economic development (the Cipolla hypothesis), and (3) fertility declines during the transition to modern economic growth (the Malthus to Solow hypothesis). The historical literature also suggests that there is: (4) a strong correlation between urbanization and literacy (Cressy 1980), and (5) a positive correlation between Protestantism and investment in human capital, since Protestant countries had on average better human capital. Finally, (6) the findings of North and Thomas (1973) suggest that countries with more secure property rights should grow faster. This section undertakes a regression analysis in order to provide some empirical evidence on the hypotheses above. Data were collected from a variety of sources. As before, GDP and GDP per capita for 23 countries and territories were obtained from Maddison (2001). Literacy rates from several European countries are from Cipolla (1969), Cressy (1980), and Stone (1954). China's literacy figures are from Rawski (1979), and Japan's are from Dore (1965) and from Roden (1985). The percentage of the American literate population was extrapolated from Lockridge (1965). India’s figures were taken from Parulekar (1957), whereas Africa’s were extrapolated from Maddison (2001). Data on fertility per woman were obtained from Livi-Bacci (1989), and Grausman (1976). European urbanization rates were obtained from de Vries (1984), whereas Asian urbanization rates are from Rozman

(1973), Grauman (1976), and Maddison (1998). Birth, mortality and infant mortality rates were obtained from Mitchell[23] (1988).

The following growth regressions were estimated for the periods 1500-1820 and 1820-1870:

$$GRGDP_{15001820} = \beta_0 + \beta_1 X_t + e_t \quad (7)$$

$$GRGDP_{18201870} = \alpha_0 + \alpha_1 X_t + \varepsilon_t \quad (8)$$

where $GRGDP_{15001820}$ and $GRGDP_{18201870}$ denote, respectively, the GDP growth rate for the periods 1500-1820 and 1820-1870, and X_t represents a set of explanatory variables such as the level of GDP per capita in 1500 (GDPCAP1500) and in 1820 (GDPCAP1820), the rate of population growth between 1500 and 1820 (GRPOP15001820), the rate of population growth between 1820 and 1870 (GRPOP18201870), the rate of literacy in 1500 (LITERACY1500) and in 1800 (LITERACY1800), the urbanization rate in 1500 (URBAN1500) and in 1800 (URBAN1800), the average number of children in 1820 (TRF 1820), a dummy variable for Protestant countries (equal to one if the majority of the population of the country is Protestant, zero otherwise), and an index from Banks (1971) reflecting the legislative efficiency in a country (LAW 1830), which varies by a degree from 0 (no efficiency) to 3 (representing maximum efficiency). I also obtained data on primary school enrolment (PRIMARY1830) for 13 countries in the sample from Easterlin (1996). For most regressions I used LITERACY1800 instead of PRIMARY1830 in order to save degrees of freedom, since both measures of human capital provided similar results. The estimation

23 Since much of the data in this section are based on guess estimates (such as most the Maddison data), the findings should be seen as an indication of general trends and as a catalyst for further research.

results of equations (7) and (8) are presented in tables 4 and 5 in Appendix A. Since heteroskedasticity could be considerable across countries, the standard errors for the coefficients are based on White's (1980) heteroskedasticity-consistent estimators.

For the period between 1500 and 1820, the level of GDP per capita in 1500 does not seem to be an important explanatory variable of growth performance in the period 1500-1820. This finding is not totally surprising, since some of richest countries around 1500, such as Italy in Europe and China in Asia, had disappointing growth performances during the period from 1500 and 1820. In addition, the growth of population between 1500 and 1820 (GRPOP15001820) is not significant in most specifications, suggesting that GDP per capita growth and population growth are still mostly uncorrelated. In turn, literacy in 1500 is negatively correlated with per capita growth, although the literacy coefficient is not significant. The results thus suggest that, during the period between 1500 and 1820, literacy was not an important explanatory variable of economic growth. Hence, for the period 1500-1800, the results are not consistent with the Cipolla hypothesis. Additionally, urbanization in 1500 is negatively correlated with per capita growth during the period 1500-1820. Although the urbanization coefficient is fairly small, the results are not consistent with hypothesis (4). Finally, a variable that is positively and significantly correlated with GDP per capita growth is PROTESTANT, which is consistent with hypothesis (5). On average, from 1500 and 1820, per capita growth rates in Protestant countries were about 0.155 percent per year, which is considerably higher than the average growth in the remaining countries (around 0.11 percent per annum).

The results for the period between 1820 and 1870 are markedly different. In most specifications there is a positive relationship between population growth and GDP per capita growth. Thus, during the 19^{th} century, extensive growth was already being translated into intensive growth, which is consistent with hypothesis (1). On average, a rise of one percentage points in population is associated with an increase of GDP per capita growth of about 0.3 percentage points per year. Contrary to the period 1500-1800, initial literacy (LITERACY 1800) is also an important variable in explaining GDP per capita growth during the 1820-1870 period. In general, one percent increase in literacy rates is associated with about 0.01 percent increase in the per capita GDP growth rate. Regarding hypothesis (5), and in contrast to the period 1500-1820, and, the PROTESTANT dummy is not significant in most specifications. Thus, Protestantism does not seem to have had a direct influence in the process of development during the period between 1820 and 1870. The link between Protestantism and economic development seems to have occurred through literacy, since PROTESTANT and LITERACY1800 are highly correlated. In addition, the coefficients on both URBAN1800 and TRF1800 are not significant. In turn, LAW1830 is highly significant and positive, suggesting that legislative efficiency is an important explanation of per capita growth during the period, which is consistent with the North and Thomas hypothesis. Regression (11) uses PRIMARY1830 instead of LITERACY1800, but the results are similar to those of the specifications that use literacy in 1800 as the human capital variable. The introduction of GDPCAP1820 does not alter the results of the specification containing the growth rate of population, although it somewhat affected the significance of the other explanatory variables. There is also a negative relationship between infant (INFMORT1800) and adult mortality and per capita GDP growth. However, this relationship is not significant. Nonlinearities in the data were also accounted for by introducing in equations (7) and (8) a quadratic term on literacy in each period. The quadratic term is not significant for the period 1500-1820. However, the coefficient on the quadratic term is negative and significant in the period 1820-1870, as we can see in regression (12)[24].

Since Cipolla (1969) and the literature on Malthus to Solow argue that human capital played an important role in economic development after the late 18th century, the determinants of literacy were estimated by equations (9) and (10). The results are presented in tables 6 and 7 in Appendix A.

$$LITERACY_{1500} = \delta_0 + \delta_1 X_t + u_t \qquad (9)$$

$$LITERACY_{1800} = \lambda_0 + \lambda_1 X_t + v_t \qquad (10)$$

In terms of literacy in 1500, one of the most noticeable results is that the dummy for PROTESTANT is almost always a highly significant explanatory variable of literacy (table 6). On average, by 1500, literacy was almost 30 percent higher in soon-to-be Protestant countries than in the remaining countries. Since Luther's 95 theses date from 1517, the results show that even before the Protestant movement started, literacy was already higher in the future Protestant countries. Thus, there is some evidence to suggest that there was already a certain predisposition in these countries to promote literacy even before the Protestant Reformation took place. Second, urbanization is positively

[24] Since literacy seems to matter in the period 1820-1870, but not in the period 1500-1820, I also tested for parameter inconstancy. The data pertaining to both periods were pooled together and the following equation was estimated: $Y_i = \lambda_0 + \lambda_2 D_i + \phi_1 LIT_i + \phi_2 (D_i LIT_i) + \varepsilon_1$
where Y_i represents the growth rate of per capita GDP, LIT denotes literacy, and $D_i = 1$ for observations in the period 1500-1820 and equals 0 for observations in the period 1820-1870. However, both the slope and intercept coefficients on the dummy variable are not statistically significant. There is thus insufficient evidence to conclude that the regressions for both periods are different. Therefore, a change in the coefficients does not seem to explain the different results on the importance of literacy for economic growth during the periods 1500-1820 and 1820-1870.

correlated with literacy, although the coefficient on URBAN1500 is not always significant. This result is consistent with the view that there were higher returns to education in urban centers than in the countryside. Third, the level of GDP per capita in 1500 is positively correlated with literacy in 1500. On average, by 1500, some of the richest countries had also the highest literacy rates. Similarly, the growth rate of GDP per capita during the period 1000-1500 is positively correlated with literacy in 1500. Finally, population growth between 1000 and 1500 is not an important explanatory variable for literacy in 1500.

The results concerning literacy in 1800 are presented in table 7 in Appendix A. In most specifications literacy is strongly correlated with PROTESTANT. On average, Protestant countries had literacy rates almost 15 percent higher than non-Protestant countries. Therefore, more than a subjective work ethic *a la* Weber, it seems that Protestant countries had better human capital, which was then translated into higher rates of GDP per capita growth in the 19th century[25]. Moreover, in all specifications urbanization is positively correlated with literacy in 1800. In general, one percent increase in urbanization rates is associated with an increase of one-percentage point in literacy rates. As expected, the average number of children (TFR1800) is negatively correlated

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[25] In these countries, human capital was not only better for the average worker, but also their entrepreneurs and industrialists were much more likely to adopt and invent new technologies and organizational methods (Jacob 1997). Sweden provides a good example of the link between Protestantism and high literacy. Although it remained a poor country until the end of the 19th century, by 1850 Sweden had already the highest literacy rates in Europe. High literacy was made possible by both cultural and religious factors (Sandeberg 1979). Namely, Pietistic Lutheranism as the dominant religion in Sweden played a crucial role in fostering literacy, since it advocated that every good Christian had the duty to read the Bible every day. By the mid-19th century, Sweden had one of the highest life expectancies in Europe, as well as relatively low birth and death rates.

with literacy rates. Namely, each additional child is associated with a decrease of about 5 percentage points in literacy rates. This result seems to indicate that, indeed, during the 19^{th} century there were increasing returns to human capital. Thus, countries in which parents were substituting child quality for child quantity had higher literacy rates, and, consequently, higher rates of GDP per capita growth. Literacy is also positively correlated with legislative efficiency (LAW1830). On average, one point increase in the index (say, from 0 or no legislative efficiency, to 1, or low legislative efficiency) leads to an increase in the literacy rates of about 6 percent. The growth rate of per capita GDP in the period 1500-1820 (GRCAP15001820) is included in some specifications, but the coefficient is not always significant. Similarly, the coefficient on the growth rate of population in the period 1500-1820 is not significant. Finally, infant mortality is negatively correlated with literacy in 1800, which is consistent with the micro studies on fertility and mortality.

Therefore, the regression results based on cross-country macro data are consistent with the findings of the micro data for some early European developers, providing additional evidence on the emergence of modern economic growth.

3. Concluding Remarks

This paper presented empirical evidence on the transition "from Malthus to Solow". The empirical results indicate that temporary intensive growth spurts occurred in several pre-industrial economies. Nevertheless, this paper argues Britain was the first country to experience modern economic growth during the Industrial Revolution, since this is the period when the "symptoms of modernity" became permanent.

The results of a vector autoregression are also consistent with the view that the Industrial Revolution was a period of discontinuities in the process of world economic development. In addition, the paper presented some cross-country evidence for two main periods: 1500-1820 and 1820-1870. Cross-country regressions show that: 1) literacy was highly correlated with the level of economic development and the rates of per capita growth, 2) the average number of children per woman was negatively correlated with per capita GDP growth as well as literacy rates, and 3) urbanization was positively correlated with literacy. There is also evidence that parents started substituting child quality for child quantity during the 19th century, although fertility decisions were highly correlated with the ongoing decline in infant mortality. Micro data relating fertility and mortality rates with real wages for some early European developers not only indicate this change in fertility decisions in the 19th century, but also the close interaction between death and birth rates.

All in all, the empirical results in this chapter suggest that future research should incorporate some of the features that are present in the data. On the one hand, as de Vries (2001) emphasized, our models of the transition to modern economic growth should be more historical. As argued above, pre-industrial economies were much more dynamic than some of our current modeling implies, and certainly were not always trapped in a low equilibrium level of income. Since extensive and intensive growth spurts seem to have been a common feature in pre-industrial economies (Cameron 1997, Jones 1988, Goldstone 2002), the next generations of "Malthus to Solow" models should take into account the existence of these growth spurts in Malthusian economies. Since these growth spurts were always temporary, future research should aim to solve two great puzzles in the transition to modern economic growth: 1) why these growth spurts were not materialized into sustained growth?, and, 2) what caused sustained growth to emerge during the Industrial Revolution?

On the other hand, the empirical results on human capital indicate a high correlation between literacy and economic development. In this context, more cross-country comparative micro studies on the role of education are clearly needed, in order to further understand the importance of human capital in the transition to modern economic growth.

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APPENDIX A

TABLE 4_ GDP PER CAPITA GROWTH 1500-1820

Dependent Variable: Growth in GDP per capita 1500-1820					
Variable	(1)	(2)	(3)	(4)	(5)
Literacy 1500	-0.0079 (-1.974)	-0.008 (-1.156)	-0.0043 (-1.005)	-0.008 (-1.244)	
GRPOP15001820	0.0830 (0.697)		0.0536 (0.4731)		0.0469 (0.422)
GDPCAP1500		3.9E-06 (0.026)		0.0001 (0.788)	
PROTESTANT	0.1455 (3.813)	0.1571 (4.136)	0.158 (4.314)	0.178 (4.905)	0.1326 (4.009)
URBAN 1500			-0.0052 (-1.778)	-0.0063 (-2.047)	-0.0064 (-2.534)
CONSTANT	0.1015 (2.899)	0.1182 (1.545)	0.114 (3.376)	0.070 (0.946)	0.1079 (3.324)
R-squared	0.557	0.545	0.630	0.639	0.568
Adjusted R^2	0.479	0.464	0.538	0.549	0.4996
F-statistic	7.131	6.775	7.523	7.0835	8.322
Prob(F-statistic)	0.0026	0.0032	0.0021	0.0017	0.0009

TABLE 5_ GDP PER CAPITA GROWTH 1820-1870

Dependent Variable: Growth in GDP per capita 1820-1870							
Variable	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Literacy 1800	0.0093 (1.714)	0.0066 (1.624)	0.016 (1.977)	0.0065 (0.762)	0.0055 (0.104)		0.0318 (3.065)
PRIMARY1830						0.0717 (1.796)	
GRPOP820870	0.280 (2.453)	0.577 (2.110)	0.213 (1.661)	0.1411 (1.417)		0.165 (1.119)	0.288 (1.876)
GDPCAP1820					0.0007 (2.914)		
PROTESTANT	0.0985 (0.366)				0.274 (1.246)	0.178 (0.420)	0.0058 (0.024)
URBAN 1800		0.0142 (0.999)					
TRF 1820			-0.101 (-0.998)				
LAW1830				0.2470 (2.059)			
LITSQUARE							-0.00029 (-2.406)
CONSTANT	0.0615 (0.419)	-0.109 (-0.563)	0.554 (0.879)	0.0136 (12.22)	-0.239 (-1.149)	0.0138 (0.091)	-0.160 (-0.932)
R-squared	0.531	0.514	0.747	0.724	0.603	0.702	0.645
Adjusted R^2	0.457	0.428	0.672	0.664	0.541	0.621	0.566
F-statistic	7.170	5.991	9.867	12.219	9.625	8.654	8.180
Prob(F-statistic)	0.002	0.0056	0.0024	0.0003	0.0004	0.003	0.0006

TABLE 6_ LITERACY AND ECONOMIC DEVELOPMENT, 1500

Dependent Variable: LITERACY in 1500					
	(13)	(14)	(15)	(16)	(17)
PROTESTANT	3.186 (1.936)	3.286 (2.939)	1.892 (0.850)	3.185 (1.885)	3.289 (2.872)
URBAN 1500	0.316 (1.936)	0.0038 (0.033)	0.638 (1.211)	0.2959 (1.831)	0.0207 (0.166)
GDGCAP1500		0.0177 (4.691)			0.018 (4.583)
GRCAP10001500			54.628 (2.237)		
GRPOP10001500				3.938 (0.271)	-4.456 (-0.444)
CONSTANT	2.387 (2.285)	-7.252 (-3.336)	-1.400 (-0.963)	1.967 (1.042)	-6.949 (-2.984)
R-squared	0.458170	0.764	0.8046	0.460	0.767
Adjusted R^2	0.397966	0.722	0.707	0.365	0.7084
F-statistic	7.610369	18.328	8.239	4.837	13.147

TABLE 7_ LITERACY AND ECONOMIC DEVELOPMENT, 1800

Dependent Variable: LITERACY in 1800						
	(18)	(19)	(20)	(21)	(22)	(23)
PROTESTANT	11.5042 (3.5459)	18.8166 (5.4585)	22.6383 (3.7384)	11.345 (3.5873)	10.7746 (2.8607)	11.938 (2.030)
URBAN 1800	0.9888 (4.8984)	0.9832 (4.4978)	1.1143 (2.9142)	0.9729 (4.6875)	1.4414 (3.4891)	1.059 (2.749)
TRF 1820	-3.4345 (-1.8929)	-5.3571 (-2.2674)	-6.6381 (-2.7116)	-3.3432 (-1.7275)	-5.5026 (-3.5324)	
INFMORT1800						-0.073 (-1.437)
GDGCAP1820					-0.0180 (-1.2633)	
LAW1830	6.3752 (3.3407)			6.0753 (2.2988)	9.5364 (2.4281)	
GRCAP15001820		37.516 (1.8161)		8.1615 (0.2815)		
GRPOP15001820			-13.6344 (-0.2788)			-38.328 (-2.341)
CONSTANT	22.294 (1.9318)	32.7961 (2.1871)	45.0621 (2.6406)	21.373 (1.741)	43.5622 (2.9588)	31.459 (1.906)
R-squared	0.9689	0.9436	0.9387	0.9693	0.9750	0.976
Adjusted R^2	0.9534	0.9153	0.9081	0.9473	0.9572	0.946
F-statistic	62.382	33.427	30.6317	44.186	54.697	32.384