Chapter 4

FROM STAGNATION TO GROWTH: UNIFIED GROWTH THEORY

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Contents

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Abstract

The transition from stagnation to growth and the associated phenomenon of the great divergence have been the subject of an intensive research in the growth literature in recent years. The discrepancy between the predictions of exogenous and endogenous growth models and the process of development over most of human history, induced growth theorists to advance an alternative theory that would capture in a single unified framework the contemporary era of sustained economic growth, the epoch of Malthusian stagnation that had characterized most of the process of development, and the fundamental driving forces of the recent transition between these distinct regimes.

The advancement of unified growth theory was fueled by the conviction that the understanding of the contemporary growth process would be limited and distorted unless growth theory would be based on micro-foundations that would reflect the qualitative aspects of the growth process in its entirety. In particular, the hurdles faced by less

developed economies in reaching a state of sustained economic growth would remain obscured unless the origin of the transition of the currently developed economies into a state of sustained economic growth would be identified, and its implications would be modified to account for the additional economic forces faced by less developed economies in an interdependent world.

Unified growth theory suggests that the transition from stagnation to growth is an inevitable outcome of the process of development. The inherent Malthusian interaction between the level of technology and the size and the composition of the population accelerated the pace of technological progress, and ultimately raised the importance of human capital in the production process. The rise in the demand for human capital in the second phase of industrialization, and its impact on the formation of human capital as well as on the onset of the demographic transition, brought about significant technological advancements along with a reduction in fertility rates and population growth, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita, and paving the way for the emergence of sustained economic growth.

Variations in the timing of the transition from stagnation to growth and thus in economic performance across countries reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, social, cultural, and political factors. In particular, once a technologically driven demand for human capital emerged in the second phase of industrialization, the prevalence of human capital promoting institutions determined the extensiveness of human capital formation, the timing of the demographic transition, and the pace of the transition from stagnation to growth.

Keywords

growth, technological progress, demographic transition, human capital, evolution, natural selection, Malthusian stagnation

JEL classification: O11, O14, O33, O40, J11, J13

1. Introduction

This chapter examines the recent advance of a *unified growth theory* that is designed to capture the complexity of the process of growth and development over the entire course of human history.

The evolution of economies during the major portion of human history was marked by Malthusian Stagnation. Technological progress and population growth were miniscule by modern standards and the average growth rate of income per capita in various regions of the world was even slower due to the offsetting effect of population growth on the expansion of resources per capita. In the past two centuries, in contrast, the pace of technological progress increased significantly in association with the process of industrialization. Various regions of the world departed from the Malthusian trap and experienced initially a considerable rise in the growth rates of income per capita and population. Unlike episodes of technological progress in the pre-Industrial Revolution era that failed to generate sustained economic growth, the increasing role of human capital in the production process in the second phase of industrialization ultimately prompted a demographic transition, liberating the gains in productivity from the counterbalancing effects of population growth. The decline in the growth rate of population and the associated enhancement of technological progress and human capital formation paved the way for the emergence of the modern state of sustained economic growth.

The transitions from a Malthusian epoch to a state of sustained economic growth and the related phenomenon of the Great Divergence, as depicted in Figure 1, have significantly shaped the contemporary world economy.[1] Nevertheless, the distinct qualitative aspects of the growth process during most of human history were virtually ignored in the shaping of growth models, resulting in a growth theory that is consistent with a small fragment of human history.

The inconsistency of exogenous and endogenous growth models with some of the most fundamental features of process of development, has led recently to a search for a unified theory that would unveil the underlying micro-foundations of the growth process in its entirety, capturing the epoch of Malthusian Stagnation that characterized most of human history, the contemporary era of modern economic growth, and the underlying driving forces that triggered the recent transition between these regimes and the associated phenomenon of the Great Divergence in income per capita across countries.

The preoccupation of growth theory with empirical regularities that have characterized the growth process of developed economies in the past century and of less developed economies in the last few decades, has become harder to justify from a scientific viewpoint in light of the existence of vast evidence about qualitatively different

[1] The ratio of GDP per capita between the richest region and the poorest region in the world was only 1.1 : 1 in the year 1000, 2 : 1 in the year 1500, and 3 : 1 in the year 1820. In the course of the 'Great Divergence' the ratio of GDP per capita between the richest region and the poorest region has widened considerably from a modest 3 : 1 ratio in 1820, to a 5 : 1 ratio in 1870, a 9 : 1 ratio in 1913, a 15 : 1 ratio in 1950, and a 18 : 1 ratio in 2001.

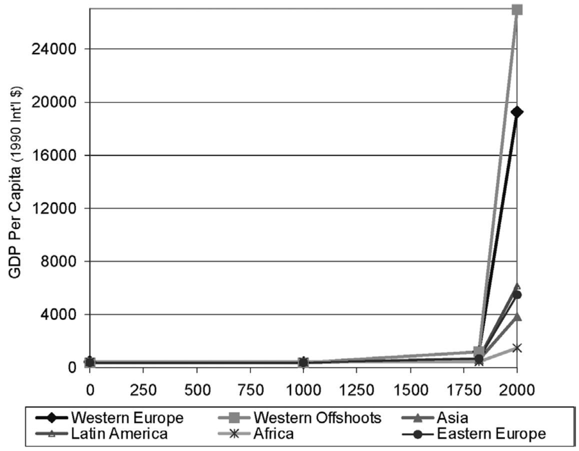

Figure 1. The evolution of regional income per capita over the years 1–2000. Source: Maddison (2003).[2]

empirical regularities that characterized the growth process over most of human existence. It has become evident that in the absence of a unified growth theory that is consistent with the entire process of development, the understanding of the contemporary growth process would be limited and distorted. As stated eloquently by Copernicus: “It is as though an artist were to gather the hands, feet, head and other members for his images from diverse models, each part perfectly drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man.”[3]

The evolution of theories in older scientific disciplines suggests that theories that are founded on the basis of a subset of the existing observations and their driving forces, may be attractive in the short run, but non-robust and eventually non-durable in the long run.[4] The attempts to develop unified theories in physics have been based on the conviction that all physical phenomena should be explainable by some underlying unity.[5] Similarly, the entire process of development and its foundamental forces ought to be captured by a unified growth theory.

[2] According to Maddison’s classification, “Western Offshoots” consist of the United States, Canada, Australia and New Zealand.

[3] Quoted in Kuhn (1957).

[4] For instance, Classical Thermodynamics that lacked micro-foundations was ultimately superseded by the micro-based Statistical Mechanics.

[5] *Unified Field Theory*, for instance, proposes to unify by a set of general laws the four distinct forces that are known to control all the observed interactions in matter: electromagnetism, gravitation, the weak force, and the strong force. The term ‘unified field theory’ was coined by Einstein, whose research on relativity led him to the hypothesis that it should be possible to find a unifying theory for the electromagnetic and gravitational forces.

The transition from stagnation to growth and the associated phenomenon of the great divergence have been the subject of intensive research in the growth literature in recent years.[6] It has been increasingly recognized that the understanding of the contemporary growth process would be fragile and incomplete unless growth theory could be based on proper micro-foundations that would reflect the various qualitative aspects of the growth process and their central driving forces. Moreover, it has become apparent that a comprehensive understanding of the hurdles faced by less developed economies in reaching a state of sustained economic growth would be futile unless the factors that prompted the transition of the currently developed economies into a state of sustained economic growth could be identified and their implications would be modified to account for the differences in the growth structure of less developed economies in an interdependent world.

Imposing the constraint that a single theory should account for the entire intricate process of development and its prime causes in the last thousands of years is a discipline that would enhance the viability of growth theory. A unified theory of economic growth would reveal the fundamental micro-foundations that are consistent with the process of economic development over the entire course of human history, rather that with the last century only, boosting the confidence in growth theory, its predictions and policy implications. Moreover, it would improve the understanding of the underlying factors that led to the transition from stagnation to growth of the currently developed countries, shedding light on the growth process of the less developed economies.

The establishment of a unified growth theory has been a great intellectual challenge, requiring major methodological innovations in the construction of dynamical systems that could capture the complexity which characterized the evolution of economies from a Malthusian epoch to a state of sustained economic growth. Historical evidence suggests that the transition from the Malthusian epoch to a state of sustained economic growth, rapid as it may appear, was a gradual process and thus could not plausibly be viewed as the outcome of a major exogenous shock that shifted economies from the basin of attraction of the Malthusian epoch into the basin of attraction of the Modern Growth Regime.[7] The simplest methodology for the generation of a phase transition – a major shock in an environment characterized by multiple locally stable equilibria –

[6] The transition from Malthusian stagnation to sustained economic growth was explored by Galor and Weil (1999, 2000), Lucas (2002), Galor and Moav (2002), Hansen and Prescott (2002), Jones (2001), as well as others, and the association of Great Divergence with this transition was analyzed by Galor and Mountford (2003).

[7] As established in Section 2, and consistently with the revisionist view of the Industrial Revolution, neither the 19th century's take-off of the currently developed world, nor the recent take-off of less developed economies provide evidence for an unprecedented shock that generated a quantum leap in income per-capita. In particular, technological progress could not be viewed as a shock to the system. As argued by Mokyr (2002) technological progress during the Industrial Revolution was an outcome of a gradual endogenous process that took place over this time period. Similarly, technological progress in less developed economies was an outcome of a deliberate decision by entrepreneurs to adopt existing advanced technologies.

was therefore not applicable for the generation of the observed transition from stagnation to growth.

An alternative methodology for the observed phase transition was rather difficult to establish since a unified growth theory in which economies take off gradually but swiftly from an epoch of a stable Malthusian stagnation would necessitate a *gradual* escape from an absorbing (stable) equilibrium – a contradiction to the essence of a stable equilibrium. Ultimately, however, it has become apparent that the observed rapid, continuous, phase transition would be captured by a single dynamical system, if the set of steady-state equilibria and their stability would be altered qualitatively in the process of development. As proposed in unified growth theory, first advanced by Galor and Weil (2000), during the Malthusian epoch the dynamical system would have to be characterized by a stable Malthusian equilibrium, but eventually, due to the evolution of latent state variables the dynamical system would change qualitatively, the Malthusian equilibrium would vanish endogenously, leaving the arena to the gravitational forces of the emerging Modern-Growth Regime, and permitting the economy to take off and to converge to a modern-growth steady-state equilibrium.

The observed role of the demographic transition in the shift from the Post-Malthusian Regime to the Sustained Growth Regime and the associated non-monotonic evolution of the relationship between income per capita and population growth added to the complexity of the desirable dynamical system. In order to capture this additional transition unified growth theory had to generate endogenously, in the midst of the process of industrialization, a reversal in the positive Malthusian effect of income on population, providing the reduction in fertility the observed role in the transition to a state of sustained economic growth.

As elaborated in this chapter, unified growth theory explores the fundamental factors that generated the remarkable escape from the Malthusian epoch and their significance for the understanding of the contemporary growth process of developed and less developed economies. It deciphers some of the most fundamental questions that have been shrouded in mystery: what accounts for the epoch of stagnation that characterized most of human history? what is the origin of the sudden spurt in growth rates of output per capita and population? why had episodes of technological progress in the pre-industrialization era failed to generate sustained economic growth? what was the source of the dramatic reversal in the positive relationship between income per capita and population that existed throughout most of human history? what triggered the demographic transition? would the transition to a state of sustained economic growth have been feasible without the demographic transition? and, what are the underlying behavioral and technological structures that could simultaneously account for these distinct phases of development and what are their implications for the contemporary growth process of developed and underdeveloped countries?

Moreover, unified growth theory sheds light on the perplexing phenomenon of the Great Divergence in income per capita across regions of the world in the past two centuries: what accounts for the sudden take-off from stagnation to growth in some countries in the world and the persistent stagnation in others? why has the positive link between income per capita and population growth reversed its course in some economies but not in others? why have the differences in income per capita across countries increased so markedly in the last two centuries? and has the transition to a state of sustained economic growth in advanced economies adversely affected the process of development in less-developed economies?

Unified growth theory suggests that the transition from stagnation to growth is an inevitable by-product of the process of development. The inherent Malthusian interaction between technology and population, accelerated the pace of technological progress, and ultimately brought about an industrial demand for human capital, stimulating human capital formation, and thus further technological progress, and triggering a demographic transition, that has enabled economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita. Moreover, the theory suggests that differences in the timing of the take-off from stagnation to growth across countries contributed significantly to the Great Divergence and to the emergence of convergence clubs. Variations in the economic performance across countries and regions (e.g., earlier industrialization in England than in China) reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, demographic, and cultural factors, trade patterns, colonial status, and public policy.

2. Historical evidence

This section examines the historical evidence about the evolution of the relationship between income per capita, population growth, technological change and human capital formation during the course of three distinct regimes that have characterized the process of economic development: The Malthusian Epoch, The Post-Malthusian Regime, and the Sustained Growth Regime.

During the Malthusian Epoch that characterized most of human history, technological progress and population growth were insignificant by modern standards. The level of income per capita had a positive effect on population and the average growth rate of income per capita in the long-run, as depicted in Figure 2, was negligible due to the slow pace of technological progress as well as the counterbalancing effect of population growth on the expansion of resources per capita. During the Post Malthusian Regime, the pace of technological progress markedly increased in association with the process of industrialization, triggering a take-off from the Malthusian trap. The growth rate of income per capita, as depicted in Figures 1 and 2, increased significantly but the positive Malthusian effect of income per capita on population growth was still maintained, generating a sizable increase in population growth that offset some of the potential gains in income per capita. The acceleration in the rate of technological progress in the second phase of industrialization, and its interaction with human capital formation, eventually prompted the demographic transition. The rise in aggregate income was no longer

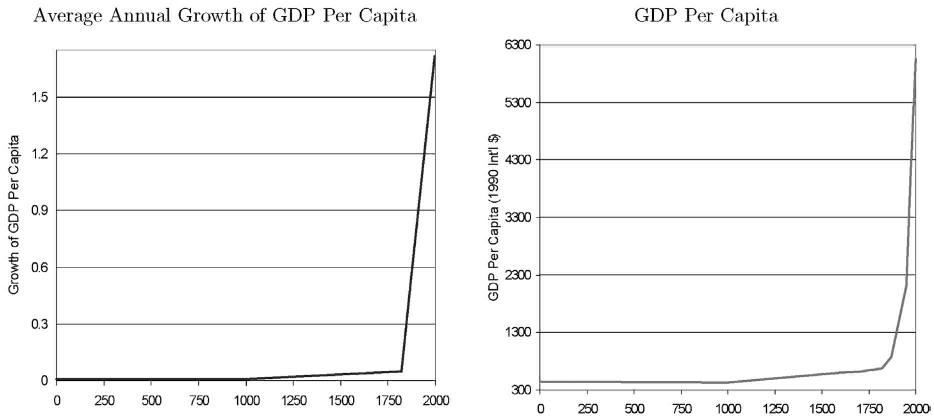

Figure 2. The evolution of the world income per capita over the years 1–2000. Sources: Maddison (2001, 2003).

counterbalanced by population growth, enabling technological progress to bring about sustained increase in income per capita.

2.1. The Malthusian epoch

During the Malthusian epoch that had characterized most of human history, humans were subjected to persistent struggle for existence. Technological progress was insignificant by modern standards and resources generated by technological progress and land expansion were channeled primarily towards an increase in the size of the population, with a minor long-run effect on income per capita. The positive effect of the standard of living on population growth along with diminishing labor productivity kept income per capita in the proximity of a subsistence level.[8] Periods marked by the absence of changes in the level of technology or in the availability of land, were characterized by a stable population size as well as a constant income per capita, whereas periods characterized by improvements in the technological environment or in the availability of land generated temporary gains in income per capita, leading eventually to a larger but not richer population. Technologically superior countries had eventually denser populations but their standard of living did not reflect the degree of their technological advancement.[9]

[8] This subsistence level of consumption may be well above the minimal physiological requirements that are necessary in order to sustain an active human being.

[9] Thus, as reflected in the viewpoint of a prominent observer of the period, "the most decisive mark of the prosperity of any country [was] the increase in the number of its inhabitants" [Smith (1776)].

2.1.1. Income per capita

During the Malthusian epoch the average growth rate of output per capita was negligible and the standard of living did not differ greatly across countries. As depicted in Figure 2 the average level of income per capita during the first millennium fluctuated around $450 per year, and the average growth rate of output per capita in the world was nearly zero.[10] This state of Malthusian Stagnation persisted until the end of the 18th century. In the years 1000–1820, the average level of income per capita in the world economy was below $670 per year and the average growth rate of the world income per capita was miniscule, creeping at a rate of about 0.05% per year [Maddison (2001)].

This pattern of stagnation was observed across all regions of the world. As depicted in Figure 1, the average level of income per capita in Western and Eastern Europe, the Western Offshoots, Asia, Africa, and Latin America was in the range of $400–450 per year in the first millennium and the average growth rate in each of these regions was nearly zero. This state of stagnation persisted until the end of the 18th century across all regions and the level of income per capita in 1820 ranged from $418 per year in Africa, $581 in Asia, $692 in Latin America, and $683 in Eastern Europe, to $1202 in the Western Offshoots (i.e., United States, Canada, Australia and New Zealand), and $1204 in Western Europe. Furthermore, the average growth rate of output per capita over this period ranged from 0% in the impoverished region of Africa to a sluggish rate of 0.14% in the prosperous region of Western Europe.

Despite the stability in the evolution of the world income per capita in the Malthusian epoch, from a perspective of a millennium, wages and income per capita fluctuated significantly within regions deviating from their sluggish long-run trend over decades and sometimes over several centuries. In particular, as depicted in Figure 3, real GDP per capita in England fluctuated drastically over most of the past millennium. It declined during the 13th century, and increased sharply during the 14th and 15th centuries in response to the catastrophic population decline in the aftermath of the Black Death. This two-century rise in per capita real income stimulated population growth and brought about a decline in income per capita in the 16th century, back to its level in the first half of the 14th century. Real income per capita increased once again in the 17th century and remained stable during the 18th century, prior to its rise during the take-off in the 19th century.

2.1.2. Income and population growth

Population growth and the level of income Population growth over this era followed the Malthusian pattern as well. As depicted in Figures 4 and 5, the slow pace of resource expansion in the first millennium was reflected in a modest increase in the population of the world from 231 million people in 1 AD to 268 million in 1000 AD; a miniscule

[10] Maddison's estimates of income per capita are evaluated in terms of 1990 international dollars.

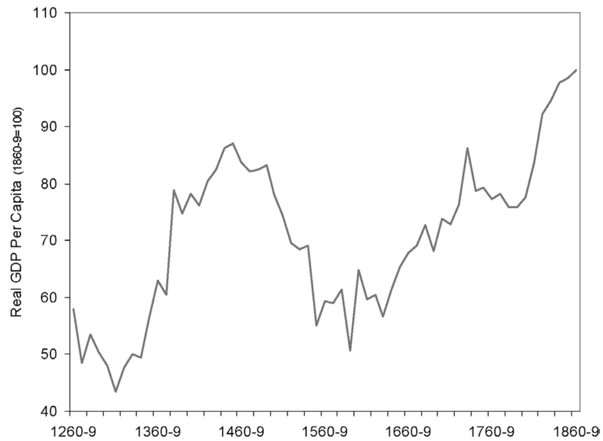

Figure 3. Fluctuations in real GDP per capita: England, 1260–1870. Source: Clark (2001).

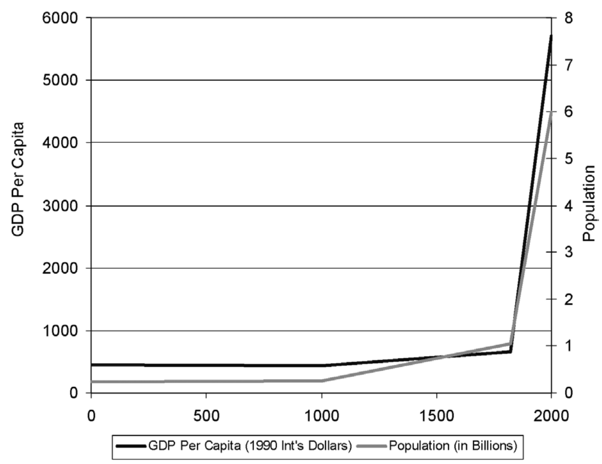

Figure 4. The evolution of world population and income per capita over the years 1–2000. Source: Maddison (2001).

average growth rate of 0.02% per year.[11] The more rapid (but still very slow) expansion of resources in the period 1000–1500, permitted the world population to increase by 63% over this period, from 268 million in 1000 AD to 438 million in 1500; a slow 0.1% average growth rate per year. Resource expansion over the period 1500–1820 had a more significant impact on the world population, which grew 138% from 438 million

[11] Since output per capita grew at an average rate of 0% per year over the period 0–1000, the pace of resource expansion was approximately equal to the pace of population growth, namely, 0.02% per year.

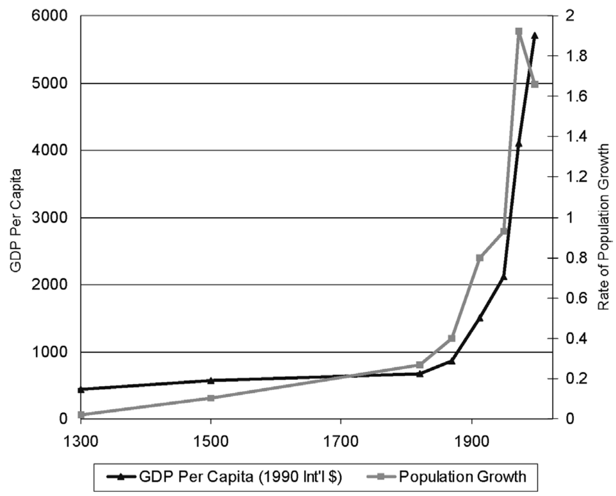

Figure 5. Population growth and income per capita in the world economy. Source: Maddison (2001).

in 1500 to 1041 million in 1820; an average pace of 0.27% per year.[12] This positive effect of income per capita on the size of the population was maintained in the last two centuries as well, as world population reached a remarkable level of nearly 6 billion people.

Moreover, the gradual increase in income per capita during the Malthusian epoch was associated with a monotonic increase in the average rate of growth of world population, as depicted in Figure 5. This pattern was exhibited within and across countries.[13]

Fluctuations in income and population Fluctuations in population and wages over this epoch exhibited the Malthusian pattern as well. Episodes of technological progress, land expansion, favorable climatic conditions, or major epidemics (that resulted in a decline of the adult population), brought about a temporary increase in real wages and income per capita. In particular, as depicted in Figure 6, the catastrophic decline in the population of England during the Black Death (1348–1349), from about 6 million

[12] Since output per capita in the world grew at an average rate of 0.05% per year in the time period 1000–1500 as well as in the period 1500–1820, the pace of resource expansion was approximately equal to the sum of the pace of population growth and the growth of output per capita. Namely, 0.15% per year in the period, 1000–1500 and 0.32% per year in the period 1500–1820.

[13] Lee (1997) reports positive income elasticity of fertility and negative income elasticity of mortality from studies examining a wide range of pre-industrial countries. Similarly, Wrigley and Schofield (1981) find a strong positive correlation between real wages and marriage rates in England over the period 1551–1801. Clark and Hamilton (2003) find that in England, at the beginning of the 17th century, the number of surviving offspring is higher among households with higher level of income and literacy rates, suggesting that the positive effect of income on fertility is present cross-sectionally, as well.

Figure 6. Population and real wages: England, 1250–1750. Sources: Clark (2001, 2002).

to about 3.5 million people, increased significantly the land–labor ratio, tripling real wages in the subsequent 150 years. Ultimately, however, most of this increase in real resources per capita was channeled towards increased fertility rates, increasing the size of the population, and bringing the real wage rate in the 1560s back to the proximity of its pre-plague level.[14]

Population density Variations in population density across countries during the Malthusian epoch reflected primarily cross country differences in technologies and land productivity. Due to the positive adjustment of population to an increase in income per capita, differences in technologies or in land productivity across countries resulted in variations in population density rather than in the standard of living.[15] For instance, China's technological advancement in the period 1500–1820 permitted its share of world population to increase from 23.5% to 36.6%, while its income per capita in the beginning and the end of this time interval remained constant at roughly $600 per year.[16]

This pattern of increased population density persisted until the demographic transition, namely, as long as the positive relationship between income per capita and

[14] Reliable population data is not available for the period 1405–1525 and Figure 6 is depicted under the assumption maintained by Clark (2001) that population was rather stable over this period.

[15] Consistent with the Malthusian paradigm, China's sophisticated agricultural technologies, for example, allowed high per-acre yields, but failed to raise the standard of living above subsistence. Similarly, the introduction of the potato in Ireland, in the middle of the 17th century, generated a large increase in population over two centuries without significant improvements in the standard of living. Furthermore, the destruction of potatoes by fungus in the middle of the 19th century, generated a massive decline in population due to the Great Famine and mass migration [Mokyr (1985)].

[16] The Chinese population more than tripled over this period, increasing from 103 million in 1500 to 381 million in 1820.

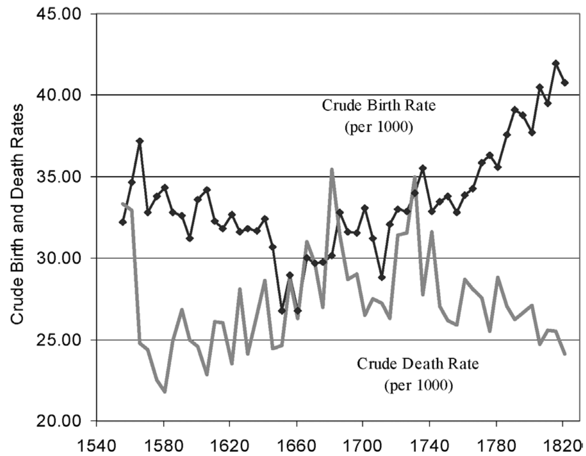

Figure 7. Fertility and mortality: England 1540–1820. Source: Wrigley and Schofield (1981).

population growth was maintained. In the period 1600–1870, United Kingdom's technological advancement relative to the rest of the world more than doubled its share of world population from 1.1% to 2.5%. Similarly, in the period 1820–1870, the land abundant, technologically advanced economy of the US experienced a 220% increase in its share of world population from 1% to 3.2%.[17]

Mortality and fertility The Malthusian demographic regime was characterized by fluctuations in fertility rates, reflecting variability in income per capita as well as changes in mortality rates. The relationship between fertility and mortality during the Malthusian epoch was complex. Periods of rising income per capita permitted a rise in the number of surviving offspring, inducing an increase in fertility rates along with a reduction in mortality rates, due to improved nourishment, and health infrastructure. Periods of rising mortality rates (e.g., the black death) induced an increase in fertility rates so as to maintain the number of surviving offspring that can be supported by existing resources.

In particular, demographic patterns in England during the 14th and 15th centuries, as depicted in Figure 6, suggest that an (exogenous) increase in mortality rates was indeed associated with a significant rise in fertility rates. However, the period 1540–1820 in England, vividly demonstrates a negative relationship between mortality rates and fertility rates. As depicted in Figure 7, an increase in mortality rates over the period 1560–1650 was associated with a decline in fertility rates, whereas the rise in income per capita in the time period 1680–1820 was associated with a decline in mortality rates along with increasing fertility rates.

[17] The population of the United Kingdom nearly quadrupled over the period 1700–1870, increasing from 8.6 million in 1700 to 31.4 million in 1870. Similarly, the population of the United states increased 40-fold, from 1.0 million in 1700 to 40.2 million in 1870, due to a significant labor migration, as well as high fertility rates.

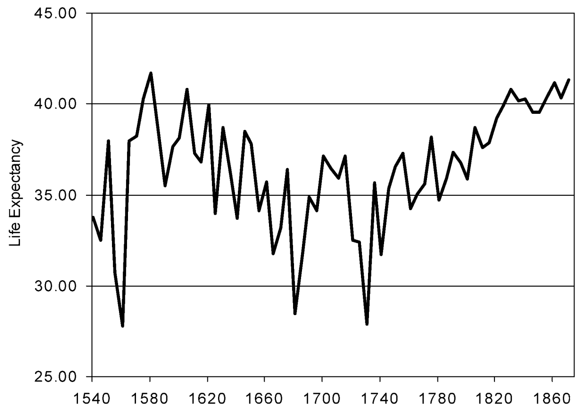

Figure 8. Life expectancy: England, 1540–1870. Source: Wrigley and Schofield (1981).

Life expectancy Life expectancy at birth fluctuated in the Malthusian epoch, ranging from 24 in Egypt in the time period 33–258 AD, to 42 in England at the end of the 16th century. In the initial process of European urbanization, the percentage of urban population increased six-fold from about 3% in 1520 to nearly 18% in 1750 [De Vries (1984) and Bairoch (1988)]. This rapid increase in population density, without significant changes in health infrastructure, generated a rise in mortality rates and a decline in life expectancy. As depicted in Figures 7 and 8, over the period 1580–1740 mortality rates increased by 50% and life expectancy at birth fell from about 40 to nearly 30 years [Wrigley and Schofield (1981)]. A decline in mortality along with a rise in life expectancy began in the 1740s. Life expectancy at birth rose from about 30 to 40 in England and from 25 to 40 in France over the period 1740–1830 [Livi-Bacci (1997)].

2.2. The Post-Malthusian Regime

During the Post-Malthusian Regime the pace of technological progress markedly increased along the process of industrialization.[18] The growth rate of output per capita increased significantly, as depicted in Figures 1, 2 and 3, but the positive Malthusian effect of income per capita on population growth was still maintained, generating a sizable increase in population growth, as depicted in Figures 4 and 5, and offsetting some of the potential gains in income per capita.

The take-off of developed regions from the Malthusian Regime was associated with the Industrial Revolution and occurred at the beginning of the 19th century, whereas the take-off of less developed regions occurred towards the beginning of the 20th century and was delayed in some countries well into the 20th century. The Post-Malthusian

[18] Ironically, shortly before the publication of Malthus' influential essay, some regions in the world began to emerge from the trap that he described.

Regime ended with the decline in population growth in Western Europe and the Western Offshoots (i.e. United States, Canada, Australia and New Zealand) towards the end of the 19th century, and in less developed regions in the second half of the 20th century.

2.2.1. *Income per capita*

During the Post-Malthusian Regime the average growth rate of output per capita increased significantly and the standard of living started to differ considerably across countries. As depicted in Figure 2, the average growth rate of output per capita in the world soared from 0.05% per year in the time period 1500–1820 to 0.53% per year in 1820–1870, and 1.3% per year in 1870–1913. The timing of the take-off and its magnitude differed across regions. As depicted in Figure 9, the take-off from the Malthusian Epoch and the transition to the Post-Malthusian Regime occurred in Western Europe, the Western Offshoots, and Eastern Europe at the beginning of the 19th century, whereas in Latin America, Asia (excluding China) and Africa it took place at the end of the 19th century.

Among the regions that took off at the beginning of the 19th century, the growth rate of income per capita in Western Europe increased from 0.15% per year in the years 1500–1820 to 0.95% per year in the time period 1820–1870, and the growth rates of income per capita of the Western Offshoots increased over the corresponding time periods from 0.34% per year to 1.42% per year. In contrast, the take-off in Eastern Europe was more modest, and its growth rate increased from 0.1% per year in the period 1500–1820 to 0.63% per year in the time interval 1820–1870. Among the regions that took off towards the end of the 19th century, the average growth rate of income per capita in Latin America jumped from a sluggish rate of 0.11% per year in the years 1820–1870 to a considerable rate of 1.81% per year in the time period 1870–1913, whereas Africa's growth rates increased more modestly from 0.12% per year in the years 1820–1870 to 0.64% per year in time interval 1870–1913 and 1.02% per year in the period 1913–1950. Asia's (excluding Japan, China and India) take-off was modest as well, increasing from 0.13% per year in the years 1820–1870 to 0.64% per year in the 1870–1913 period.[19]

The level of income per capita in the various regions of the world, as depicted in Figure 1, ranged in 1870 from $444 in Africa, $543 in Asia, $698 in Latin America, and $871 in Eastern Europe, to $1974 in Western Europe and $2431 in the Western Offshoots. Thus, the differential timing of the take-off from the Malthusian epoch, increased the gap between the richest region of Western Europe and the Western Offshoots to the impoverished region of Africa from about 3 : 1 in 1820 to approximately 5 : 1 in 1870.

[19] Japan's average growth rate increased from 0.19% per year in the period 1820–1870, to 1.48% per year in the period 1870–1913. India's growth rate increased from 0% per year to 0.54% per year over the corresponding periods, whereas China's take-off was delayed till the 1950s.

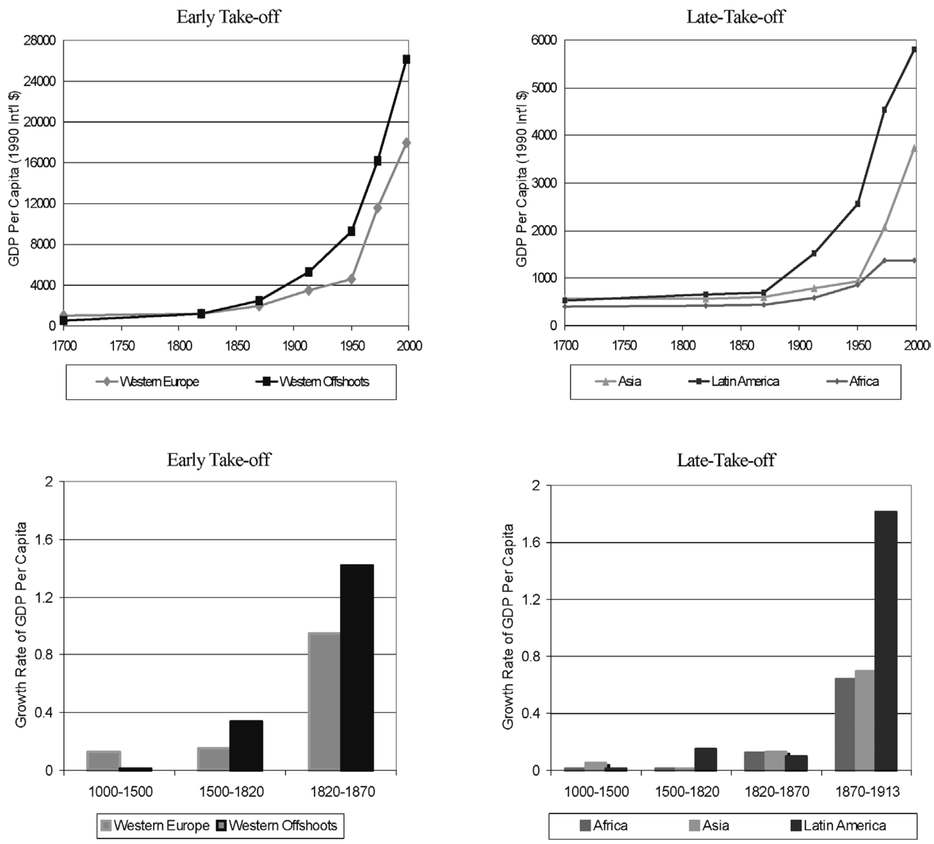

Figure 9. The differential timing of the take-off across regions. Source: Maddison (2001).

The acceleration in technological progress and the accumulation of physical capital and to a lesser extent human capital, generated a gradual rise in real wages in the urban sector and (partly due to labor mobility) in the rural sector as well. As depicted in Figure 10, the take-off from the Malthusian epoch in the aftermath of the Industrial Revolution was associated in England with a modest rise in real wages in the first decades of the 19th century and a very significant rise in real wages after 1870.[20] A very significant rise in real wages was experienced in France, as well, after 1860.

[20] Stokey (2001) attributes about half of the rise in real wage over the period 1780–1850 to the forces of international trade. Moreover, the study suggests that technological change in manufacturing was three times as important as technological change in the energy sector, in contributing to output growth.

Figure 10. Real wages in England and France during the take-off from the Malthusian Epoch. Sources: Clark (2002) for England, and Levy-Leboyer and Bourguignon (1990) for France.

2.2.2. Income and population growth

The rapid increase in income per capita in the Post-Malthusian Regime was channeled partly towards an increase in the size of the population. During this regime, the Malthusian mechanism linking higher income to higher population growth continued to function, but the effect of higher population on diluting resources per capita, and thus lowering income per capita, was counteracted by the acceleration in technological progress and capital accumulation, allowing income per capita to rise despite the offsetting effects of population growth.

The Western European take-off along with that of the Western Offshoots brought about a sharp increase in population growth in these regions and consequently a modest rise in population growth in the world as a whole. The subsequent take-off of less developed regions and the associated increase in their population growth brought about a significant rise in population growth in the world. The rate of population growth in the world increased from an average rate of 0.27% per year in the period 1500–1820 to 0.4% per year in the years 1820–1870, and to 0.8% per year in the time interval 1870–1913. Furthermore, despite the decline in population growth in Western Europe and the Western Offshoots towards the end of the 19th century and the beginning of the 20th century, the delayed take-off of less developed regions and the significant increase in their income per capita prior to their demographic transitions generated a further increase in the rate of population growth in the world to 0.93% per year in the period 1913–1950, and a sharp rise to a high rate of 1.92% per year in the period 1950–1973. Ultimately, the onset of the demographic transition in less developed economies in the second half of the 20th century, gradually reduced population growth rates to 1.66% per year in the 1973–1998 period [Maddison (2001)].

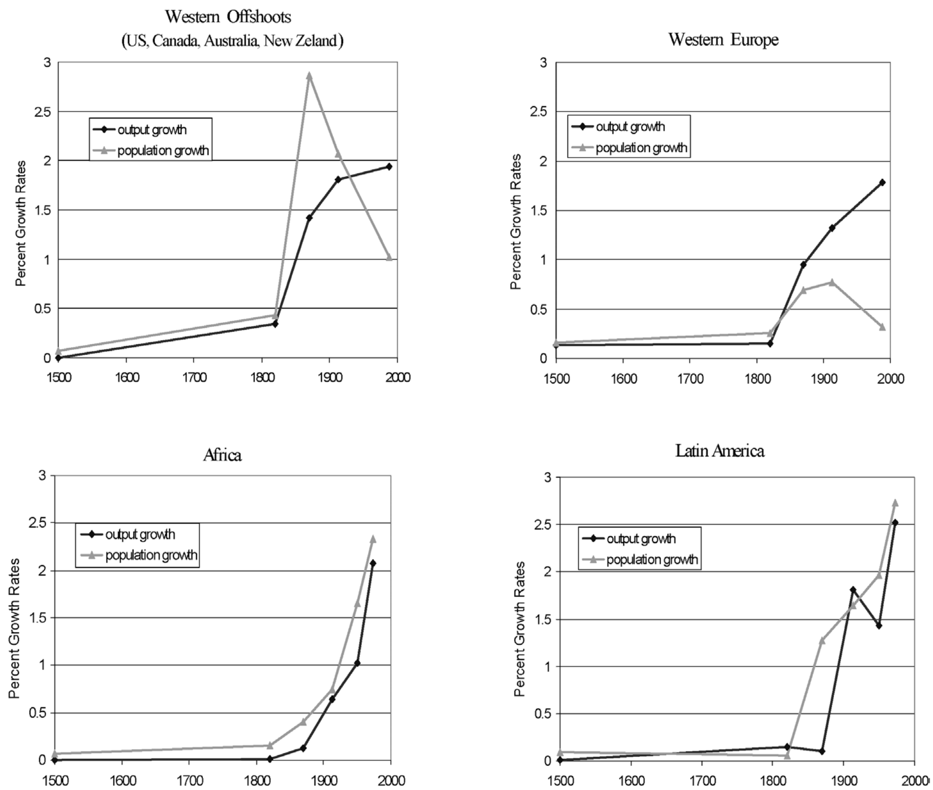

Figure 11. Regional growth of GDP per capita and population: 1500–2000. Source: Maddison (2001).

Growth in income per capita and population growth As depicted in Figure 11, the take-off in the growth rate of income per capita in all regions of the world was associated with a take-off in population growth. In particular, the average growth rates of income per capita in Western Europe over the time period 1820–1870 rose to an annual rate of 0.95% (from 0.15% in the period 1500–1820) along with a significant increase in population growth to an annual rate of about 0.7% (from 0.26% in the period 1500–1820). Similarly, the average growth rates of income per capita in the Western Offshoots over the years 1820–1870 rose to an annual rate of 1.42% (from 0.34% in the period 1500–1820) along with a significant increase in population growth to an annual rate of about 2.87% (from 0.43% in the period 1500–1820).

A similar pattern was observed in Asia, and as depicted in Figure 11, in Africa and Latin America as well. The average growth rates of income per capita in Latin America over the years 1870–1913 rose to an annual rate of 1.81% (from 0.1% in the period 1820–1870) and subsequently to an annual rate of 1.43% in time interval 1913–1950 and 2.52% in the time period 1950–1973 along with a significant increase in population growth to an annual rate of 1.64% in the period 1870–1913, 1.97% in the years 1913–1950, and 2.73% in the period 1950–1973, prior to the decline in the context of the demographic transition. Similarly, the average growth rates of income per capita in Africa over the 1870–1913 period rose to an annual rate of 0.64% (from 0.12% in the period 1820–1870) and subsequently to an annual rate of 1.02% in the years 1913–1950 and 2.07% in the period 1950–1973, along with a monotonic increase in population growth from a modest average annual rate of 0.4% in the years 1820–1870, to a 0.75% in the years 1870–1913, 1.65% in the years 1913–1950, 2.33% in the time interval 1950–1973, and a rapid average annual rate of 2.73% in the period 1973–1998.

Technological leaders and land-abundant regions during the Post-Malthusian era improved their relative position in the world in terms of their level of income per capita as well as their population size. The increase in population density of technological leaders persisted as long as the positive relationship between income per capita and population growth was maintained. Western Europe's technological advancement relative to the rest of the world increased its share of world population by 16% from 12.8% in 1820 to 14.8% in 1870, whereas the regional technological leader, the United Kingdom, increased its share of world population by 25% (from 2% to 2.5%) over this fifty-year period. Moreover, land abundance and technological advancement in the Western Offshoots (US, Australia, New Zealand and Canada) increased their share of world population by 227% over a fifty-year period, from 1.1% in 1820 to 3.6% in 1870.

The rate of population growth relative to the growth rate of aggregate income declined gradually over the period. For instance, the growth rate of total output in Western Europe was 0.3% per year between 1500 and 1700, and 0.6% per year between 1700 and 1820. In both periods, two thirds of the increase in total output was matched by increased population growth, and the growth of income per capita was only 0.1% per year in the earlier period and 0.2% in the later one. In the United Kingdom, where growth was the fastest, the same rough division between total output growth and population growth can be observed: total output grew at an annual rate of 1.1% in the 120 years after 1700, while population grew at an annual rate of 0.7%. Population and income per capita continued to grow after 1820, but increasingly the growth of total output was expressed as growth of income per capita. Population growth was 40% as large as total output growth over the time period 1820–1870, dropping further after the demographic transition to about 20% of output growth over the 1929–1990 period.

Fertility and mortality The relaxation in the households' budget constraint in the Post-Malthusian Regime permitted an increase in fertility rates along with an increase in literacy rates and years of schooling. Despite the decline in mortality rates, fertility rates (as well as population growth) increased in most of Western Europe until the second half of the 19th century [Coale and Treadway (1986)].[21] In particular, as depicted in Figure 12, in spite of a century of decline in mortality rates, the crude birth rates in

[21] See Dyson and Murphy (1985) as well.

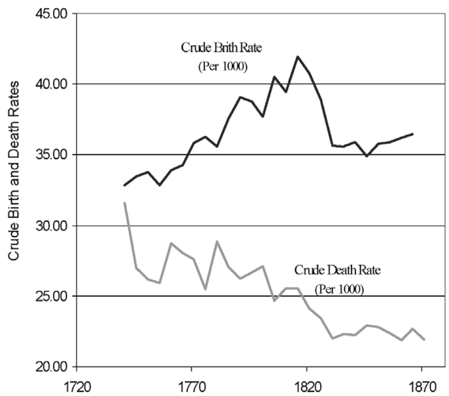

Figure 12. Fertility, mortality and net reproduction rate: England, 1730–1871. Source: Wrigley and Schofield (1981).

England increased over the 18th century and the beginning of the 19th century. Thus, the *Net Reproduction Rate* (i.e., the number of daughters per woman who reach the reproduction age) increased from about the replacement level of 1 surviving daughter per woman in 1740 to about 1.5 surviving daughters per woman in the eve of the demographic transition in 1870.

It appears that the significant rise in income per capita in the Post-Malthusian Regime increased the desirable number of surviving offspring and thus, despite the decline in mortality rates, fertility increased significantly so as to enable households to reach this higher desirable level of surviving offspring.

Fertility rates and marriage age Fertility was controlled during this period, despite the absence of modern contraceptive methods, partly via adjustment in marriage rates.[22] As depicted in Figure 13, increased fertility was achieved by earlier female's age of marriage, and a decline in fertility by a delay in the marriage age.[23]

2.2.3. Industrialization and urbanization

The take-off of developed and less developed regions from the Malthusian epoch was associated with the acceleration in the process of industrialization as well as with a significant rise in urbanization.

[22] The importance of this mechanism of fertility control is reflected in the assertion by William Cobbett (1763–1835) – a leader of the campaign against the changes brought by the Industrial Revolution – ". . . men, who are able and willing to work, cannot support their families, and ought . . . to be compelled to lead a life of celibacy, for fear of having children to be starved".

[23] The same pattern is observed in the relationship between *Crude Birth Rates* and *Crude Marriage Rates* (per 1000).

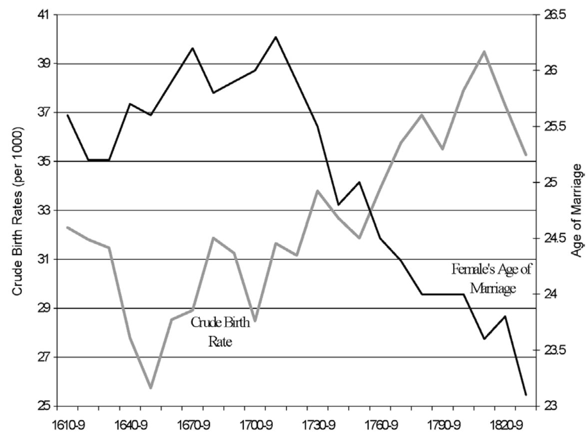

Figure 13. Fertility rates and female's age of marriage. Source: Wrigley and Schofield (1981).

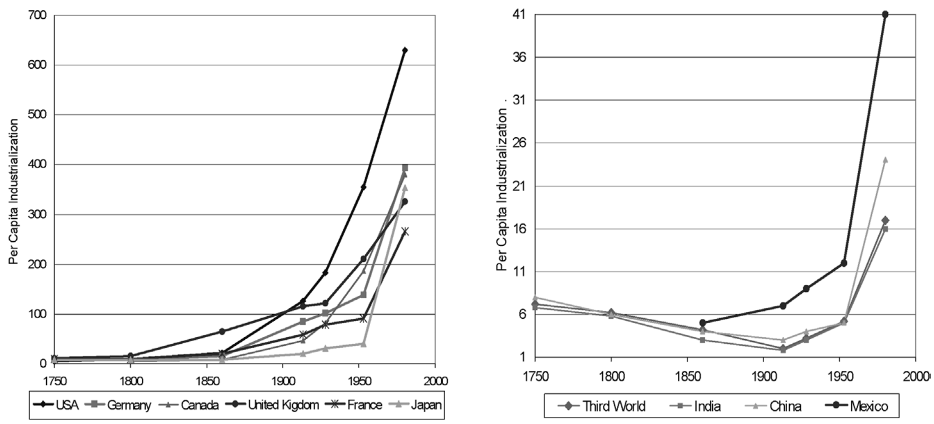

Figure 14. Per capita levels of industrialization: (UK in 1900 = 100). Source: Bairoch (1982).[24]

Industrialization The take-off in the developed regions was accompanied by a rapid process of industrialization. As depicted in Figure 14, *per-capita level of industrialization* (measuring per capita volume of industrial production) increased significantly in the United Kingdom since 1750, rising 50% over the 1750–1800 period, quadrupling in the years 1800–1860, and nearly doubling in the time period 1860–1913. Similarly per-capita level of industrialization accelerated in the United States, doubling in the

[24] Notes: Countries are defined according to their 1913 boundaries. Germany from 1953 is defined as East and West Germany. India after 1928 includes Pakistan.

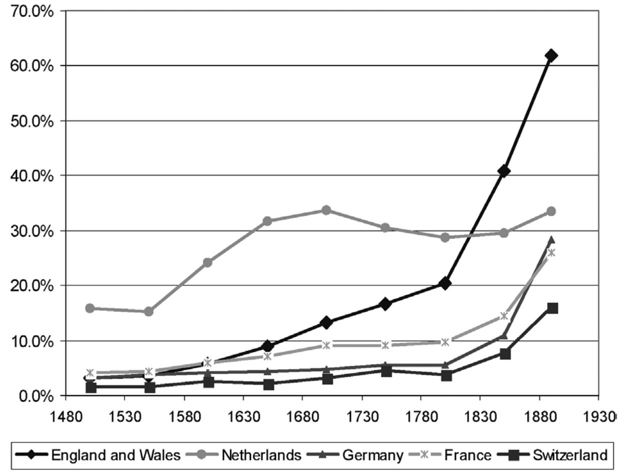

Figure 15. Percentage of the population in cities with population larger than 10,000. Europe: 1490–1910. Sources: Bairoch (1988) and De Vries (1984).

1750–1800 as well as 1800–1860 periods, and increasing six-fold in the years 1860–1913. A similar pattern was experienced in Germany, France, Sweden, Switzerland, Belgium, and Canada. Industrialization nearly doubled in the 1800–1860 period, further accelerating in the time interval 1860–1913.

The take-off of less developed economies in the 20th century was associated with increased industrialization as well. However, as depicted in Figure 14, during the 19th century these economies experienced a decline in *per capita industrialization* (i.e., per capita volume of industrial production), reflecting the adverse effect of the sizable increase in population on the level of industrial production per capita (even in the absence of an absolute decline in industrial production) as well as the forces of globalization and colonialism, that induced less developed economies to specialize in the production of raw materials.[25]

Urbanization The take-off from Malthusian stagnation and the acceleration in the process of industrialization increased significantly the process of urbanization. As reflected in Figure 15, the percentage of the population that lived in European cities with a population larger than 10,000 people nearly tripled over the years 1750–1870, from 17% to 54%. Similarly, the percentage of the population in England that lived in cities with population larger than 5,000 quadrupled over the 1750–1910 period, from 18% to 75% [Bairoch (1988)].

[25] The sources of the decline in the industrialization of less developed economies are explored by Galor and Mountford (2003). The effect of colonialism on the patterns of production and thus trade is examined by Acemoglu, Johnson and Robinson (2002) and Bertocchi and Canova (2002).

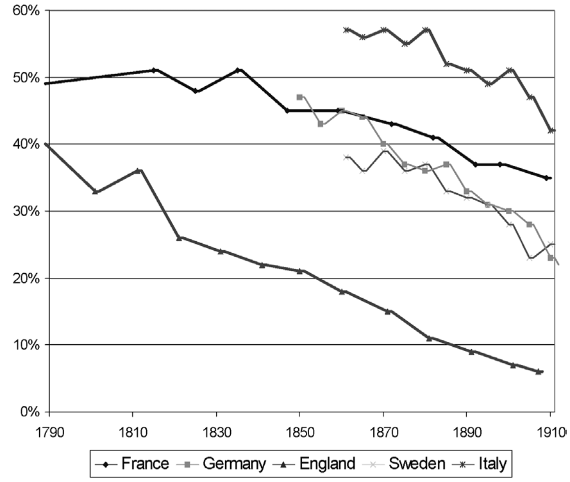

Figure 16. The decline in the percentage of agricultural production in total output: Europe: 1790–1910. Source: Mitchell (1981).

This rapid processes of industrialization and urbanization was accompanied by a rapid decline in the share of agricultural production in total output, as depicted in Figure 16. For instance, this share declined in England from 40% in 1790 to 7% in 1910.

2.2.4. *Early stages of human capital formation*

The acceleration in technological progress during the Post-Malthusian Regime and the associated increase in income per capita stimulated the accumulation of human capital in the form of literacy rates, schooling, and health. The increase in the investment in human capital was induced by the gradual relaxation in households' budget constraints (as reflected by the rise in real wages and income per capita), as well as by qualitative changes in the economic environment that increased the demand for human capital and induced households to invest in the education of their offspring.

In the first phase of the Industrial Revolution, human capital had a limited role in the production process. Education was motivated by a variety of reasons, such as religion, enlightenment, social control, moral conformity, sociopolitical stability, social and national cohesion, and military efficiency. The extensiveness of public education was therefore not necessarily correlated with industrial development and it differed across countries due to political, cultural, social, historical and institutional factors. In the second phase of the Industrial Revolution, however, the demand for education increased, reflecting the increasing skill requirements in the process of industrialization.[26]

[26] Evidence suggests that in Western Europe, the economic interests of capitalists were a significant driving force behind the implementation of educational reforms, reflecting the interest of capitalists in human capital formation and thus in the provision of public education [Galor and Moav (2006)].

During the Post-Malthusian Regime, the average number of years of schooling in England and Wales rose from 2.3 for the cohort born between 1801 and 1805, to 5.2 for the cohort born in the years 1852–1856 [Matthews et al. (1982)]. Furthermore, human capital as reflected by the level of health of the labor force increased over this period. In particular, between 1740 and 1840 life expectancy at birth rose from 33 to 40 in England (Figure 8), and from 25 to 40 in France.

The process of industrialization was eventually characterized by a gradual increase in the relative importance of human capital in less developed economies as well. As documented by Barro and Lee (2000) educational attainment increased significantly across all less developed regions in the Post-Malthusian Regime (that ended with the decline in population growth in the 1970s in Latin America and Asia, and was still in motion in Africa at the end of the 20th century). In particular, the average years of schooling increased from 3.5 in 1960 to 4.4 in 1975 in Latin America, from 1.6 in 1960 to 3.4 in 2000 in Sub-Saharan Africa, and from 1.4 in 1960 to 1.9 in 1975 in South Asia.

2.3. The Sustained Growth Regime

The acceleration in technological progress and industrialization in the Post-Malthusian Regime and its interaction with the accumulation of human capital brought about a demographic transition, paving the way to a transition to an era of sustained economic growth. In the post demographic-transition period, the rise in aggregate income due to technological progress and factor accumulation has no longer been counterbalanced by population growth, permitting sustained growth in income per capita in regions that have experienced sustained technological progress and factor accumulation.

The transition of the developed regions of Western Europe and the Western Offshoots to the state of sustained economic growth occurred towards the end of the 19th century, whereas the transition of some less developed countries in Asia and Latin America occurred towards the end of the 20th century. Africa, in contrast, is still struggling to make this transition.

2.3.1. Growth of income per capita

During the Sustained Growth Regime the average growth rate of output per capita increased significantly along with the decline in population growth. The acceleration in technological progress and the associated rise in the demand for human capital brought about a demographic transition in Western Europe, Western Offshoots, and in many of the less advanced economies, permitting sustained increase in income per capita.

Income per capita in the last century has advanced at a stable rate of about 2% per year in Western Europe and the Western Offshoots, as depicted in Figure 17. In contrast, some less developed regions experienced sustained growth rates of output per capita only in the last decades. As depicted in Figure 18, the growth rate of output per capita

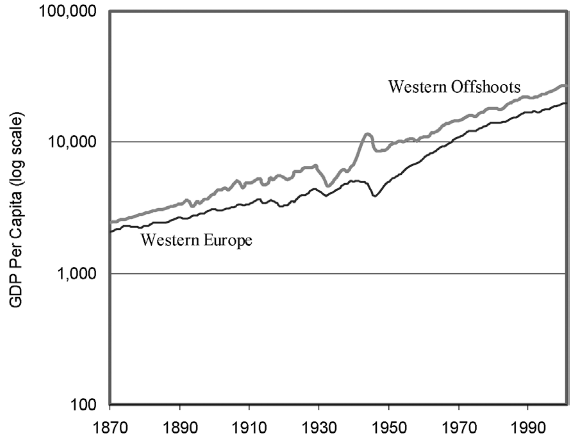

Figure 17. Sustained economic growth: Western Europe and the Western Offshoots, 1870–2001. Source: Maddison (2003).

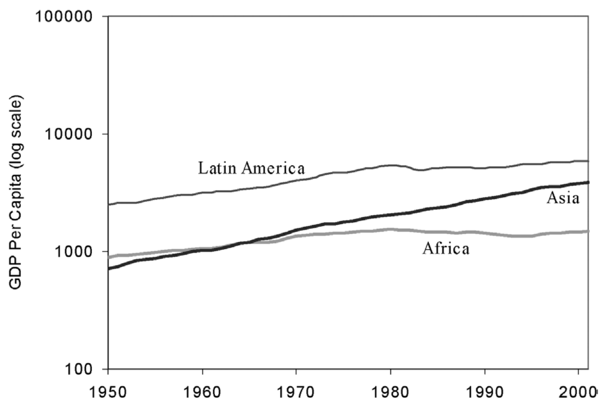

Figure 18. Income per capita in Africa, Asia and Latin America, 1950–2001. Source: Maddison (2003).

in Asia has been stable in the last 50 years, the growth rate in Latin America has been declining over this period, and the growth of Africa vanished in the last few decades.[27]

The transition to a state of sustained economic growth in developed as well as less developed regions was accompanied by a rapid process of industrialization. As depicted in Figure 14, the *per capita level of industrialization* (measuring per capita volume of industrial production) doubled in the time period 1860–1913 and tripled in the course

[27] Extensive evidence about the growth process in the last four decades is surveyed by Barro and Sala-i-Martin (2003).

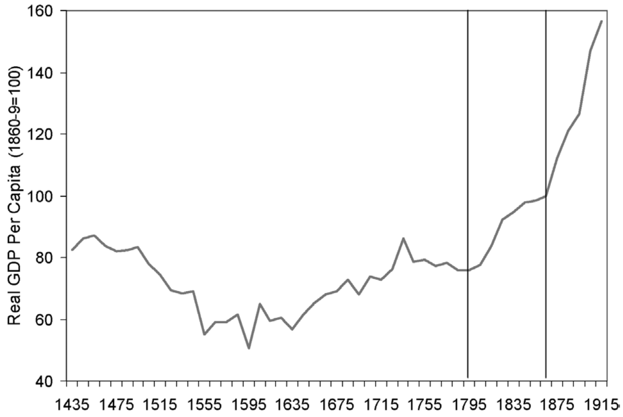

Figure 19. The sharp rise in real GDP per capita in the transition to sustained economic growth: England 1435–1915. Sources: Clark (2001) and Feinstein (1972).

of the 20th century. Similarly, the per capita level of industrialization in the United States, increased six-fold over the years 1860–1913, and tripled along the 20th century. A similar pattern was experienced in Germany, France, Sweden, Switzerland, Belgium, and Canada where industrialization increased significantly in the time interval 1860–1913 as well as over the rest of the 20th century. Moreover, less developed economies that made the transition to a state of sustained economic growth in recent decades have experienced a significant increase in industrialization.

The transition to a state of sustained economic growth was characterized by a gradual increase in the importance of the accumulation of human capital relative to physical capital as well as with a sharp decline in fertility rates. In the first phase of the Industrial Revolution (1760–1830), capital accumulation as a fraction of GDP increased significantly whereas literacy rates remained largely unchanged. Skills and literacy requirements were minimal, the state devoted virtually no resources to raise the level of literacy of the masses, and workers developed skills primarily through on-the-job training [Green (1990) and Mokyr (1990, 1993)]. Consequently, literacy rates did not increase during the period 1750–1830 [Sanderson (1995)].

In the second phase of the Industrial Revolution, however, the pace of capital accumulation subsided, the education of the labor force markedly increased and skills became necessary for production. The investment ratio which increased from 6% in 1760 to 11.7% in 1831, remained at around 11% on average in the years 1856–1913 [Crafts (1985) and Matthews et al. (1982)]. In contrast, the average years of schooling of male in the labor force, that did not change significantly until the 1830s, tripled by the beginning of the 20th century [Matthews et al. (1982, p. 573)]. The significant rise in the level of income per capita in England as of 1865, as depicted in Figure 19, was associated with an increase in the standard of living [Voth (2004)], and an increase in school enrollment of 10-year olds from 40% in 1870 to 100% in 1900. Moreover, Total

Fertility Rates in England sharply declined over this period from about 5 in 1875, to nearly 2 in 1925.

The transition to a state of sustained economic growth in the US, as well, was characterized by a gradual increase in the importance of the accumulation of human capital relative to physical capital. Over the time period 1890–1999, the contribution of human capital accumulation to the growth process in the US nearly doubled whereas the contribution of physical capital declined significantly. Goldin and Katz (2001) show that the rate of growth of educational productivity was 0.29% per year over the 1890–1915 period, accounting for about 11% of the annual growth rate of output per capita over this period.[28] In the period 1915–1999, the rate of growth of educational productivity was 0.53% per year accounting for about 20% of the annual growth rate of output per capita over this period. Abramovitz and David (2000) report that the fraction of the growth rate of output per capita that is directly attributed to physical capital accumulation declined from an average of 56% in the years 1800–1890 to 31% in the period 1890–1927 and 21% in the time interval 1929–1966.

2.3.2. The demographic transition

The demographic transition swept the world in the course of the last century. The unprecedented increase in population growth during the Post-Malthusian Regime was ultimately reversed and the demographic transition brought about a significant reduction in fertility rates and population growth in various regions of the world, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita. The demographic transition enhanced the growth process via three channels: (a) the reduction of the dilution of the stock of capital and land; (b) the enhancement of investment in human capital; (c) the alteration of the age distribution of the population, temporarily increasing the size of the labor force relative to the population as a whole.

The decline in population growth The timing of the demographic transition differed significantly across regions. As depicted in Figure 20, the reduction in population growth occurred in Western Europe, the Western Offshoots, and Eastern Europe towards the end of the 19th century and in the beginning of the 20th century, whereas Latin America and Asia experienced a decline in the rate of population growth only in the last decades of the 20th century. Africa's population growth, in contrast, has been rising steadily, although this pattern is likely to reverse in the near future due to the decline in fertility rates in this region since the 1980s.

The Western Offshoots experienced the earliest decline in population growth, from an average annual rate of 2.87% in the period 1820–1870 to an annual average rate of

[28] They measure educational productivity by the contribution of education to the educational wage differentials.

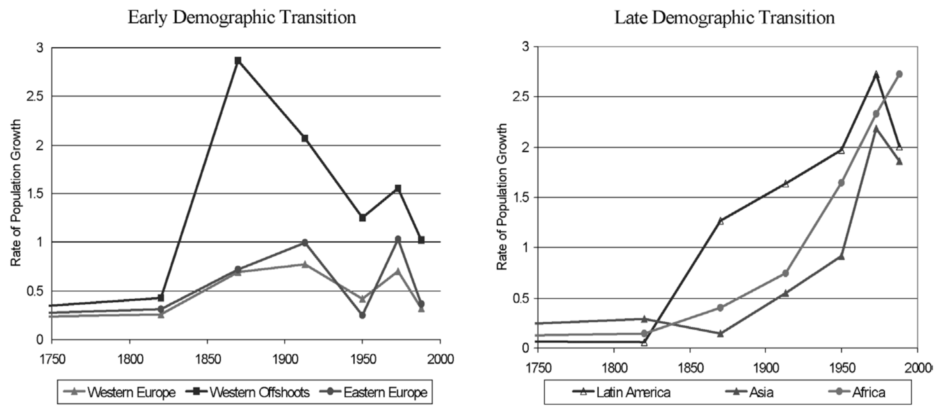

Figure 20. The differential timing of the demographic transition across regions. Source: Maddison (2001).

2.07% in the time interval 1870–1913 and 1.25% in the years 1913–1950.[29] In Western Europe population growth declined from a significantly lower average level of 0.77% per year in the period 1870–1913 to an average rate of 0.42% per year in the period 1913–1950. A similar reduction occurred in Eastern Europe as well.[30]

In contrast, in Latin America and Asia the reduction in population growth started to take place in the 1970s, whereas the average population growth in Africa has been rising, despite a modest decline in fertility rates.[31] Latin America experienced a decline in population growth from an average annual rate of 2.73% in the years 1950–1973 to an annual average rate of 2.01% in the period 1973–1998. Similarly, Asia (excluding Japan) experienced a decline in population growth from an average annual rate of 2.21% in the time period 1950–1973 to an average annual rate of 1.86% in the 1973–1998 period. The decline in fertility in these less developed regions, however, has been more significant, indicating a sharp forthcoming decline in population growth during the next decades.

Africa's increased resources in the Post-Malthusian Regime, however, have been channeled primarily towards population growth. Africa's population growth rate has increased monotonically from a modest average annual rate of 0.4% over the years 1820–1870, to a 0.75% in the time interval 1870–1913, 1.65% in the period 1913–1950, 2.33% in 1950–1973, and a rapid average annual rate of 2.73% in the 1973–1998 period. Consequently, the share of the African population in the world increased by 41%

[29] Migration played a significant role in the rate of population growth of these land-abundant countries.

[30] A sharper reduction in population growth occurred in the United Kingdom, from 0.87% per year in the period 1870–1913 to 0.27% per year in the period 1913–1950.

[31] As depicted in Figure 21, the decline in Total Fertility Rates in these countries started earlier. The delay in the decline in population growth could be attributed to an increase in life expectancy as well as an increase in the relative size of cohorts of women in a reproduction age.

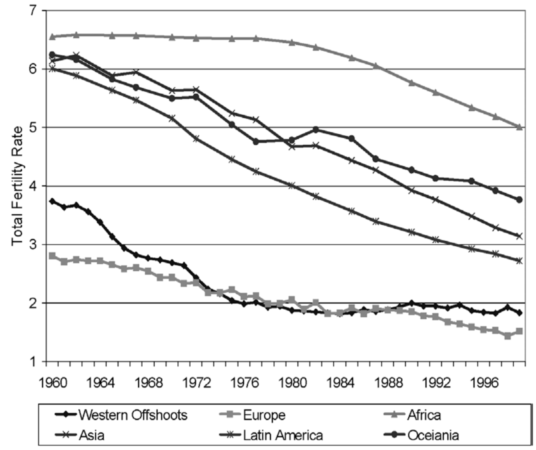

Figure 21. The evolution of Total Fertility Rate across regions, 1960–1999. Source: World Development Indicators (2001).

in the 60-year period 1913–1973 (from 7% in 1913 to 9.9% in 1973), and an additional 30% in the last 25 years, from 9.9% in 1973 to 12.9% in 1998.

Fertility decline The decline in population growth followed the decline in fertility rates. As depicted in Figure 21, *Total Fertility Rate* over the period 1960–1999 plummeted from 6 to 2.7 in Latin America and declined sharply from 6.14 to 3.14 in Asia.[32] Furthermore, *Total Fertility Rate* in Western Europe and the Western Offshoots declined over this period below the replacement level: from 2.8 in 1960 to 1.5 in 1999 in Western Europe and from 3.84 in 1960 to 1.83 in 1999 in the Western Offshoots [World Development Indicators (2001)]. Even in Africa *Total Fertility Rate* declined moderately from 6.55 in 1960 to 5.0 in 1999.

The demographic transition in Western Europe occurred towards the turn of the 19th century. A sharp reduction in fertility took place simultaneously in several countries in the 1870s, and resulted in a decline of about 1/3 in fertility rates in various states within a 50-year period.[33]

As depicted in Figure 22, *Crude Birth Rates* in England declined by 44%, from 36 (per 1000) in 1875, to 20 (per 1000) in 1920. Similarly, live births per 1000 women

[32] For a comprehensive discussion of the virtues and drawbacks of the various measures of fertility: *TFR*, *NNR*, and *CBR*, see Weil (2004).

[33] Coale and Treadway (1986) find that a 10% decline in fertility rates was completed in 59% of all European countries in the time period 1890–1920. In particular, a 10% decline was completed in Belgium in 1881, Switzerland in 1887, Germany in 1888, England and Wales in 1892, Scotland in 1894, Netherlands in 1897, Denmark in 1898, Sweden in 1902, Norway in 1903, Austria in 1907, Hungary in 1910, Finland in 1912, Greece and Italy in 1913, Portugal in 1916, Spain in 1920, and Ireland in 1922.

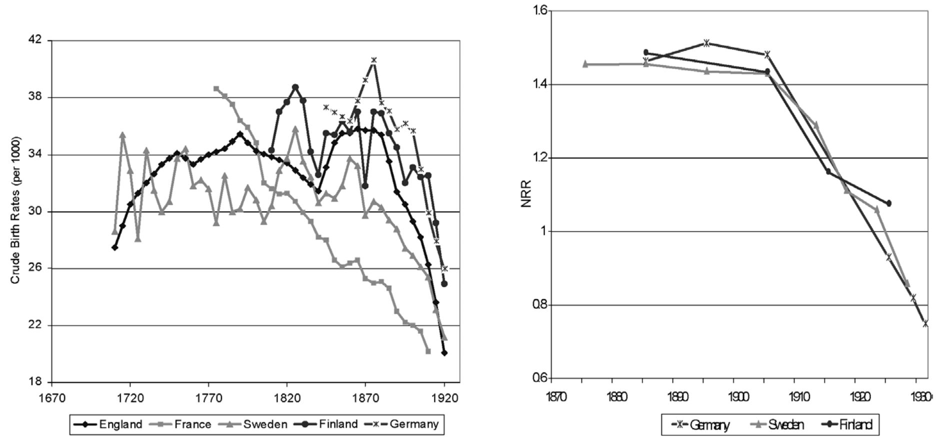

Figure 22. The demographic transition in Western Europe: *Crude Birth Rates* and *Net Reproduction Rates*. Sources: Andorka (1978) and Kuzynski (1969).

aged 15–44 fell from 153.6 in 1871–1880 to 109.0 in 1901–1910 [Wrigley (1969)]. In Germany, *Crude Birth Rates* declined 37%, from 41 (per 1000) in 1875 to 26 (per 1000) in 1920. Sweden's *Crude Birth Rates* declined 32%, from 31 (per 1000) in 1875 to 21 (per 1000) in 1920, and in Finland they declined 32%, from 37 (per 1000) in 1875 to 25 (per 1000) in 1920. Finally, although the timing of demographic transition in France represents an anomaly, starting in the second half of the 18th century, France experienced an additional significant reduction in fertility in the time period 1865–1910, and its *Crude Birth Rates* declined by 26%, from 27 (per 1000) in 1965 to 20 (per 1000) in 1910.

The decline in the crude birth rates in the course of the demographic transition was accompanied by a significant decline in the *Net Reproduction Rate* (i.e., the number of daughters per woman who reach the reproduction age), as depicted in Figure 22. Namely, the decline in fertility during the demographic transition outpaced the decline in mortality rates, and brought about a decline in the number of children who survived to their reproduction age.

Similar patterns are observed in the evolution of *Total Fertility Rates* in Western Europe, as depicted in Figure 23. *Total Fertility Rates* (TFR) peaked in the 1870s and then declined sharply and simultaneously across Western European States. In England, TFR declined by 51%, from 4.94 children in 1875, to 2.4 in 1920. In Germany, TFR declined 57%, from 5.29 in 1885 to 2.26 in 1920. Sweden's TFR declined 61%, from 4.51 in 1876 to 1.77 in 1931, in Finland they declined 52%, from 4.96 in 1876 to 2.4 in 1931 and in France, where a major decline occurred in the years 1750–1850, an additional decline took place in the same time period from 3.45 in 1880 to 1.65 in 1920.

Figure 23. The demographic transition in Western Europe: Total Fertility Rates. Source: Chesnais (1992).

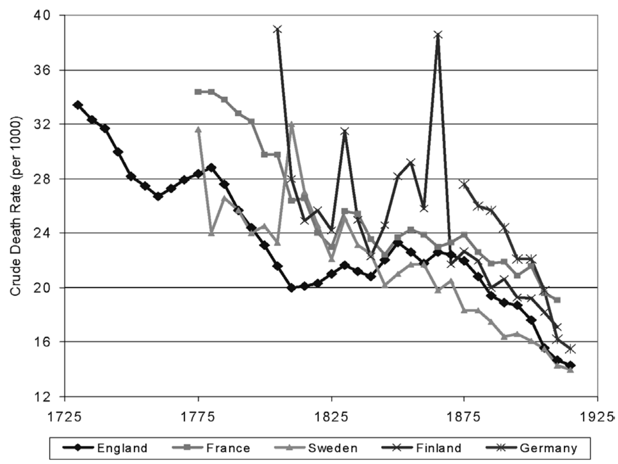

Figure 24. The mortality decline in Western Europe, 1730–1920. Source: Andorka (1978).

Mortality decline The mortality decline preceded the decline in fertility rates in most countries in the world, with the notable exceptions of France and the United States. The decline in mortality rates preceded the decline in fertility rates in Western European countries in the 1730–1920 period, as depicted in Figures 22 and 24. The decline in mortality rates began in England 140 years prior to the decline in fertility, and in Sweden and Finland nearly 100 years prior to the decline in fertility.

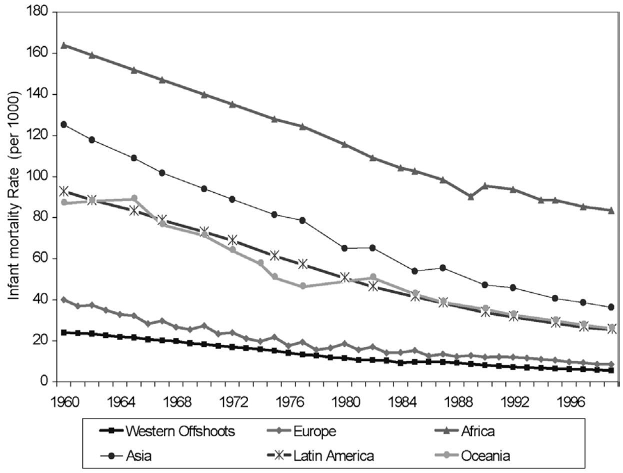

Figure 25. The decline in infant mortality rates across regions, 1960–1999. Source: World Development Indicators (2001).

A similar sequence of events emerges from the pattern of mortality and fertility decline in less developed regions. As depicted in Figures 21 and 25, a sharp decline in infant mortality rates as of 1960 preceded the decline in fertility rates in Africa that took place since the 1980s. Moreover, existing evidence indicates a simultaneous reduction in mortality and fertility in the 1960–2000 period in all other regions.

Life expectancy The decline in mortality rates in developed countries since the 18th century, as depicted in Figure 24, corresponded to a gradual increase in life expectancy, generating a further inducement for investment in human capital. As depicted in Figure 26, life expectancy at birth in England increased at a stable pace from 32 years in the 1720s to about 41 years in the 1870s. This pace of the rise in life expectancy increased towards the end of the 19th century and life expectancy reached the levels of 50 years in 1906, 60 years in 1930 and 77 years in 1996.

Similarly, the significant decline in mortality rates across less developed regions in the past century, corresponded to an increase in life expectancy. As depicted in Figure 27, life expectancy increased significantly in developed regions in the 19th century, whereas the rise in life expectancy in less developed regions occurred throughout the 20th century, stimulating further human capital formation.

In particular, life expectancy nearly tripled in the course of the 20th century in Asia, rising from a level of 24 years in 1900 to 66 years in 1999, reflecting the rise in income per capita as well as the diffusion of medical technology. Similarly, life expectancy in Africa more than doubled from 24 years in 1900 to 52 years in 1999. In contrast, the more rapid advancement in income per capita in Latin America generated an earlier rise in longevity. Life expectancy increased modestly during the 19th century and more

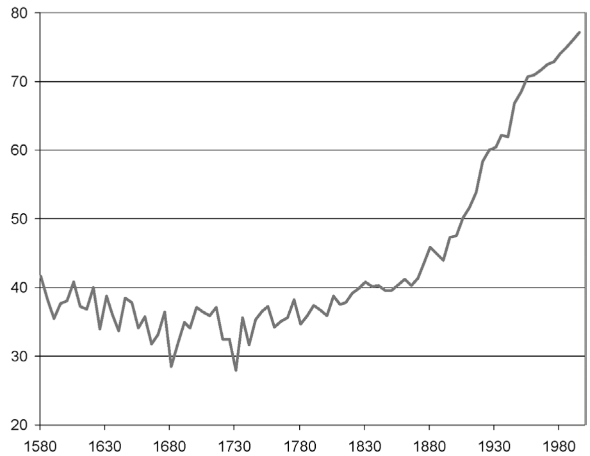

Figure 26. The evolution of life expectancy: England 1580–1996. Sources: Wrigley and Schofield (1981) for 1726–1871 and Human Mortality Database (2003) for 1876–1996.

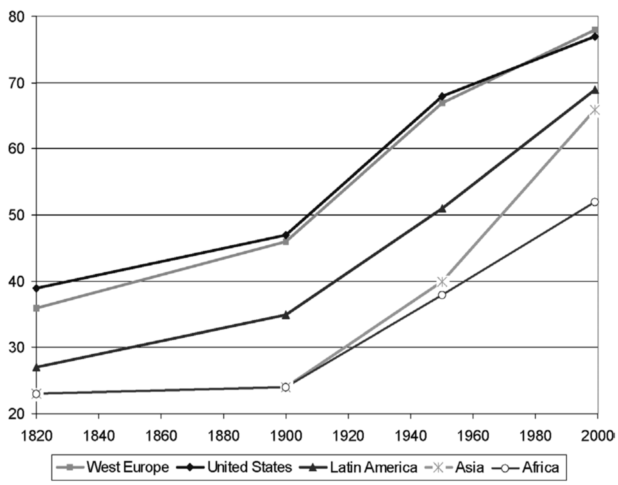

Figure 27. The evolution of life expectancy across regions, 1820–1999. Source: Maddison (2001).

significantly in the course of the 20th century, from 35 years in 1900 to 69 years in 1999.

2.3.3. Industrial development and human capital formation

The process of industrialization was characterized by a gradual increase in the relative importance of human capital in the production process. The acceleration in the rate of technological progress increased gradually the demand for human capital, inducing individuals to invest in education, and stimulating further technological advancement. Moreover, in developed as well as less developed regions, the onset of the process of human capital accumulation preceded the onset of the demographic transition, suggesting that the rise in the demand for human capital in the process of industrialization and the subsequent accumulation of human capital played a significant role in the demographic transition and the transition to a state of sustained economic growth.

Developed economies In the first phase of the Industrial Revolution, the extensiveness of the provision of public education was not correlated with industrial development and it differed across countries due to political, cultural, social, historical and institutional factors. Human capital had a limited role in the production process and education served religious, social, and national goals. In contrast, in the second phase of the Industrial Revolution the demand for skilled labor in the growing industrial sector markedly increased. Human capital formation was designed primarily to satisfy the increasing skill requirements in the process of industrialization, and industrialists became involved in shaping the educational system.

Notably, the reversal of the Malthusian relation between income and population growth during the demographic transition, corresponded to an increase in the level of resources invested in each child. For example, the literacy rate among men, which was stable at around 65% in the first phase of the Industrial Revolution, increased significantly during the second phase, reaching nearly 100% at the end of the 19th century [Clark (2003)]. In addition, the proportion of children aged 5 to 14 in primary schools increased from 11% in 1855 to 74% in 1900. A similar pattern is observed in other European societies [Flora et al. (1983)]. In particular, as depicted in Figure 28, the proportion of children aged 5 to 14 in primary schools in France increased significantly in the second phase of industrialization, rising from 30% in 1832 to 86% in 1901.

Evidence about the evolution of the return to human capital over this period are scarce and controversial. They do not indicate that the skill premium increased markedly in Europe over the course of the 19th century [Clark (2003)]. One can argue that the lack of clear evidence about the increase in the return to human capital over this period is an indication for the absence of a significant increase in the demand for human capital. This partial equilibrium argument, however, is flawed. The return to human capital is affected by the demand and the supply of human capital. Technological progress in the second phase of the Industrial Revolution brought about an increase in the demand for human capital, and indeed, in the absence of a supply response, one would have expected an increase in the return to human capital. However, the significant increase in schooling that took place in the 19th century, and in particular the introduction of public education that lowered the cost of education, generated a significant increase in the supply of educated workers. Some of this supply response was a direct reaction of the increase in the demand for human capital, and thus may only operate to partially offset the increase in the return to human capital. However, the removal of the adverse effect of credit constraints on the acquisition of human capital (as reflected by the introduction

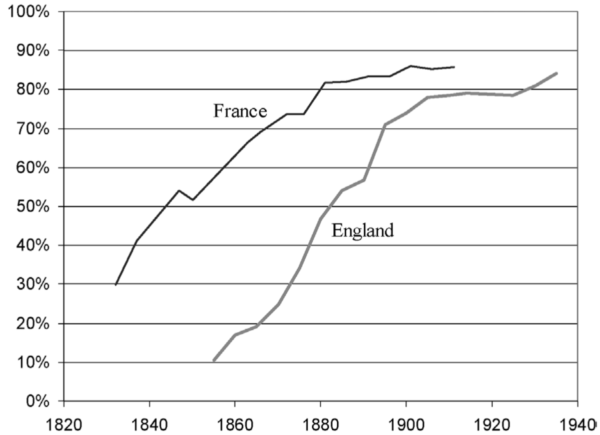

Figure 28. The fraction of children age 5–14 in public primary schools, 1820–1940. Source: Flora et al. (1983).

of public education) generated an additional force that increased the supply of educated labor and operated towards a reduction in the return to human capital.[34]

A. The industrial base for education reforms in the 19th century Education reforms in developed countries in the 18th and 19th centuries provide a profound insight about the significance of industrial development in the formation of human capital (and thus in the onset of the demographic transition) in the second half of the 19th century. In particular, differences in the timing of the establishment of a national system of public education between England and Continental Europe are instrumental in isolating the role of industrial forces in human capital formation from other forces such as social control, moral conformity, enlightenment, sociopolitical stability, social and national cohesion, and military efficiency.

England In the first phase of the Industrial Revolution (1760–1830), capital accumulation increased significantly without a corresponding increase in the supply of skilled labor. The investment ratio increased from 6% in 1760 to 11.7% in 1831 [Crafts (1985, p. 73)]. In contrast, literacy rates remained largely unchanged and the state devoted virtually no resources to raising the level of literacy of the masses. During the first stages of the Industrial Revolution, literacy was largely a cultural skill or a hierarchical symbol

[34] This argument is supported indirectly by contemporary evidence about higher rates of return to human capital in less developed economies than in developed economies [Psacharopoulos and Patrinos (2002)]. The greater prevalence of credit markets imperfections and other barriers for the acquisition of skills in less developed economies enabled only a partial supply response to industrial demand for human capital, contributing to this differential in the skill premium.

and had limited demand in the production process.[35] For instance, in 1841 only 4.9% of male workers and only 2.2% of female workers were in occupations in which literacy was strictly required [Mitch (1992, pp. 14–15)]. During this period, an illiterate labor force could operate the existing technology, and economic growth was not impeded by educational retardation.[36] Workers developed skills primarily through on-the-job training, and child labor was highly valuable.

The development of a national public system of education in England lagged behind other Western European countries by nearly half a century and the literacy rate hardly increased in the period 1750–1830 [Sanderson (1995, pp. 2–10)].[37] As argued by Green (1990, pp. 293–294), "Britain's early industrialization had occurred without direct state intervention and developed successfully, at least in its early stages, within a laissez-faire framework. Firstly, state intervention was thought unnecessary for developing technical skills, where the initial requirements were slight and adequately met by traditional means. Secondly, the very success of Britain's early industrial expansion encouraged complacency about the importance of scientific skills and theoretical knowledge which became a liability in a later period when empirical knowledge, inventiveness and thumb methods were no longer adequate." Furthermore, as argued by Landes (1969, p. 340) "although certain workers – supervisory and office personnel in particular – must be able to read and do the elementary arithmetical operations in order to perform their duties, large share of the work of industry can be performed by illiterates as indeed it was especially in the early days of the industrial revolution".

England initiated a sequence of reforms in its educational system since the 1830s and literacy rates gradually increased. The process was initially motivated by non-industrial reasons such as religion, social control, moral conformity, enlightenment, and military efficiency, as was the case in other European countries (e.g., Germany, France, Holland, Switzerland) that had supported public education much earlier. However, in light of the modest demand for skills and literacy by the capitalists, the level of governmental support was rather small.[38]

In the second phase of the Industrial Revolution, the demand for skilled labor in the growing industrial sector markedly increased and the proportion of children aged 5 to 14 in primary schools increased from 11% in 1855 to 25% in 1870 [Flora et al. (1983)]. Job advertisements, for instance, suggest that literacy became an increasingly desired characteristic for employment as of the 1850s [Mitch (1993, p. 292)]. In light

35 See Mokyr (1993, 2001).

36 Some have argued that the low skill requirements even declined over this period. For instance, Sanderson (1995, p. 89) suggests that the emerging economy created a whole range of new occupations which require even less literacy and education than the old ones.

37 For instance, in his parliamentary speech in defense of his 1837 education bill, the Whig politician, Henry Brougham, reflected upon this gap: "It cannot be doubted that some legislative effort must at length be made to remove from this country the opprobrium of having done less for education of the people than any of the more civilized nations on earth" [Green (1990, pp. 10–11)].

38 Even in 1869 the government funded only one-third of school expenditure [Green (1990, pp. 6–7)].

of the industrial competition from other countries, capitalists started to recognize the importance of technical education for the provision of skilled workers. As noted by Sanderson (1995, pp. 10–13), "reading . . . enabled the efficient functioning of an urban industrial society laced with letter writing, drawing up wills, apprenticeship indentures, passing bills of exchange, and notice and advertisement reading". Moreover, manufacturers argued that: "universal education is required in order to select, from the mass of the workers, those who respond well to schooling and would make a good foreman on the shop floor" [Simon (1987, p. 104)].

As it became apparent that skills were necessary for the creation of an industrial society, replacing previous ideas that the acquisition of literacy would make the working classes receptive to radical and subversive ideas, capitalists lobbied for the provision of public education for the masses. The pure laissez-faire policy failed in developing a proper educational system and capitalists demanded government intervention in the provision of education. As James Kitson, a Leeds iron-master and an advocate of technical education explained to the Select Committee on Scientific Instruction (1867–1868): ". . . the question is so extensive that individual manufacturers are not able to grapple with it, and if they went to immense trouble to establish schools they would be doing it in order that others may reap the benefit" [Green (1990, p. 295)].[39]

An additional turning point in the attitude of capitalists towards public education was the Paris Exhibition of 1867, where the limitations of English scientific and technical education became clearly evident. Unlike the 1851 exhibition in which England won most of the prizes, the English performance in Paris was rather poor; of the 90 classes of manufacturers, Britain dominated only in 10. Lyon Playfair, who was one of the jurors, reported that: "a singular accordance of opinion prevailed that our country has shown little inventiveness and made little progress in the peaceful arts of industry since 1862". This lack of progress "upon which there was most unanimity conviction is that France, Prussia, Austria, Belgium and Switzerland possess good systems of industrial education and that England possesses none" [Green (1990, p. 296)].

In 1868, the government established the Parliamentary Select Committee on Scientific Education. This was the origin of nearly 20 years of various parliamentary investigations into the relationship between sciences, industry, and education, that were designed to address the capitalists' outcry about the necessity of universal public education. A sequence of reports by the committee in 1868, the Royal Commission on Scientific Instruction and the Advancement of Science during the period 1872–75, and by the Royal Commission on Technical Education in 1882, underlined the inadequate training for supervisors, managers and proprietors, as well as workers. They argued that most managers and proprietors did not understand the manufacturing process and thus, failed to promote efficiency, investigate innovative techniques, or value the skills of their workers [Green (1990, pp. 297–298)]. In particular, W.E. Forster, the Vice President of the committee of the Council of Education told The House of Commons: "Upon

[39] Indeed, the Factory Act of 1802 required owners of textile mills to provide elementary instruction for their apprentices, but the law was poorly enforced [Cameron (1989, pp. 216–217)].

the speedy provision of elementary education depends our industrial prosperity . . . if we leave our work-folk any longer unskilled . . . they will become overmatched in the competition of the world" [Hurt (1971, pp. 223–224)]. The reports made various recommendations which highlighted the need to redefine elementary schools, to revise the curriculum throughout the entire school system, particularly with respect to industry and manufacture, and to improve teachers' training.

In addition, in 1868, secondary schools were investigated by the Schools Inquiry Commission. It found the level of instruction in the vast majority of schools very unsatisfactory, reflecting the employment of untrained teachers and the use of antiquated teaching methods. Their main proposal was to organize a state inspection of secondary schools and to provide efficient education geared towards the specific needs of its consumers. In particular, the Royal Commission on Technical Education of 1882 confirmed that England was being overtaken by the industrial superiority of Prussia, France and the United States and recommended the introduction of technical and scientific education into secondary schools.

It appears that the English government gradually yielded to the pressure by capitalists as well as labor unions, and increased its contributions to elementary as well as higher education. In the 1870 Education Act, the government assumed responsibility for ensuring universal elementary education, although it did not provide either free or compulsory education. In 1880, prior to the significant extension of the franchise of 1884 that made the working class the majority in most industrial countries, education was made compulsory throughout England. The 1889 Technical Instruction Act allowed the new local councils to set up technical instruction committees, and the 1890 Local Taxation Act provided public funds that could be spent on technical education [Green (1990, p. 299)].

School enrollment of 10-year olds increased from 40% in 1870 to 100% in 1900, the literacy rate among men, which was stable at around 65% in the first phase of the Industrial Revolution, increased significantly during the second phase, reaching nearly 100% at the end of the 19th century [Clark (2002)], and the proportion of children aged 5 to 14 in primary schools increased in the second half of the 19th century, from 11% in 1855 to 74% in 1900 [Flora et al. (1983)]. Finally, the 1902 Balfour Act marked the consolidation of a national education system. It created state secondary schools [Ringer (1979) and Green (1990, p. 6)] and science and engineering as well as their application to technology gained prominence [Mokyr (1990, 2002)].

Continental Europe The early development of public education occurred in the western countries of continental Europe (e.g., Prussia, France, Sweden, and the Netherlands) well before the Industrial Revolution. The provision of public education at this early stage was motivated by several goals such as social and national cohesion, military efficiency, enlightenment, moral conformity, sociopolitical stability as well as religious reasons. However, as was the case in England, massive educational reforms occurred in the second half of the 19th century due to the rising demand for skills in the process of industrialization. As noted by Green (1990, pp. 293–294) "In continental Europe industrialization occurred under the tutelage of the state and began its accelerated development later when techniques were already becoming more scientific; technical and scientific education had been vigorously promoted from the center as an essential adjunct of economic growth and one that was recognized to be indispensable for countries which wished to close Britain's industrial lead."

In France the initial development of the education system occurred well before the Industrial Revolution, but the process was intensified and transformed to satisfy industrial needs in the second phase of the Industrial Revolution. The early development of elementary and secondary education in the 17th and 18th centuries was dominated by the Church and religious orders. Some state intervention in technical and vocational training was designed to reinforce development in commerce, manufacturing and military efficiency. After the French Revolution, the state established universal primary schools. Nevertheless, enrollment rates remained rather low. The state concentrated on the development of secondary and higher education with the objective of producing an effective elite to operate the military and governmental apparatus. Secondary education remained highly selective, offering general and technical instruction largely to the middle class [Green (1990, pp. 135–137 and 141–142)]. Legislative proposals during the National Convention quoted by Cubberley (1920, pp. 514–517) are revealing about the underlying motives for education in this period: "... Children of all classes were to receive education, physical, moral and intellectual, best adapted to develop in them republican manners, patriotism, and the love of labor ... They are to be taken into the fields and workshops where they may see agricultural and mechanical operations going on ..."

The process of industrialization in France, the associated increase in the demand for skilled labor, and the breakdown of the traditional apprenticeship system, significantly affected the attitude towards education. State grants for primary schools gradually increased in the 1830s and legislation made an attempt to provide primary education in all regions, extend the higher education, and provide teacher training and school inspections. The number of communities without schools fell by 50% from 1837 to 1850 and as the influence of industrialists on the structure of education intensified, education became more stratified according to occupational patterns [Anderson (1975, pp. 15, 31)]. According to Green (1990, p. 157): "[This] legislation ... reflected the economic development of the period and thus the increasing need for skilled labor." The eagerness of capitalists for rapid education reforms was reflected by the organization of industrial societies that financed schools specializing in chemistry, design, mechanical weaving, spinning, and commerce [Anderson (1975, pp. 86, 204)].

As was the case in England, industrial competition led industrialists to lobby for the provision of public education. The Great Exhibition of 1851 and the London Exhibition of 1862 created the impression that the technological gap between France and other European nations was narrowing and that French manufacturers ought to invest in the education of their labor force to maintain their technological superiority. Subsequently, reports on the state of the industrial education by commissions established in the years 1862 to 1865 reflected the plea of industrialists for the provision of industrial education on a large scale and for the implementation of scientific knowledge in the industry. "The goal of modern education . . . can no longer be to form men of letters, idle admirers of the past, but men of science, builders of the present, initiators of the future."[40]

Education reforms in France were extensive in the second phase of the Industrial Revolution, and by 1881 a universal, free, compulsory and secular primary school system had been established and technical and scientific education further emphasized. Illiteracy rates among conscripts tested at the age of 20 declined gradually from 38% in 1851–55 to 17% in 1876–80 [Anderson (1975, p. 158)], and the proportion of children aged 5 to 14 in primary schools increased from 51.5% in 1850 to 86% in 1901 [Flora et al. (1983)]. Hence, the process of industrialization, and the increase in the demand for skilled labor in the production process, led industrialists to support the provision of universal education, contributing to the extensiveness of education as well as to its focus on industrial needs.

In Prussia, as well, the initial steps towards compulsory education took place at the beginning of the 18th century well before the Industrial Revolution. Education was viewed primarily as a method to unify the state. In the second part of the 18th century, education was made compulsory for all children aged 5 to 13. Nevertheless, these regulations were not strictly enforced partly due to the lack of funding (in light of the difficulty of taxing landlords for this purpose), and partly due to their adverse effect on child labor income. At the beginning of the 19th century, motivated by the need for national cohesion, military efficiency, and trained bureaucrats, the education system was further reformed. Provincial and district school boards were established, education was compulsory (and secular) for a three-year period, and the Gymnasium was reconstituting as a state institution that provided nine years of education for the elite [Cubberly (1920) and Green (1990)].

The process of industrialization in Prussia and the associated increase in the demand for skilled labor led to significant pressure for educational reforms and thereby to the implementation of universal elementary schooling. Taxes were imposed to finance the school system and teacher's training was established. Secondary schools started to serve industrial needs as well, the Realschulen, which emphasized the teaching of mathematics and science, was gradually adopted, and vocational and trade schools were founded. Total enrollment in secondary school increased six fold from 1870 to 1911 [Flora et al. (1983)]. "School courses . . . had the function of converting the occupational requirements of public administration, commerce and industry into educational qualifications . . ." [Muller (1987, pp. 23–24)]. Furthermore, the Industrial Revolution significantly affected the nature of education in German universities. German industrialists who perceived advanced technology as the competitive edge that could boost German industry, lobbied for reforms in the operation of universities, and offered to pay to reshape their activities so as to favor their interest in technological training and industrial applications of basic research [McClelland (1980, pp. 300–301)].

[40] L'enseignement professionnel (1864, p. 332), quoted in Anderson (1975, p. 194).

The structure of education in the Netherlands also reflected the interest of capitalists in the skill formation of the masses. In particular, as early as the 1830s, industrial schools were established and funded by private organizations, representing industrialists and entrepreneurs. Ultimately, in the latter part of the 19th century, the state, urged by industrialists and entrepreneurs, started to support these schools [Wolthuis (1999, pp. 92–93, 119, 139–140, 168, 171–172)].

United States The process of industrialization in the US also increased the importance of human capital in the production process. Evidence provided by Abramovitz and David (2000) and Goldin and Katz (2001) suggests that over the period 1890–1999, the contribution of human capital accumulation to the growth process of the United States nearly doubled.[41] As argued by Goldin (2001), the rise of the industrial, business and commerce sectors in the late 19th and early 20th centuries increased the demand for managers, clerical workers, and educated sales personnel who were trained in accounting, typing, shorthand, algebra, and commerce. Furthermore, in the late 1910s, technologically advanced industries demanded blue-collar craft workers who were trained in geometry, algebra, chemistry, mechanical drawing, etc. The structure of education was transformed in response to industrial development and the increasing importance of human capital in the production process, and American high schools adapted to the needs of the modern workplace of the early 20th century. Total enrollment in public secondary schools increased 70-fold from 1870 to 1950 [Kurian (1994)].[42]

B. Human capital formation and inequality In the first phase of the Industrial Revolution, prior to the implementation of significant education reforms, physical capital accumulation was the prime engine of economic growth. In the absence of significant human capital formation, the concentration of capital among the capitalists widened wealth inequality. Once education reforms were implemented, however, the significant increase in the return to labor relative to capital, as well as the significant increase in the

[41] It should be noted that literacy rates in the US were rather high prior to this increase in the demand for skilled labor. Literacy rates among the white population were already 89% in 1870, 92% in 1890, and 95% in 1910 [Engerman and Sokoloff (2000)]. Education in earlier periods was motivated by social control, moral conformity, and social and national cohesion, as well as required skills for trade and commerce. In particular, Field (1976) and Bowles and Gintis (1975) argue that educational reforms were designed to *sustain* the existing social order, by displacing social problems into the school system.

[42] As noted by Galor and Moav (2006), due to differences in the structure of education finance in the US in comparison to European countries, capitalists in the US had only limited incentives to lobby for the provision of education and support it financially. Unlike the central role that government funding played in the provision of public education in European countries, the evolution of the educational system in the US was based on local initiatives and funding. The local nature of the education initiatives in the US induced community members, in urban as well as rural areas, to play a significant role in advancing their schooling system. American capitalists, however, faced limited incentives to support the provision of education within a county in an environment where labor was mobile across counties and the benefits from educational expenditure in one county may be reaped by employers in other counties.

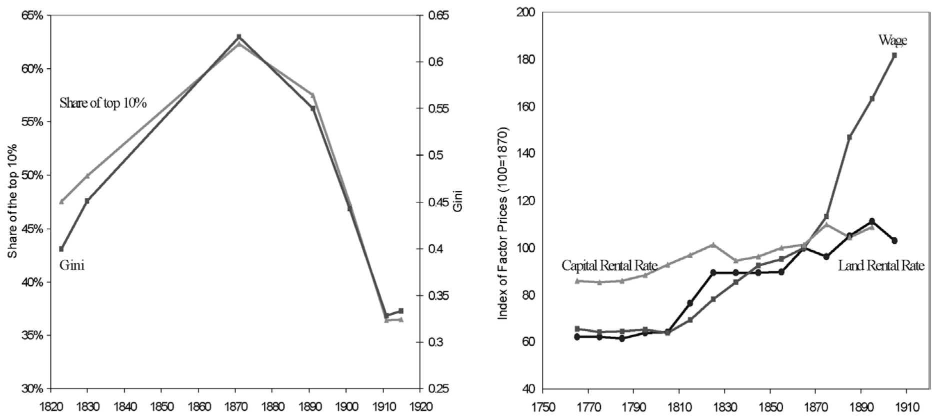

Figure 29. Wealth inequality and factor prices: England 1820–1920. Sources: Williamson (1985) for inequality and Clark (2002, 2003) for factor prices.

real return to labor and the associated accumulation of assets by the workers, brought about a decline in inequality.

Evidence suggests that in the first phase of the Industrial Revolution, prior to the implementation of education reforms, capital accumulation brought about a gradual increase in wages along with an increase in the wage–rental ratio. Education reforms in the second phase of the Industrial Revolution were associated with a sharp increase in real wages along with a sharp increase in the wage–rental ratio.[43] Finally, wealth inequality widened in the first phase of the Industrial Revolution and reversed its course in the second phase, once significant education reforms were implemented.

As documented in Figure 29, based on a controversial study, over the time period 1823–1915, wealth inequality in the UK peaked around 1870 and declined thereafter, in close association with the patterns of enrollment rates and factor prices, depicted in Figures 28 and 29.[44] It appears that the decline in inequality was associated with the significant changes that occurred around 1870 in the relative returns to the main factors of production possessed by capitalists and workers. These changes in factor prices reflect the increase in enrollment rates and its delayed effect on the skill level per worker.

Similar patterns of the effect of education on factor prices and, therefore, on inequality are observed in France as well. As argued by Morrisson and Snyder (2000), wealth inequality in France increased during the first half of the 19th century, and started to decline in the last decades of the 19th century in close association with the rise in education rates depicted in Figure 28, the rise in real wages depicted in Figure 10, and a

[43] It should be noted that the main source of the increase in real wages was not a decline in prices. Over this period nominal wages increased significantly as well.

[44] It should be noted that the return to capital increased moderately over this period, despite the increase in the supply of capital, reflecting technological progress, population growth, and accumulation of human capital.

declining trend of the return to capital over the 19th century. The decline in inequality in France appears to be associated with the significant changes in the relative returns to the main factors of production possessed by capitalists and workers in the second part of the 19th century. As depicted in Figure 10, based on the data presented in Levy-Leboyer and Bourguignon (1990), real wages, as well as the wage–rental ratio, increased significantly as of 1860, reflecting the rise in the demand for skilled labor and the effect of the increase in enrollment rates on the skill level per worker.

The German experience is consistent with this pattern as well. Inequality in Germany peaked towards the end of the 19th century [Morrisson and Snyder (2000)] in association with a significant increase in the real wages and in the wage–rental ratio from the 1880s [Spree (1977) and Berghahn (1994)], which is in turn related to the provision of industrial education in the second half of the 19th century.

The link between the expansion of education and the reduction in inequality is present in the US as well. Wealth inequality in the US, which increased gradually from colonial times until the second half of the 19th century, reversed its course at the turn of the century and maintained its declining pattern during the first half of the 20th century [Lindert and Williamson (1976)]. As argued by Goldin (2001), the emergence of the "new economy" in the early 20th century increased the demand for educated workers. The creation of publicly funded mass modern secondary schools from 1910 to 1940 provided general and practical education, contributed to workers productivity, and opened the gates for college education. This expansion facilitated social and geographic mobility and generated a large decrease in inequality in economic outcomes.

C. Independence of education reforms from political reforms in the 19th century The 19th century was marked by significant political reforms along with the described education reforms. One could therefore challenge the significance of the industrial motive for education reform, suggesting that political reforms during the 19th century shifted the balance of power towards the working class and enabled workers to implement education reforms against the interest of the industrial elite. However, political reforms that took place in the 19th century had no apparent effect on education reforms over this period, strengthening the hypothesis that indeed industrial development, and the increasing demand for human capital, were the trigger for human capital formation and the demographic transition. Education reforms took place in autocratic states that did not relinquish political power throughout the 19th century, and major reforms occurred in societies in the midst of the process of democratization well before the stage at which the working class constituted the majority among the voters.

In particular, the most significant education reforms in the UK were completed before the voting majority shifted to the working class. The patterns of education and political reforms in the UK during the 19th century are depicted in Figure 30. The Reform Act of 1832 nearly doubled the total electorate, but nevertheless only 13% of the voting-age population were enfranchised. Artisans, the working class, and some sections of the lower middle class remained outside of the political system. The franchise was extended further in the Reform Acts of 1867 and 1884 and the total electorate nearly doubled in

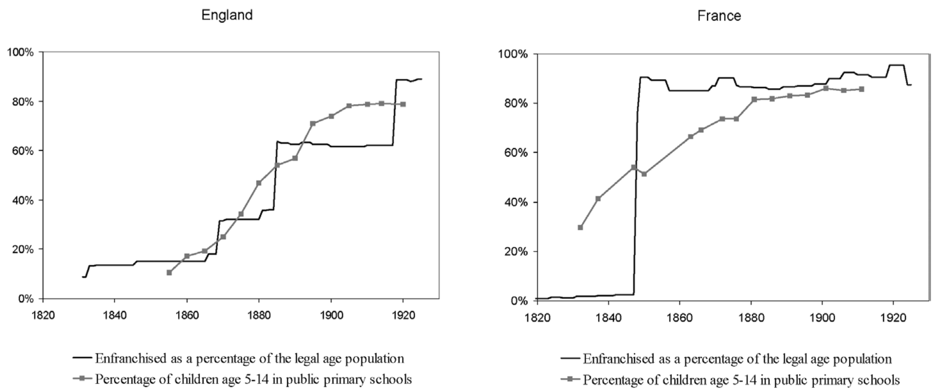

Figure 30. The evolution of voting rights and school enrollment. Source: Flora et al. (1983).

each of these episodes. However, working-class voters did not become the majority in all urban counties until 1884 [Craig (1989)].

The onset of England's education reforms, and in particular, the fundamental Education Act of 1870 and its major extension in 1880 occurred prior to the political reforms of 1884 that made the working class the majority in most counties. As depicted in Figure 30, a trend of significant increase in primary education was established well before the extension of the franchise in the context of the 1867 and 1884 Reform Acts. In particular, the proportion of children aged 5 to 14 in primary schools increased five-fold (and surpassed 50%) over the three decades prior to the qualitative extension of the franchise in 1884 in which the working class was granted a majority in all urban counties. Furthermore, the political reforms do not appear to have any effect on the pattern of education reform. In fact, the average growth rate of education attendance from decade to decade over the period 1855 to 1920 reaches a peak at around the Reform Act of 1884 and starts declining thereafter. It is interesting to note, however, that the abolishment of education fees in nearly all elementary schools occurs only in 1891, after the Reform Act of 1884, suggesting that the political power of the working class may have affected the distribution of education costs across the population, but the decision to educate the masses was taken independently of the political power of the working class.

In France, as well, the expanding pattern of education preceded the major political reform that gave the voting majority to the working class. The patterns of education and political reforms in France during the 19th century are depicted in Figure 30. Prior to 1848, restrictions limited the electorate to less than 2.5% of the voting-age population. The 1848 revolution led to the introduction of nearly universal voting rights for males. Nevertheless, the proportion of children aged 5 to 14 in primary schools doubled (and exceeded 50%) over the two decades prior to the qualitative extension of the franchise in 1848 in which the working class was granted a majority among voters. Furthermore, the political reforms of 1848 do not appear to have any effect on the pattern of education expansion.

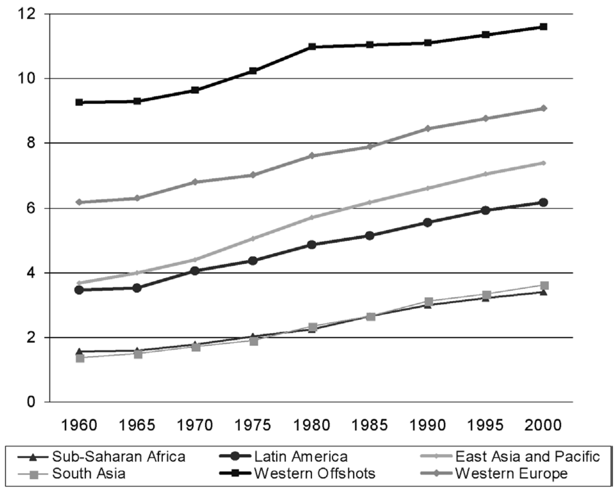

Figure 31. The evolution of average years of education: 1960–2000. Source: Barro and Lee (2000).

A similar pattern occurs in other European countries. Political reforms in the Netherlands did not affect the trend of education expansion and the proportion of children aged 5 to 14 in primary schools exceeded 60% well before the major political reforms of 1887 and 1897. Similarly, the trends of political and education reforms in Sweden, Italy, Norway, Prussia and Russia do not lend credence to the alternative hypothesis.

Less developed economies The process of industrialization was characterized by a gradual increase in the relative importance of human capital in less developed economies as well. As depicted in Figure 31, educational attainment increased significantly across all less developed regions. Moreover, in line with the pattern that emerged among developed economies in the 19th century, the increase in educational attainment preceded or occurred simultaneously with the decline in total fertility rates. In particular, the average years of schooling in Africa increased by 44% (from 1.56 to 2.44) prior to the onset of decline in total fertility rates in 1980, as depicted in Figure 23.

2.3.4. International trade and industrialization

The process of industrialization in developed economies was enhanced by the expansion of international trade. During the 19th century, North–South trade, as well as North–North trade, expanded significantly due to a rapid industrialization in Northwest Europe as well as the reduction of trade barriers and transportation costs and the benefits of the gold standard. The ratio of world trade to output was about 2% in 1800, but then it rose to 10% in 1870, to 17% in 1900 and 21% in 1913 [Estavadeordal, Frantz and Taylor (2002)]. While much of this trade occurred between industrial economies a significant proportion was between industrial and non-industrial economies. As shown in

Table 1
Regional shares of world trade in manufactures. Source: Yates (1959).

	1876–1880		1896–1900		1913	
	Exports	Imports	Exports	Imports	Exports	Imports
UK and Ireland	37.8%	9.1%	31.5%	10.4%	25.3%	8.2%
Northwest Europe	47.1%	18.1%	45.8%	20.3%	47.9%	24.4%
Other Europe	9.2%	13.3%	10.3%	12.2%	8.3%	15.4%
U.S. and Canada	4.4%	7.7%	7.4%	9.6%	10.6%	12.1%
Rest of the World	1.5%	51.8%	5.0%	47.5%	7.9%	39.9%

Table 1, before 1900 nearly 50% of manufactured exports were to non-European and non-North American economies. By the end of 19th century a clear pattern of specialization emerged. The UK and Northwest Europe were net importers of primary products and net exporters of manufactured goods, whereas the exports of Asia, Oceania, Latin America and Africa were overwhelmingly composed of primary products [Findlay and O'Rourke (2003)].

Atlantic trade as well as trade with Asia, in an era of colonialism, had a major effect on European growth starting in the late 16th century [Pomeranz (2000)]. In addition, later expansion of international trade contributed further to the process of industrialization in the UK and Europe [O'Rourke and Williamson (1999)]. For the UK, the proportion of foreign trade to national income grew from about 10% in the 1780s to about 26% over the years 1837–45, and 51.5% in the time period 1909–13 [Kuznets (1967)]. Other European economies experienced a similar pattern as well. The proportion of foreign trade to national income on the eve of World War I was 53.7% in France, 38.3% in Germany, 33.8% in Italy, and 40.4% in Sweden [Kuznets (1967, Table 4)]. Furthermore, export was critical for the viability of some industries, especially the cotton industry, where 70% of the UK output was exported in the 1870s. The quantitative study of Stokey (2001) suggests that trade was instrumental for the increased share of manufacturing in total output in the UK, as well as for the significant rise in real wages, and the empirical examination of O'Rourke and Williamson (2005) demonstrates that trade was a significant force behind the rise in productivity in the UK. Thus while it appears that technological advances could have spawned the Industrial Revolution without an expansion of international trade, the growth in exports increased the pace of industrialization and the growth rate of output per capita.[45]

[45] Pomeranz (2000), provides historical evidence for the vital role of trade in the take-off of the European economies. He argues that technological and development differences between Europe and Asia were minor around 1750, but the discovery of the New World enabled Europe, via Atlantic trade, to overcome 'land constraints' and to take off technologically.

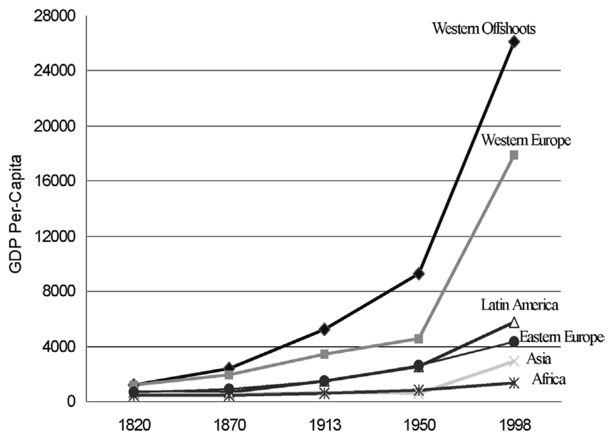

Figure 32. The great divergence. Source: Maddison (2001).

2.4. The great divergence

The differential timing of the take-off from stagnation to growth across countries, and the corresponding variations in the timing of the demographic transition, led to a great divergence in income per capita as well as population growth.

The last two centuries have witnessed dramatic changes in the distribution of income and population across the globe. Some regions have excelled in the growth of income per capita, while other regions have been dominant in population growth. Inequality in the world economy was negligible till the 19th century. The ratio of GDP per capita between the richest region and the poorest region in the world was only 1.1 : 1 in 1000, 2 : 1 in 1500 and 3 : 1 in 1820. As depicted in Figure 32, there has been a 'Great Divergence' in income per capita among countries and regions in the past two centuries. In particular, the ratio of GDP per capita between the richest group (Western Offshoots) and the poorest region (Africa) has widened considerably from a modest 3 : 1 ratio in 1820, to 5 : 1 ratio in 1870, 9 : 1 ratio in 1913, 15 : 1 in 1950, and 18 : 1 ratio in 2001.

An equally momentous transformation occurred in the distribution of world population across regions, as depicted in Figure 33. The earlier take-off of Western European countries increased the amount of resources that could be devoted for the increase in family size, permitting a 16% increase in the share of their population in the world economy within a 50 year period (from 12.8% in 1820 to 14.8% in 1870). However, the early onset in the Western European demographic transition and the long delay in the demographic transition of less developed regions, well into the 2nd half of the 20th century, led to a 55% decline in the share of Western European population in the world, from 14.8% in 1870 to 6.6% in 1998. In contrast, the prolongation of the Post-Malthusian period among less developed regions, in association with the delay in their demographic transition well into the second half of 20th century, channeled their increased resources towards a significant increase in their population. Africa's share

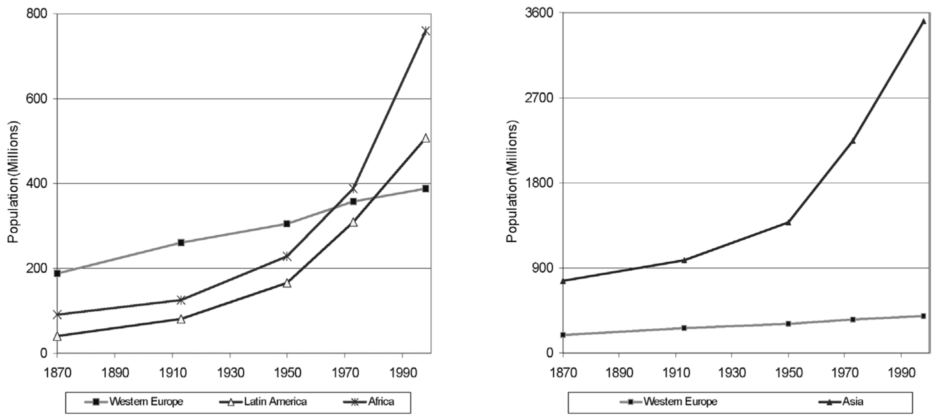

Figure 33. Divergence in regional populations. Source: Maddison (2001).

of world population increased 84%, from 7% in 1913 to 12.9% in 1998, Asia's share of world population increased 11% from 51.7% in 1913 to 57.4% in 1998, and Latin American countries increased their share in world population from 2% in 1820 to 8.6% in 1998.

Thus, while the ratio of income per capita in Western Europe to that in Asia has tripled in the last two centuries, the ratio of Asian to European population has doubled.[46]

The divergence that has been witnessed in the last two centuries has been maintained across countries in the last decades as well [e.g., Jones (1997) and Pritchett (1997)]. Interestingly, however, Sala-i-Martin (2002) shows that divergence has not been observed in recent decades across people in the world (i.e., when national boundaries are removed).

3. The fundamental challenges

The establishment of a unified theory of economic growth that can account for the intricate process of development over the course of the last thousands of years has been one of the most significant research challenges faced by researchers in the field of growth and development. A unified theory unveils the underlying micro-foundations that are consistent with the entire process of economic development, enhancing the confidence in the viability of growth theory, its predictions and policy implications, while improving the understanding of the driving forces that led to the recent transition from stagnation to growth and the Great Divergence. Moreover, a comprehensive

[46] Over the period 1820–1998, the ratio between income per capita in Western Europe and Asia (excluding Japan) grew 2.9 times, whereas the ratio between the Asian population (excluding Japan) and the Western European population grew 1.7 times [Maddison (2001)].

understanding of the hurdles faced by less developed economies in reaching a state of sustained economic growth would be futile, unless the forces that initiated the transition of the currently developed economies into a state of sustained economic growth would be identified, and modified, to account for the differences in the evolutionary structure of less developed economies in an interdependent world.

The evidence presented in Section 2 suggests that the preoccupation of growth theory with the empirical regularities that have characterized the growth process of developed economies in the past century and of less developed economies in the last few decades, has become harder to justify from a scientific viewpoint. Could we justify the use of selective observations about the recent course of the growth process and its principal causes in the formulation of exogenous and endogenous growth models? Could we be confident about the predictions of a theory that is not based on micro-foundations that match the major characteristics of the entire growth process? The evolution of theories in older scientific disciplines suggests that theories that are founded on the basis of a subset of the existing observations are fragile and non-durable, and are often generating increasingly distorted predictions.

3.1. Mysteries of the growth process

The underlying determinants of the stunning recent escape from the Malthusian trap have been shrouded in mystery and their significance for the understanding of the contemporary growth process has been explored only very recently. What are the major economic forces that led to the epoch of Malthusian stagnation that characterized most of human history? What is the origin of the sudden spurt in growth rates of output per capita and population that occurred in the course of the take-off from stagnation to growth? Why had episodes of technological progress in the pre-industrialization era failed to generate sustained economic growth? What was the source of the dramatic reversal in the positive relationship between income per capita and population that existed throughout most human history? What are the main forces that prompted the demographic transition? Would the transition to a state of sustained economic growth be feasible without the demographic transition? Are there underlying unified behavioral and technological structures that can account for these distinct phases of development simultaneously and what are their implications for the contemporary growth process?

The mind-boggling phenomenon of the Great Divergence in income per capita across regions of the world in the past two centuries, that accompanied the take-off from an epoch of stagnation to a state of sustained economic growth, presents additional unresolved mysteries about the growth process. What accounts for the sudden take-off from stagnation to growth in some countries in the world and the persistent stagnation in others? Why has the positive link between income per capita and population growth reversed its course in some economies but not in others? Why have the differences in income per capita across countries increased so markedly in the last two centuries? Did the pace of transition to sustained economic growth in advanced economies adversely affect the process of development in less-developed economies?

The transitions from a Malthusian epoch to a state of sustained economic growth and the emergence of the Great Divergence have shaped the current growth process in the world economy. Nevertheless, non-unified growth models overlooked these significant underlying forces of the process of development.

3.2. The incompatibility of non-unified growth theories

Existing (non-unified) growth models are unable to capture the growth process over the entire course of human history. Malthusian models capture the growth process during the Malthusian epoch, but are incompatible with the transition to the Modern Growth Regime. Neoclassical growth models (with endogenous or exogenous technological change), in contrast, are compatible with the growth process of the *developed* economies during the Modern Growth Regime, but fail to capture the evolution of economies during the Malthusian epoch, the origin of the take-off from the Malthusian epoch into the Post-Malthusian Regime, and the sources of the demographic transition and the emergence of the Modern Growth Regime. Moreover, the failure of non-unified growth models in identifying the underlying factors that led to the transition from stagnation to growth, limits their applicability for the contemporary growth process of the less developed economies, and thereby for the current evolution of the world income distribution.

3.2.1. Malthusian and Post-Malthusian theories

The Malthusian theories The Malthusian theory, as was outlined initially by Malthus (1798), captures the main attributes of the epoch of Malthusian stagnation that had characterized most of human existence, but is utterly inconsistent with the prime characteristics of the Modern Growth Regime.[47]

The theory suggests that the stagnation in the evolution of income per capita over this epoch reflected the counterbalancing effect of population growth on the expansion of resources, in an environment characterized by diminishing returns to labor. The expansion of resources, according to Malthus, led to an increase in population growth, reflecting the natural result of the "passion between the sexes".[48] In contrast, when population size grew beyond the capacity of the available resources, it was reduced by the "preventive check" (i.e., intentional reduction of fertility) as well as by the "positive check" (i.e., the tool of nature due to malnutrition, disease, and famine).

According to the theory, periods marked by the absence of changes in the level of technology or in the availability of land, were characterized by a stable population size

[47] The Malthusian theory was formalized recently. Kremer (1993) models a reduced-form interaction between population and technology along a Malthusian equilibrium, and Lucas (2002) presents a Malthusian model in which households optimize over fertility and consumption, labor is subjected to diminishing returns due to the presence of a fixed quantity of land, and the Malthusian level of income per capita is determined endogenously.

[48] As argued by Malthus (1798), "The passion between the sexes has appeared in every age to be so nearly the same, that it may always be considered, in algebraic language as a given quantity."

as well as a constant income per capita. In contrast, episodes of technological progress, land expansion, and favorable climatic conditions, brought about temporary gains in income per capita, triggering an increase in the size of the population which led eventually to a decline in income per capita to its long-run level. The theory proposes, therefore, that variation in population density across countries during the Malthusian epoch reflected primarily cross-country differences in technologies and land productivity. Due to the positive adjustment of population to an increase in income per capita, differences in technologies or in land productivity across countries resulted in variations in population density rather than in the standard of living.

The Malthusian theory generates predictions that are largely consistent with the characteristics of economies during the Malthusian epoch, as described in Section 2.1. It suggests that: (a) technological progress or resource expansion would lead to a larger population, without altering the level of income in the long run, (b) income per capita would fluctuate during the Malthusian epoch around a constant level, and (c) technologically superior countries would have eventually denser populations but their standard of living in the long run would not reflect the degree of their technological advancement. These predictions, however, are irremediably inconsistent with the relationship between income per capita and population that has existed in the post-demographic transition era as well as with the state of sustained economic growth that had characterized the Modern Growth Regime.

Unified theories of economic growth, in contrast, incorporate the main ingredients of the Malthusian economy into a broader context, focusing on the interaction between technology, the size of the population, and the distribution of its characteristics, generating the main ingredients of the Malthusian epoch as well as an inevitable take-off to the Post Malthusian Regime and the Modern Growth Regime.

The Post-Malthusian theories The Post-Malthusian theories capture the acceleration of the growth rate of income per capita and population growth that occurred during the Post-Malthusian Regime in association with the process of industrialization. They do not capture, however, the stagnation during the Malthusian epoch and the economic forces that gradually emerged in this era and brought about the take-off from the Malthusian trap. Moreover, these theories do not account for the factors that ultimately triggered the demographic transition and the shift to a state of sustained economic growth.[49]

[49] Models that are not based on Malthusian elements are unable to capture the long epoch of Malthusian stagnation in which output per capita fluctuates around a subsistence level. For instance, an interesting research by Goodfriend and McDermott (1995) demonstrates that exogenous population growth increases population density and hence generates a greater scope for the division of labor inducing the development of markets and economic growth. Their model, therefore, generates a take-off from non-Malthusian stagnation to Post-Malthusian Regime in which population and output are positively related. The model lacks Malthusian elements and counter-factually it implies, therefore, that since the emergence of a market economy over 5000 years ago growth has been strictly positive. Moreover, it does not generate the forces that would bring about

These theories suggest that during the Post-Malthusian Regime the acceleration in technological progress and the associated rise in income per capita was only channeled partly towards an increase in the size of the population. Although, the Malthusian mechanism, linking higher income to higher population growth, continued to function, the effect of higher population on the dilution of resources per capita, and thus on the reduction of income per capita, was counteracted by the acceleration in technological progress and capital accumulation, allowing income per capita to rise despite the offsetting effects of population growth.

Kremer (1993), in an attempt to defend the role of the scale effect in endogenous growth models, examines a reduced-form of the co-evolution of population and technology in a Malthusian and Post Malthusian environment, providing evidence for the presence of a scale effect in the pre-demographic transition era.[50] Kremer's Post-Malthusian theory, however, does not identify the factors that brought about the take-off from the Malthusian trap, as well as the driving forces behind the demographic transition and the transition to a state of sustained economic growth.

Unified theories capture the main characteristics of the Post-Malthusian Regime, and generate in contrast, the endogenous driving forces that brought about the take-off from the Malthusian epoch into this regime and ultimately enabled the economy to experience a demographic transition and to reside in a state of sustained economic growth.

3.2.2. Theories of modern economic growth

Exogenous growth models [e.g., Solow (1956)] that have focused primarily on the role of factor accumulation in the growth process, as well as endogenous growth models [e.g., Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992)] that have devoted their attention to the role of endogenous technological progress in the process of development, were designed to capture the main characteristics of the Modern Growth Regime. These models, however, are inconsistent with the pattern of development that had characterized economies over most of human history, and they do not posses the research methodology that could shed light on the process of development in its entirety.

Non-unified growth models do not unveil the underlying micro-foundations of the intricate patterns of the growth process over human history, and thus they could not capture the epoch of Malthusian stagnation that characterized most of human history, the underlying driving forces that triggered the transition from stagnation to growth, the hurdles faced by less developed economies in reaching a state of sustained economic

the demographic transition and ultimately sustained economic growth. In the long-run the economy remains in the Post-Malthuisan Regime in which the growth of population and output are positively related. Other non-Malthusian models that abstract from population growth and generate an acceleration of output growth along the process of industrialization include Acemoglu and Zilibotti (1997).

[50] Komlos and Artzrouni (1990) simulate an escape from a Malthusian trap based on the Malthusian and Boserupian interaction between population and technology.

growth, and the associated phenomenon of the Great Divergence in income per capita across countries.[51]

Moreover, although the evolution of the demographic regime in the course of human history appears essential for the understanding of the evolution of income per capita over the process of development, most endogenous and exogenous growth models abstract from the determination of population growth over the growth process, and their predictions are inconsistent with the demographic structure over the course of human history.[52]

Non-unified growth models with endogenous population have been largely oriented toward the modern regime, capturing some aspects of the recent negative relationship between population growth and income per capita, but failing to capture the significance of the positive effect of income per capita on population growth that had characterized most of human existence, as well as the economic factors that triggered the demographic transition and the take-off to a state of sustained economic growth.[53]

3.3. Theories of the demographic transition and their empirical assessment

This section examines various mechanisms that have been proposed as possible triggers for the demographic transition, assessing their empirical validity, and their potential role in the transition from stagnation to growth.[54]

The demographic transition that swept the world in the course of the last century has been identified as one of the prime forces in the movement from an epoch of stagnation to a state of sustained economic growth, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita. Theories of the demographic transition attempt to capture the determinants of this significant reduction in fertility rates and population growth in various regions of

[51] As long as the neoclassical production structure of non-decreasing returns to scale is maintained, non-unified growth models could not be modified to account for the Malthusian epoch by the incorporation of endogenous population growth. For instance, suppose that the optimal growth model would be augmented to account for endogenous population. Suppose further, that the parameters of the model would be chosen so as to assure that the level of income per capita would reflect the level that existed during the Malthusian epoch and population growth will be near replacement level as was the case during this era. This equilibrium would not possess the prime characteristic of a Malthusian equilibrium. Namely, technological progress would raise income per capita permanently due to the fact that adjustments in population growth would not offset this rise of income (as long as the return to labor is characterized by non-diminishing returns to scale).

[52] In fact, most endogenous growth models that focus exclusively on the modern growth regime are inconsistent with the demographic structure within this regime, predicting a positive effect of population growth on (the growth rate of) income per capita. A notable exception is Dalgaard and Kreiner (2001).

[53] Research that capture aspects of the cross-section relationship between income per capita and fertility include Razin and Ben-Zion (1975), Barro and Becker (1989) and Becker, Murphy and Tamura (1990), and more recently Dahan and Tsiddon (1998), Kremer and Chen (2002), McDermott (2002), De la Croix and Doepke (2003), and Moav (2005).

[54] See Galor (2005) as well.

the world in the past century, in the aftermath of an unprecedented increase in population growth during the Post-Malthusian Regime.

The simultaneity of the demographic transition across Western European countries provides a fertile ground for the examination of the validity of the various theories in the context of countries that appear in similar stages of development, and are not overly diverse in their sociocultural heritage. The simultaneous reversal in the significant upward trend in fertility rates among Western European countries suggests that a common economic force may have triggered the demographic transition in this region and is likely to be the driving force behind the onset of the fertility decline in other regions of the world as well.

Was the onset of the demographic transition across Western European countries an outcome of a simultaneous decline in mortality rates? Was it associated with the higher levels of income enjoyed by Western European countries in the process of industrialization? Was it an outcome of the rise in the relative wages of women in the second phase of the Industrial Revolution? Or, an outcome of the regional acceleration in technological progress and its impact on the universal rise in the industrial demand for human capital in the second phase of the Industrial Revolution?

Historical evidence suggests that demographers' preferred explanation for the demographic transition – the decline in mortality rates – does not account for the *reversal* of the positive historical trend between income and fertility. Moreover, the role attributed to higher income levels in the demographic transition appears implausible. The evidence suggests that the rise in the demand for human capital is the most significant force behind the demographic transition, and it is therefore a central building block in unified growth theory.

3.3.1. The decline in infant and child mortality

The decline in infant and child mortality rates that preceded the decline in fertility rates in many countries in the world, with the notable exceptions of France and the US, has been demographers' favorite explanation for the onset of the decline in fertility in the course of the demographic transition.[55] Nevertheless, it appears that this viewpoint is based on weak theoretical reasoning and is inconsistent with historical evidence. While it is highly plausible that mortality rates were among the factors that affected the level of total fertility rates along human history, historical evidence does not lend credence to the argument that the decline in mortality rates accounts for the *reversal* of the positive historical trend between income and fertility.

The decline in mortality rates does not appear to be the trigger for the decline in fertility in Western Europe. As demonstrated in Figures 22 and 24, the mortality decline in Western Europe started nearly a century prior to the decline in fertility and it was

[55] The effect of the decline in mortality rates on the prolongation of productive life and thus, on the return to human capital is discussed in Section 3.3.3.

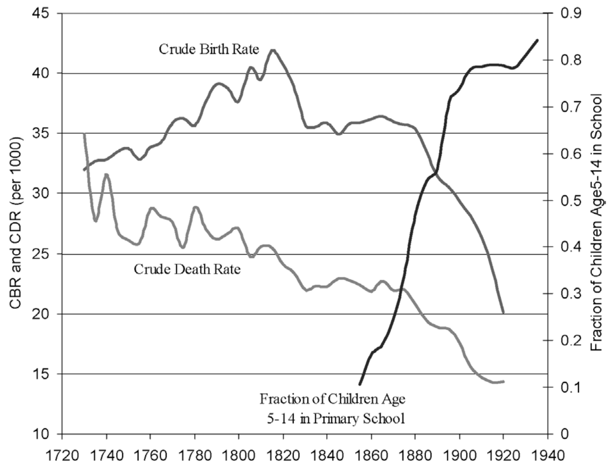

Figure 34. Investment in human capital and the demographic transition, England, 1730–1935. Sources: Flora et al. (1983) and Wrigley and Schofield (1981).

associated initially with increasing fertility rates in some countries and non-decreasing fertility rates in other countries. In particular, as demonstrated in Figure 34, the decline in mortality started in England in the 1730s and was accompanied by a steady increase in fertility rates until 1820.[56] The rise in income per capita in the Post-Malthusian Regime increased the desirable number of surviving offspring and thus, despite the decline in mortality rates, fertility did not fall so as to reach this higher desirable level of surviving offspring.[57] As depicted in Figure 34, the decline in fertility during the demographic transition occurred in a period in which the pattern of declining mortality (and its adverse effect on fertility) maintained the trend that existed in the 140 years that preceded the demographic transition.[58] The reversal in the fertility patterns in England as well as other Western European countries in the 1870s suggests, therefore, that the demographic transition was prompted by a different universal force than the decline in infant and child mortality – a force that reflects a significant change in course prior to the demographic transition.

Furthermore, most relevant from an economic point of view is the cause of the reduction in net fertility (i.e. the number of children reaching adulthood). The decline in

56 As documented by Chesnais (1992), the evolutionary patterns of infant mortality rates and crude birth rates were rather similar.

57 The same theoretical reasoning is applicable for countries in which fertility rates remained stable over this period.

58 One could argue that the decline in mortality was not internalized into the decision of households who had difficulties separating temporary decline from a permanent one. This argument is highly implausible given the fact that mortality declined monotonically for nearly 140 years prior to the demographic transition. It is inconceivable that six generations of households did not update information about mortality rates in their immediate surrounding, while keeping the collective memories about mortality rates two centuries earlier.

the number of surviving offspring that was observed during the demographic transition (e.g., Figure 22) is unlikely to follow from mortality decline. Mortality decline would lead to a reduction in the number of surviving offspring if the following conditions would be satisfied:[59] (i) there exists a precautionary demand for children, i.e., individuals are significantly risk averse with respect to the number of their surviving offspring and thus they hold a buffer stock of children in a high mortality environment – highly improbable from an evolutionary perspective, (ii) risk aversion with respect to consumption is not larger than risk aversion with respect to fertility – evolutionary theory would suggest the opposite), (iii) sequential fertility (i.e., replacement of non-surviving children) is modest,[60] and (iv) parental resources saved from the reduction in the number of children that do not survive to adulthood are not channeled towards childbearing.[61]

The quantitative analysis of Doepke (2005) supports the viewpoint that a decline in infant mortality rates was not the trigger for the decline in net fertility during the demographic transition. Utilizing the mortality and fertility data from England in the time period 1861–1951, he shows that in the absence of changes in other factors, the decline in child mortality in this time period should have resulted in a rise in net fertility rates, in contrast to the evidence. Similar conclusions about the insignificance of the mortality decline for the decline in fertility during the demographic transition is reached in the quantitative analysis of Fernandez-Villaverde (2005).

3.3.2. The rise in the level of income per capita

The rise in income per capita prior to the demographic transition has led some researchers to argue that the demographic transition was triggered by the rise in income per capita and its asymmetric effects on the income of households on the one hand and the opportunity cost of raising children on the other hand.

Becker (1981) advanced the argument that the decline in fertility in the course of the demographic transition is a by-product of the rise in income per capita that preceded the demographic transition. He argues that the rise in income induced a fertility decline because the positive income effect on fertility that was generated by the rise in wages was dominated by the negative substitution effect that was brought about by the rising

[59] In particular, the theoretical analysis of Kalemli-Ozcan (2002) generates a reduction in net fertility in reaction to a decline in mortality assuming (implicitly) that all these conditions are satisfied. Eckstein et al. (1999) argue in their structural quantitative analysis of the demographic transition in Sweden, that mortality decline played a role in the demographic transition. Their underlying theoretical structure, however, requires conditions (iii) and (iv) as well as specific interactions between mortality, wages, and the return to human capital.

[60] Doepke (2005) shows that regardless of the degree of risk aversion, the feasibility of sequential fertility is sufficient to preclude the decline in net fertility in reaction to a decline in mortality.

[61] An additional force that operates against the decline in the number of surviving offspring, as a result of mortality decline, is the physiological constraint on the feasible number of birth per woman. If this constraint is binding for some households in a high mortality regime, a reduction in mortality would operate towards an increase in the number of surviving offspring.

opportunity cost of children. Similarly, Becker and Lewis (1973) argue that the income elasticity with respect to child quality is greater than that with respect to child quantity, and hence a rise in income led to a decline in fertility along with a rise in the investment in each child.

This theory appears counter-factual. It suggests that the timing of the demographic transition across countries would reflect differences in income per capita. However, remarkably, as depicted in Figure 22, the decline in fertility occurred in the same decade across Western European countries that differed significantly in their income per capita. In 1870, on the eve of the demographic transition, England was the richest country in the world, with a GDP per capita of \$3191.[62] In contrast, Germany that experienced the decline in fertility in the same years as England, had in 1870 a GDP per capita of only \$1821 (i.e., 57% of that of England). Sweden's GDP per capita of \$1664 in 1870 was 48% of that of England, and Finland's GDP per capita of \$1140 in 1870 was only 36% of that of England, and nevertheless, their demographic transitions occurred in the same decade as well.[63]

The simultaneity of the demographic transition across Western European countries that differed significantly in their income per capita suggests that the high level of income that was reached by these countries in the Post-Malthusian Regime had a limited role in the demographic transition. Furthermore, cross-section evidence within countries suggests that the elasticity of the number of surviving offspring with respect to income was positive prior to the demographic transition [e.g., Clark and Hamilton (2003)], in contrast to Becker's argument that would require, at least at high income levels, a negative relationship. Moreover, a quantitative analysis of the demographic transition in England, conducted by Fernandez-Villaverde (2005), demonstrates that Becker's theory is counter-factual. In contrast to Becker's theory, the calibration suggests that a rise in income would have resulted in an increase in fertility rates, rather than in the observed decline in fertility.

Interestingly, despite the large differences in the *levels* of income per capita across European countries that experienced the demographic transition in the same time period, the *growth rates* of income per capita of these countries were rather similar, ranging from 1.9% per year in the UK, 2.12% in Norway, 2.17% in Sweden, and 2.87% in Germany, over the period 1870–1913. This observation is consistent with theories that underlined the critical role of the acceleration in technological progress, via its effect on the industrial demand for human capital, on the onset of the demographic transition [e.g., Galor and Weil (2000) and Galor and Moav (2002)].

[62] Source: Maddison (2001). GDP per capita is measured in 1990 international dollars.

[63] One can argue that the income threshold for the domination of the substitution effect differ across these set of countries due to sociocultural factors. However, the likelihood that these differential thresholds were reached within the same decade appears remote.

3.3.3. The rise in the demand for human capital

The rise in the demand for human capital in the second phase of industrialization of less developed economies, as documented in Section 2.3.3, and its close association with the timing of the demographic transitions, has led researchers to argue that the increasing role of human capital in the production process induced households to increase their investment in the human capital of their offspring, leading to the onset of the demographic transition.

Galor and Weil (1999, 2000) argue that the acceleration in the rate of technological progress gradually increased the demand for human capital in the second phase of the Industrial Revolution, inducing parents to invest in the human capital of their offspring.[64] The increase in the rate of technological progress and the associated increase in the demand for human capital brought about two effects on population growth. On the one hand, improved technology eased households' budget constraints and provided more resources for quality as well as quantity of children. On the other hand, it induced a reallocation of these increased resources toward child quality. In the early stages of the transition from the Malthusian Regime, the effect of technological progress on parental income dominated, and population growth as well as the average population quality increased. Ultimately, further increases in the rate of technological progress, that were stimulated by human capital accumulation, induced a reduction in fertility rates, generating a demographic transition in which the rate of population growth declined along with an increase in the average level of education. Thus, consistent with historical evidence, the theory suggests that prior to the demographic transition, population growth increased along with investment in human capital, whereas the demographic transition brought about a decline in population growth along with a further increase in human capital formation.[65]

Galor and Weil's theory suggests that a universal rise in the demand for human capital in the second phase of the Industrial Revolution and the simultaneous increase in educational attainment across Western European countries generated the observed simultaneous onset of the demographic transition across Western European countries that differed significantly in their levels of income per capita. The rise in the demand for human capital in the second phase of the Industrial Revolution (as documented in Section 2.3.3) led to a significant increase in the investment in children's education and therefore to a decline in fertility.

In particular, as depicted in Figure 34, the demographic transition in England was associated with a significant increase in the investment in child quality as reflected by

[64] The effect of an increase in the return to human capital on parental choice of quantity and quality of offspring is discussed in Becker (1981).

[65] Quantitative evidence provided by Greenwood and Seshadri (2002) is supportive of the role of the rise in the demand for skilled labor in the demographic transition in the US. They demonstrate that faster technological progress in an industrial skilled-intensive sector, than that in an unskilled-intensive agricultural sector, generates a demographic pattern that matches the data on the US demographic transition.

years of schooling. Quantitative evidence provided by Doepke (2004) suggests that indeed educational policy that promoted human capital formation played an important role in the demographic transition in England.

Reinforcing mechanisms

The decline in child labor The effect of the rise in the industrial demand for human capital on the reduction in the desirable number of surviving offspring was magnified via its adverse effect on child labor. It gradually increased the wage differential between parental labor and child labor, inducing parents to reduce the number of their children and to enhance the investment in their quality [Hazan and Berdugo (2002)].[66] Moreover, the rise in the importance of human capital in the production process induced industrialists to support education reforms [Galor and Moav (2006)] and thus laws that abolish child labor [Doepke and Zilibotti (2005)], inducing a reduction in the prevalence of child labor and thus in fertility. Doepke (2004) provides quantitative evidence that suggests that indeed child labor law, and to a lesser extent educational policy, played an important role in the demographic transition in England.

The rise in life expectancy The impact of the increase in the demand for human capital on the decline in the desirable number of surviving offspring may have been reinforced by the rise in life expectancy. The decline in mortality rates in developed countries since the 18th century, as depicted in Figure 24, and the recent decline in mortality rates in less developed countries, as depicted in Figure 25, corresponded to a gradual increase in life expectancy. As depicted in Figure 27, life expectancy increased in Western Europe during the 19th century from 36 in 1820 to 46 in 1900, 67 in 1950, and 78 in 1999. In particular, as depicted in Figure 26, life expectancy in England increased at a stable pace from 32 years in the 1720s to about 41 years in the 1870. This pace subsequently increased and life expectancy reached 50 years in 1900, 69 years in 1950, and 77 years in 1999. In less developed economies, in contrast, life expectancy increased markedly in the 20th century.

Despite the gradual rise in life expectancy prior to the demographic transition, investment in human capital was rather insignificant as long as a technological demand for human capital did not emerge. In particular, the increase in life expectancy in England occurred 150 years prior to the demographic transition and may have resulted in a gradual increase in literacy rates, but not at a sufficient level to induce a reduction in fertility. Similarly, the rise in life expectancy in less developed regions in the first half of

[66] The hypothesis of Hazan and Berdugo (2002) is consistent with existing historical evidence. For instance, Horrell and Humphries (1995) suggest, based on data from the United Kingdom, that earnings of children age 10–14 as a percentage of father's earning, declined from the period 1817–1839 to the period 1840–1872 by nearly 50% if the father was employed in a factory. Interestingly, the effect is significantly more pronounced if the father was employed in skilled occupations, reflecting the rise in the relative demand for skilled workers and its effect on the decline in the relative wages of children.

the 20th century has not generated a significant increase in education and a demographic transition.

In light of the technologically-based rise in the demand for human capital in the second phase of the Industrial Revolution, however, the rise in the expected length of productive life has increased the potential rate of return to investments in children's human capital, and thus re-enforced and complemented the inducement for investment in education and the associated reduction in fertility rates.[67]

Changes in marriage institutions The effect of the rise in the demand for human capital on the desirable quality of children, and thus on the decline in fertility was re-inforced by changes in marriage institutions. Gould, Moav and Simhon (2003) suggest that the rise in the demand for human capital increased the demand for educated women who have a comparative advantage in raising quality children, increasing the cost of marriage. Polygamy therefore became less affordable, inducing the transition from polygamy to monogamy, and reinforcing the decline in fertility. Edlund and Lagerlof (2002) suggest that love marriage, as opposed to arranged marriage, redirected the payment for the bride from the parent to the couple, inducing investment and human capital accumulation and thus reinforcing the decline in fertility.

Natural selection and the evolution of preferences for offspring's quality The impact of the increase in the demand for human capital on the decline in the desirable number of surviving offspring may have been magnified by cultural or genetic evolution in the attitude of individuals toward child quality. An evolutionary change in the attitude of individuals towards human capital could have generated a swift response to the increase in demand for human capital, generating a rapid decline in fertility along with an increase in human capital formation.

Human beings, like other species, confront the basic trade-off between offspring's quality and quantity in their implicit Darwinian survival strategies. Preferences for child quantity as well as for child quality reflect the well-known variety in the quantity-quality survival strategies (the K and r strategies) that exists in nature [e.g., MacArthur and Wilson (1967)]. Moreover, the allocation of resources between offspring quantity and quality is subjected to evolutionary changes [Lack (1954)].

[67] This mechanism was outlined by Galor and Weil (1999) and was examined in different settings by Erlich and Lui (1991), Soares (2005), and Hazan and Zoabi (2004). It should be noted, however, that as argued by Moav (2005), the rise in the potential return to investment in child quality due to prolongation of the productive life is not as straightforward as it may appear. It requires that the prolongation of life would affect the return to quality more than the return to quantity. For example, if parents derive utility from the aggregate wage income of their children, prolongation of life would increase the return to quantity and quality symmetrically. Hence, an additional mechanism that would increase the relative complementarity between life expectancy and human capital would be needed to generate the rise in the return to child quality. For instance, Hazan and Zoabi (2004) suggest that an increase in life expectancy, and thus the health of students, enhances the production process of human capital and thus increases the relative return to child quality. Alternatively, Moav (2005) argues that an increase in life expectancy, while having no effect on parental choice between quality and quantity, induces the offspring to increase their own human capital, lowering fertility rates in the next generation due to the comparative advantage of educated parents in educating their children.

Galor and Moav (2002) propose that during the epoch of Malthusian stagnation that characterized most of human existence, individuals with a higher valuation for offspring quality gained an evolutionary advantage and their representation in the population gradually increased. The agricultural revolution facilitated the division of labor and fostered trade relationships across individuals and communities, enhancing the complexity of human interaction and raising the return to human capital. Moreover, the evolution of the human brain in the transition to Homo sapiens and the complementarity between brain capacity and the reward for human capital increased the evolutionary optimal investment in the quality of offspring. The distribution of valuation for quality lagged behind the evolutionary optimal level and offspring of individuals with traits of higher valuation for their offspring's quality generated higher income and, in the Malthusian epoch when income was positively associated with aggregate resources allocated to child rearing, a larger number of offspring. Thus, the trait of higher valuation for quality gained the evolutionary advantage, and the Malthusian pressure gradually increased the representation of individuals whose preferences were biased towards child quality.[68]

This evolutionary process was reinforced by its interaction with economic forces. As the fraction of individuals with high valuation for quality increased, technological progress intensified, raising the rate of return to human capital. The increase in the rate of return to human capital along with the increase in the bias towards quality in the population reinforced the substitution towards child quality, setting the stage for a more rapid decline in fertility along with a significant increase in investment in human capital.

3.3.4. The decline in the gender gap

The rise in women's relative wages in the process of development, and its potential impact on the rise in female labor force participation and the associated decline in fertility rates, have been the center of another theory of the demographic transition that generates the observed hump-shaped relationship between income per capita and population growth, as depicted in Figure 11.

The rise in women's relative wages along with declining fertility rates have been observed in a large number of developed and less developed economies. In particular, as depicted in Figure 35, this pattern is observed in the US during the period 1800–1940.

Galor and Weil (1996) argue that technological progress and capital accumulation increased the relative wages of women in the process of industrialization, triggering the onset of the demographic transition. They maintain that technological progress along with physical capital accumulation complemented mental-intensive tasks rather than

[68] As discussed in Section 5, this mechanism is consistent with the gradual rise in literacy rates prior to the Industrial Revolution, as depicted in Figure 42. It suggests that the increase in the investment in human capital prior to the Industrial Revolution was a reflection of changes in the composition of preference for quality in the population that stimulated investment in human capital, prior to the increase in the demand for human capital in the second phase of the Industrial Revolution.

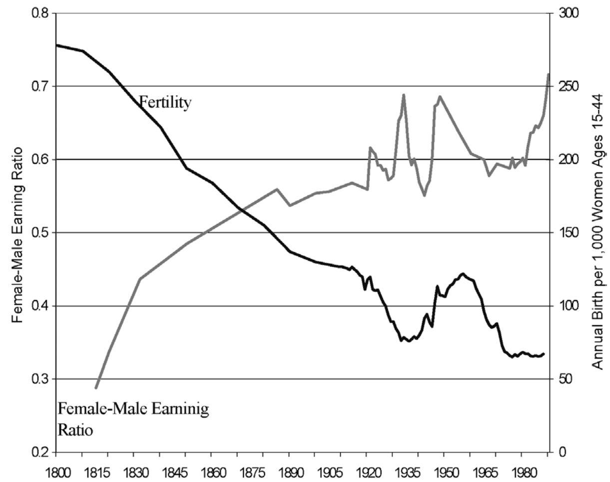

Figure 35. Female relative wages and fertility rates, United States 1800–1990. Sources: U.S. Bureau of the Census (1975) and Hernandez (2000).

physical-intensive tasks (i.e., brain rather than brawn) and thus, in light of the comparative advantage of women in mental-intensive tasks, the demand for women's labor input gradually increased in the industrial sector, increasing the absolute wages of men and women but decreasing the gender wage gap.[69] As long as the rise in women's wages was insufficient to induce a significant increase in women's labor force participation, fertility increased due to the rise in men's wages.[70] Ultimately, however, the rise in women's relative wages was sufficient to induce a significant increase in labor force participation, generating a demographic transition. Unlike the single-parent model in which an increase in income generates conflicting income and substitution effects that cancel one another, if preferences are homothetic, in the two-parent household model, if most of the burden of child rearing is placed on women, a rise in women's relative wages increases the opportunity cost of raising children more than household's income, generating a pressure towards a reduction in fertility.

[69] See Goldin (1990) as well.

[70] The U-shaped pattern of female labor force participation in the process of industrialization follows from the coexistence of an industrial sector and a non-modern production sector that is not fully rival with child rearing. Women's marginal product in the non-modern sector was not affected by capital accumulation in the industrial sector, while women's potential wages in the modern sector increased. In the early process of industrialization, therefore, capital accumulation increased labor productivity in the industrial sector, family income increased via men's wages, while female wages, based on the production of market goods in the home sector did not change. Fertility increased due to the income effect generated by the rise in men's wages, and female labor force participation fell. Eventually, capital accumulation and technological progress in the industrial sector increased female wages sufficiently, inducing a rise in female labor force participation in the industrial sector and reducing fertility.

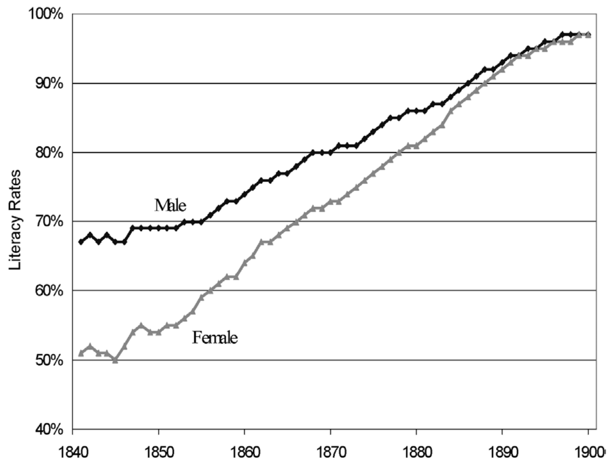

Figure 36. The decline in the human capital gap between male and female: England 1840–1900. Source: Cipolla (1969).

The process of development was associated, in addition, with a gradual decline in the human capital gap between male and female. As depicted in Figure 36, literacy rates among women which were only 76% of those among men in 1840, grew faster in the 19th century reaching men's level in 1900. The rise in the demand for human capital in the process of development induced a gradual improvement in the level of female education, raising the opportunity cost of children more than household's income, and triggering a fertility decline [Lagerlof (2003b)].

3.3.5. Other theories

The old-age security hypothesis The old-age security hypothesis has been proposed as an additional mechanism for the onset of the demographic transition. It suggests that, in the absence of capital markets that permit intertemporal lending and borrowing, children are assets that permit parents to smooth consumption over their lifetime.[71] Hence, the process of development and the establishment of capital markets reduced this motivation for rearing children, contributing to the demographic transition.

Although old-age support is a plausible element that may affect the level of fertility, it appears as a minor force in the context of the demographic transition. First, since there are rare examples in nature of offspring that support their parents in old age, it appears that old-age support could not be the prime motivation for child rearing, and thus its decline is unlikely to be a major force behind a significant reduction in fertility. Second,

[71] See Neher (1971) and Caldwell (1976) for earlier studies and Boldrin and Jones (2002) for a recent quantitative analysis.

the rise in fertility rates prior to the demographic transition, in a period of improvements in credit markets, raises doubts about the significance of this mechanism. In particular, cross-section evidence does not indicate that wealthier individuals that presumably had a better access to credit markets had a smaller number of surviving offspring. On the contrary, fertility rates in the pre-demographic transition era were positively related to levels of skills, income, and wealth [e.g., Clark and Hamilton (2003)].

Exogenous shocks – Luck Becker, Murphy and Tamura (1990) advance a theory that emphasizes the role of a major exogenous shock in triggering the demographic transition, underlying the role of luck in the determination of the relative timing of the demographic transition and thus the wealth of nations.[72] This theory generates predictions that are inconsistent with the observed demographic patterns in the process of development.[73] Existing evidence shows that the process of industrialization and the associated increase in income per capita was accompanied by sharp increase in population growth, prior to their decline in the course of the demographic transition. In their theory, in contrast, a major shock shifts the economy from the basin of attraction of a high-fertility to a low-fertility steady-state equilibrium, generating counter-factually, a monotonic decline in fertility rates along with a monotonic rise in income per capita.

4. Unified growth theory

The inconsistency of exogenous and endogenous growth models with the process of development over most of human history, induced growth theorists to develop a unified theory of economic growth that would capture in a single framework the epoch of Malthusian stagnation, the contemporary era of modern economic growth, and the underlying driving forces that triggered the recent transition between these regimes and the associated phenomenon of the Great Divergence in income per capita across countries.[74]

[72] As they argue on page S13, "Many attempts to explain why some countries have had the best economic performance in the past several centuries give too little attention to accidents and good fortune."

[73] Moreover, the theory suffers from several critical deficiencies in the micro-structure. First, the source of multiplicity of equilibria in their model is the implausible assumption that the return to education increases with the aggregate level of education in society. [Browning, Hansen and Heckman (1999), for instance, show that there is weak empirical evidence in favor of this assumption.] Second, they define erroneously the low-output, high population growth, steady state, as a Malthusian steady-state equilibrium. Their "Malthusian" steady state, however, has none of the features of a Malthusian equilibrium. In contrast to the historical evidence about the Malthusian era, in this equilibrium (in the absence of technological change) population growth rate is not at the reproduction level. Moreover, counter-factually population growth in their "Malthusian" steady state is *higher* than that in the beginning of the demographic transition. Furthermore, a small positive shock to income when the economy is in the "Malthusian" steady state initially decreases fertility in contrast to the central aspect of the Malthusian equilibrium.

[74] Growth theories that capture the endogenous evolution of population, technology, and output from stagnation to sustained economic growth have been established by Galor and Weil (1999, 2000), Galor and Moav

The advancement of unified growth theory was fueled by the conviction that the understanding of the contemporary growth process would be limited and distorted unless growth theory would be based on micro-foundations that would reflect the qualitative aspects of the growth process in its entirety. In particular, the hurdles faced by less developed economies in reaching a state of sustained economic growth would remain obscure unless the origin of the transition of the currently developed economies into a state of sustained economic growth would be identified and its implications would be modified to account for the additional economic forces faced by less developed economies in an interdependent world.[75]

The establishment of a unified growth theory has been a great intellectual challenge, requiring major methodological innovations in the construction of dynamical systems that would capture the complexity that has characterized the evolution of economies from a Malthusian epoch to a state of sustained economic growth. In light of historical evidence that suggests that the take-off from the Malthusian epoch to a state of sustained economic growth, rapid as it may appear, was a gradual process, a unified growth theory in which economies take off gradually but swiftly from an epoch of a stable Malthusian stagnation would necessitate a *gradual* escape from an absorbing (stable) equilibrium, in contradiction to the concept of a stable equilibrium. Thus, it has become apparent that the observed rapid, continuous phase transition would be captured by a single dynamical system, if the set of steady-state equilibria and their stability would be altered qualitatively in the process of development. As proposed by Galor and Weil (2000), during the Malthusian epoch the dynamical system would have to be characterized by a stable Malthusian equilibrium, but ultimately due to the evolution of latent state variables [i.e., the rise in a latent demand for human capital in Galor and Weil (2000) and the evolution of the distribution of genetic characteristics in Galor and Moav (2002)], the Malthusian steady-state equilibrium would vanish endogenously leaving the arena for the gravitational forces of the emerging Modern Growth Regime, and permitting the economy to take off and to converge to a modern-growth steady-state equilibrium.

The observed role of the demographic transition in the shift from the Post-Malthusian Regime to the Sustained Growth Regime, and the associated non-monotonic evolution of the relationship between income per capita and population growth, added to the complexity of the desirable dynamical system. Capturing this additional transition required an endogenous reversal in the positive Malthusian effect of income on population in the second phase of industrialization, providing the reduction in fertility the observed role in the transition to a state of sustained economic growth.

(2002), Hansen and Prescott (2002), Jones (2001), Kogel and Prskawetz (2001), Hazan and Berdugo (2002), Tamura (2002), Lagerlof (2003a, 2003b, 2006), Doepke (2004), Fernandez-Villaverde (2005), as well as others. The Great Divergence and its association with the transition from stagnation to growth was explored in a unified setting by Galor and Mountford (2003).

[75] Although the structure of unified growth theories is based on the experience of Europe and its offshoots, since these were the areas that completed the transition from the Malthusian regime to modern growth, these theories could be modified to account for the incomplete transition of the less developed countries, integrating the significant influence of the import of pre-existing production and health technologies on their process of development.

4.1. From stagnation to growth

The first unified growth theory in which the endogenous evolution of population, technology, and income per capita is consistent with the process of development in the last thousands of years was advanced by Galor and Weil (2000). The theory captures the three regimes that have characterized the process of development as well as the fundamental driving forces that generated the transition from an epoch of Malthusian stagnation to a state of sustained economic growth.

The theory proposes that in early stages of development economies were in the proximity of a stable Malthusian equilibrium. Technology advanced rather slowly, and generated proportional increases in output and population. The inherent positive interaction between population and technology in this epoch, however, gradually increased the pace of technological progress, and due to the delayed adjustment of population, output per capita advanced at a miniscule rate. The slow pace of technological progress in the Malthusian epoch provided a limited scope for human capital in the production process and parents, therefore, had no incentive to reallocate resources towards human capital formation of their offspring.

The Malthusian interaction between technology and population accelerated the pace of technological progress and permitted a take-off to the Post-Malthusian Regime. The expansion of resources was partially counterbalanced by the enlargement of population and the economy was characterized by rapid growth rates of income per capita and population. The acceleration in technological progress ultimately increased the demand for human capital, generating two opposing effects on population growth. On the one hand, it eased households' budget constraints, allowing the allocation of more resources for raising children. On the other hand, it induced a reallocation of resources toward child quality. In the Post-Malthusian Regime, due to the modest demand for human capital, the first effect dominated and the rise in real income permitted households to increase the number as well the quality of their children.

As investment in human capital took place, the Malthusian steady-state equilibrium vanished and the economy started to be attracted by the gravitational forces of the Modern Growth Regime. The interaction between investment in human capital and technological progress generated a virtuous circle: human capital generated faster technological progress, which in turn further raised the demand for human capital, inducing further investment in child quality, and triggering the onset of the demographic transition and the emergence of a state of sustained economic growth.[76]

The theory suggests that the transition from stagnation to growth is an inevitable outcome of the process of development. The inherent Malthusian interaction between the level of technology and the size of the population accelerated the pace of technological progress, and eventually raised the importance of human capital in the production

[76] In less developed countries the stock of human capital determines the pace of adoption of existing technologies, whereas in developed countries it determined the pace of advancement of the technological frontier.

process. The rise in the demand for human capital in the second phase of the industrial revolution and its impact on the formation of human capital as well as on the onset of the demographic transition brought about significant technological advancements along with a reduction in fertility rates and population growth, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita, and paving the way for the emergence of sustained economic growth.

Variations in the timing of the transition from stagnation to growth and thus in economic performance across countries (e.g., England's earlier industrialization in comparison to China) reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, demographic, and cultural factors, trade patterns, colonial status, and public policy. In particular, once a technologically-driven demand for human capital emerged in the second phase of industrialization, the prevalence of human capital promoting institutions determined the extensiveness of human capital formation, the timing of the demographic transition, and the pace of the transition from stagnation to growth. Thus, unified growth theory provides the natural framework of analysis in which variations in the economic performance across countries and regions could be examined based on the effect of variations in educational, institutional, geographical, and cultural factors on the pace of the transition from stagnation to growth.

The unified theory of Galor and Weil is calibrated by Lagerlof (2006). His analysis demonstrates that the theory *quantitatively* replicates the observed time paths of population, income per capita, and human capital, generating (a) the Malthusian oscillations in population and output per capita during the Malthusian epoch, (b) an endogenous take-off from Malthusian stagnation that is associated with an acceleration in technological progress and is accompanied initially by a rapid increase in population growth, and (c) a rise in the demand for human capital, followed by a demographic transition and sustained economic growth.

4.1.1. Central building blocks

The theory is based upon the interaction between several building blocks: the Malthusian elements, the engines of technological progress, the origin of human capital formation, and the determinants of parental choice regarding the quantity and quality of offspring.

The Malthusian elements. Individuals are subjected to subsistence consumption constraint. As long as the constraint is binding, an increase in income results in an increase in population growth. Technological progress, which brings about temporary gains in income per capita, triggers therefore in early stages of development an increase in the size of the population that offsets the gain in income per capita due to the existence of diminishing returns to labor. Growth in income per capita is ultimately generated, despite diminishing returns to labor, since technological progress outpaces the rate of population growth.

The forces behind technological progress in the process of development. The size of the population stimulates technological progress in early stages of development [Boserup (1965)], whereas investment in human capital is the prime engine of technological progress in more advanced stages of development. In the Malthusian era, the technological frontier was not distant from the working environment of most individuals, and the scale of the population affected the rate of technological progress due to its effect on: (a) the supply of innovative ideas, (b) the demand for new technologies, (c) the rate of technological diffusion, (d) the division of labor, and (e) the scope for trade.[77] As the distance between the knowledge of an uneducated individual and the technological frontier gets larger, however, the role of human capital becomes more significant in technological advancement [e.g., Nelson and Phelps (1966)] and individuals with high levels of human capital are more likely to advance the technological frontier.

The origin of human capital formation. The introduction of new technologies is mostly skill-biased although in the long run, these technologies may be either "skill biased" or "skill saving". The "disequilibrium" brought about by technological change raises the demand for human capital.[78] Technological progress reduces the adaptability of existing human capital to the new technological environment and educated individuals have a comparative advantage in adapting to the new technological environment.[79]

The determination of paternal decisions regarding the quantity and quality of their offspring. Individuals choose the number of children and their quality in the face of a constraint on the total amount of time that can be devoted to child-raising and labor market activities. The rise in the demand for human capital induces parents to substitute quality for quantity of children.[80]

4.1.2. The basic structure of the model

Consider an overlapping-generations economy in which activity extends over infinite discrete time. In every period the economy produces a single homogeneous good using

77 The positive effect of the scale of the population on technological progress in the Malthusian epoch is supported by Boserup (1965) and recent evidence by Kremer (1993). The role of the scale of the population in the modern era is, however, controversial. The distance to the technological frontier is significantly larger and population size per-se may have an ambiguous effect on technological progress, if it comes on the account of population quality.

78 If the return to education rises with the *level* of technology the qualitative results would not be affected. Adopting this mechanism, however, would be equivalent to assuming that changes in technology were skill-biased throughout human history. Although on average technological change may have been skilled biased, Galor and Weil's mechanism is consistent with periods in which the characteristics of new technologies could be defined as unskilled-biased, most notably, in the first phase of the industrial revolution.

79 Schultz (1975) cites a wide range of evidence in support of this assumption. More recently, Foster and Rosenzweig (1996) find that technological change during the green revolution in India raised the return to schooling, and that school enrollment rate responded positively to this higher return. The effect of technological transition on the return to human capital is at the center of the theoretical approach of Galor and Tsiddon (1997), Galor and Moav (2000), and Hassler and Rodriguez Mora (2000).

80 The existence of a trade-off between quantity and quality of children is supported empirically [e.g., Rosenzweig and Wolpin (1980) and Hanushek (1992)].

land and efficiency units of labor as inputs. The supply of land is exogenous and fixed over time whereas the number of efficiency units of labor is determined by households' decisions in the preceding period regarding the number and level of human capital of their children.

Production of final output Production occurs according to a constant returns to scale technology that is subject to endogenous technological progress. The output produced at time t, Y_t, is

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

where H_t is the aggregate quantity of efficiency units of labor employed in period t, X is land employed in production in every period t, A_t represents the endogenously determined technological level in period t, and $A_t X$ are therefore the "effective resources" employed in production in period t, and $\alpha \in (0, 1)$.

Output per worker produced at time t, y_t, is

$$y_t = h_t^{\alpha} x_t^{1-\alpha}, \tag{2}$$

where $h_t \equiv H_t/L_t$ is the level of efficiency units of labor per worker, and $x_t \equiv (A_t X)/L_t$ is the level of effective resources per worker at time t.

Suppose that there are no property rights over land.[81] The return to land is therefore zero, and the wage per efficiency unit of labor is equal to the output per efficiency unit of labor:

$$w_t = (x_t/h_t)^{1-\alpha}. \tag{3}$$

Preferences and budget constraints In each period t, a generation that consists of L_t identical individuals joins the labor force. Each individual has a single parent. Members of generation t (those who join the labor force in period t) live for two periods. In the first period of life (childhood), $t - 1$, individuals consume a fraction of their parental unit time endowment. The required time increases with children's quality. In the second period of life (parenthood), t, individuals are endowed with one unit of time, which they allocate between child rearing and labor force participation. They choose the optimal mixture of quantity and quality of (surviving) children and supply their remaining time in the labor market, consuming their wages.

Individuals' preferences are represented by a utility function defined over consumption above a subsistence level $\tilde{c} > 0$, as well as over the quantity and quality (measured

[81] The modeling of the production side is based upon two simplifying assumptions. First, capital is not an input in the production function, and second the return to land is zero. Alternatively it could have been assumed that the economy is small and open to a world capital market in which the interest rate is constant. In this case, the quantity of capital will be set to equalize its marginal product to the interest rate, while the price of land will follow a path such that the total return on land (rent plus net price appreciation) is also equal to the interest rate. Allowing for capital accumulation and property rights over land would complicate the model to the point of intractability, but would not affect the qualitative results.

by human capital) of their (surviving) children:[82]

$$u^t = (c_t)^{1-\gamma}(n_t h_{t+1})^{\gamma}, \quad \gamma \in (0, 1), \tag{4}$$

where c_t is the consumption of individual of generation t, n_t is the number of children of individual t, and h_{t+1} is the level of human capital of each child.[83] The utility function is strictly monotonically increasing and strictly quasi-concave, satisfying the conventional boundary conditions that assure, for a sufficiently high income, the existence of an interior solution for the utility maximization problem. However, for a sufficiently low level of income the subsistence consumption constraint is binding and there is a corner solution with respect to the consumption level.[84]

Individuals choose the number of children and their quality in the face of a constraint on the total amount of time that can be devoted to child-raising and labor market activities. For simplicity, only time is required in order to produce child quantity and quality.[85] Let $\tau + e_{t+1}$ be the time cost for a member i of generation t of raising a child with a level of education (quality) e_{t+1}. That is, τ is the fraction of the individual's unit time endowment that is required in order to raise a child, regardless of quality, and e_{t+1} is the fraction of the individual's unit time endowment that is devoted for the education of each child.[86]

Consider members of generation t who are endowed with h_t efficiency units of labor at time t. Define potential income, z_t, as the earning if the entire time endowment is devoted to labor force participation, earning the competitive market wage, w_t, per efficiency unit. The potential income, $z_t \equiv w_t h_t$, is divided between consumption, c_t, and expenditure on child rearing (quantity as well as quality), evaluated according to the value of the time cost, i.e., $w_t h_t[\tau + e_{t+1}]$, per child. Hence, in the second period of life (parenthood), the individual faces the budget constraint

$$w_t h_t n_t(\tau + e_{t+1}) + c_t \leqslant w_t h_t \equiv z_t. \tag{5}$$

[82] For simplicity parents derive utility from the expected number of surviving offspring and the parental cost of child rearing is associated only with surviving children. A more realistic cost structure would not affect the qualitative features of the theory.

[83] Alternatively, the utility function could have been defined over consumption above subsistence rather than over a consumption set that is truncated from below by the subsistence consumption constraint. In particular, if $u^t = (c_t - \tilde{c})^{(1-\gamma)}(n_t h_{t+1})^{\gamma}$, the qualitative analysis would not be affected, but the complexity of the dynamical system would be greatly enhanced. The income expansion path would be smooth, transforming continuously from being nearly vertical for low levels of potential income to asymptotically horizontal for high levels of potential income. The subsistence consumption constraint would therefore generate the Malthusian effect of income on population growth at low income levels.

[84] The subsistence consumption constraint generates the positive income elasticity of population growth at low income levels, since higher income allows individuals to afford more children.

[85] If both time and goods are required in order to produce child quality, the process we describe would be intensified. As the economy develops and wages increase, the relative cost of a quality child will diminish and individuals will substitute quality for quantity of children.

[86] τ is assumed to be sufficiently small so as to assure that population can have a positive growth rate. That is, $\tau < \gamma$.

The production of human capital Individuals' level of human capital is determined by their quality (education) as well as by the technological environment. Technological progress reduces the adaptability of existing human capital for the new technological environment (the 'erosion effect'). Education, however, lessens the adverse effects of technological progress. That is, skilled individuals have a comparative advantage in adapting to the new technological environment. In particular, the time required for learning the new technology diminishes with the level of education and increases with the rate of technological change.

The level of human capital of children of a member i of generation t, h^i_{t+1}, is an increasing strictly concave function of their parental time investment in education, e^i_{t+1}, and a decreasing strictly convex function of the rate of technological progress, g_{t+1}:

$$h_{t+1} = h(e_{t+1}, g_{t+1}), \tag{6}$$

where $g_{t+1} \equiv (A_{t+1} - A_t)/A_t$. Education lessens the adverse effect of technological progress. That is, technology complements skills in the production of human capital (i.e., $h_{eg}(e^i_{t+1}, g_{t+1}) > 0$). In the absence of investment in quality, each individual has a basic level human capital that is normalized to 1 in a stationary technological environment, i.e., $h(0, 0) = 1$.[87]

Optimization Members of generation t choose the number and quality of their children, and therefore their own consumption, so as to maximize their intertemporal utility function subject to the subsistence consumption constraint. Substituting (5)–(6) into (4), the optimization problem of a member of generation t is:

$$\{n_t, e_{t+1}\} = \operatorname{argmax}\{w_t h_t[1 - n_t(\tau + e_{t+1})]\}^{1-\gamma}\{(n_t h(e_{t+1}, g_{t+1}))\}^{\gamma} \tag{7}$$

subject to:

$$w_t h_t[1 - n_t(\tau + e_{t+1})] \geqslant \tilde{c};$$
$$(n_t, e_{t+1}) \geqslant 0.$$

Hence, as long as potential income at time t is sufficiently high so as to assure that $c_t > \tilde{c}$ (i.e., as long as $z_t \equiv w_t h_t$, is above the level of potential income at which the subsistence constraint is just binding, (i.e., $z_t > \tilde{z} \equiv \tilde{c}/(1 - \gamma)$)), the fraction of time spent by individual t raising children is γ, while $1 - \gamma$ is devoted for labor force participation. However, if $z_t \leqslant \tilde{z}$, the subsistence constraint is binding, the fraction of time necessary to assure subsistence consumption, $\tilde{c}$, is larger than $1-\gamma$ and the fraction

87 For simplicity, investment in quality is not beneficial in a stationary technological environment, i.e., $h_e(0, 0) = 0$, and in the absence of investment in education, there exists a sufficiently rapid technological progress, that due to the erosion effect renders the existing human capital obsolete (i.e., $\lim_{g\to\infty} h(0, g_{t+1}) = 0$). Furthermore, although the potential number of efficiency units of labor is diminished due to the transition from the existing technological state to a superior one (due to the erosion effect), each individual operates with a superior level of technology and the productivity effect is assumed to dominate. That is, $\partial y_t/\partial g_t > 0$.

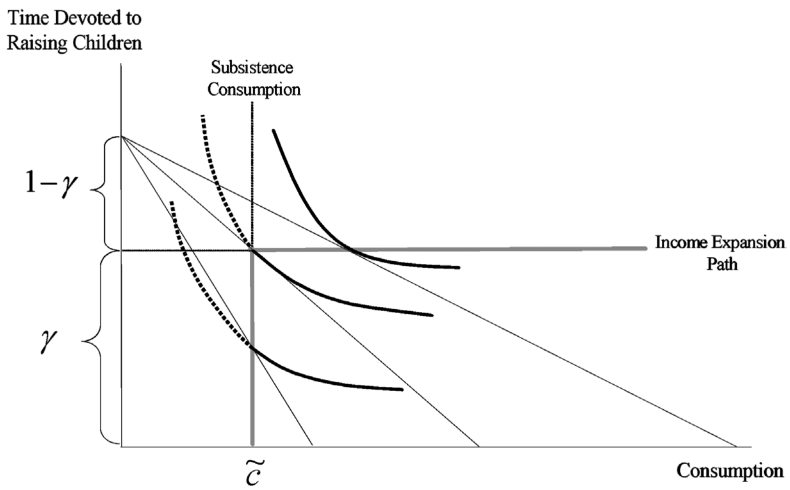

Figure 37. Preferences, constraints, and income expansion path.

of time devoted for child rearing is therefore below γ. That is,

$$n_t[\tau + e_{t+1}] = \begin{cases} \gamma & \text{if } z_t \geqslant \tilde{z}, \\ 1 - [\tilde{c}/w_t h_t] & \text{if } z_t \leqslant \tilde{z}. \end{cases} \tag{8}$$

Figure 37 shows the effect of an increase in potential income z_t on the individual's allocation of time between child rearing and consumption. The income expansion path is vertical as long as the subsistence consumption constraint is binding. As the wage per efficiency unit of labor increases in this income range, the individual can generate the subsistence consumption with a smaller labor force participation and the fraction of time devoted to child rearing increases. Once the level of income is sufficiently high such that the subsistence consumption constraint is not binding, the income expansion path becomes horizontal at a level γ in terms of time devoted to child rearing.

Furthermore, the optimization with respect to e_{t+1} implies that the level of education chosen by members of generation t for their children, e_{t+1}, is an increasing function of g_{t+1}.

$$e_{t+1} = e(g_{t+1}) \begin{cases} = 0 & \text{if } g_{t+1} \leqslant \hat{g}, \\ > 0 & \text{if } g_{t+1} > \hat{g} \end{cases} \tag{9}$$

where $e'(g_{t+1}) > 0$ and $e''(g_{t+1}) < 0 \; \forall g_{t+1} > \hat{g} > 0$.[88] Hence, regardless of whether potential income is above or below $\tilde{z}$, increases in wages will not change the division of child-rearing time between quality and quantity. However, the division between time

[88] $e''(g_{t+1})$ depends upon the third derivatives of the production function of human capital. $e''(g_{t+1})$ is assumed to be concave, which appears plausible.

spent on quality and time spent on quantity is affected by the rate of technological progress, which changes the return to education.

Furthermore, substituting (9) into (8), it follows that n_t is:

$$n_t = \begin{cases} \dfrac{\gamma}{\tau + e(g_{t+1})} \equiv n^b(g_{t+1}) & \text{if } z_t \geqslant \tilde{z}, \\ \dfrac{1 - [\tilde{c}/z_t]}{\tau + e(g_{t+1})} \equiv n^a\big(g_{t+1}, z(e_{t,} g_t, x_t)\big) & \text{if } z_t \leqslant \tilde{z} \end{cases} \tag{10}$$

where $z_t \equiv w_t h_t = z(e_{t,} g_t, x_t)$ as follows from (3) and (6).

Hence, as follows from the properties of $e(g_{t+1})$, $n^b(g_{t+1})$, and $n^a(g_{t+1}, z_t)$:

(a) *An increase in the rate of technological progress reduces the number of children and increases their quality, i.e.,*

$$\partial n_t/\partial g_{t+1} \leqslant 0 \quad \text{and} \quad \partial e_{t+1}/\partial g_{t+1} \geqslant 0.$$

(b) *If the subsistence consumption constraint is binding* (*i.e., if parental potential income is below* $\tilde{z}$), *an increase in parental potential income raises the number of children, but has no effect on their quality, i.e.,*

$$\partial n_t/\partial z_t > 0 \quad \text{and} \quad \partial e_{t+1}/\partial z_t = 0 \quad \text{if } z_t < \tilde{z}.$$

(c) *If the subsistence consumption constraint is not binding* (*i.e., if parental potential income is above* $\tilde{z}$), *an increase in parental potential income does not affect the number of children and their quality, i.e.,*

$$\partial n_t/\partial z_t = \partial e_{t+1}/\partial z_t = 0 \quad \text{if } z_t > \tilde{z}.$$

Technological progress Suppose that technological progress, g_{t+1}, that takes place between periods t and $t+1$ depends upon the education per capita among the working generation in period t, e_t, and the population size in period t, L_t:[89]

$$g_{t+1} \equiv \frac{A_{t+1} - A_t}{A_t} = g(e_t, L_t), \tag{11}$$

where for $e_t \geqslant 0$ and a sufficiently large population size L_t, $g(0, L_t) > 0$, $g_i(e_t, L_t) > 0$, and $g_{ii}(e_t, L_t) < 0$, $i = e_t, L_t$.[90] Hence, for a sufficiently large population size,

[89] While the role of the scale effect in the Malthusian epoch is essential, none of the existing results depend on the presence or the absence of the scale effect in the modern era. The functional form of technological progress given in (11) can capture both the presence and the absence of the scale effect in the modern era. In particular, the scale effect can be removed, once investment in education is positive, assuming for instance that $\lim_{L\to\infty} g_L(e_t, L) = 0$ for $e_t > 0$.

[90] For a sufficiently small population the rate of technological progress is strictly positive only every several periods. Furthermore, the number of periods that pass between two episodes of technological improvement declines with the size of population. These assumptions assure that in early stages of development the economy is in a Malthusian steady state with zero growth rate of output per capita, but ultimately the growth rates is positive and slow. If technological progress would occur in every time period at a pace that increases with the size of population, the growth rate of output per capita would always be positive, despite the adjustment in the size of population.

the rate of technological progress between time t and $t+1$ is a positive, increasing, strictly concave function of the size of adult population and the level of education of the working generation at time t. Furthermore, the rate of technological progress is positive even if labor quality is zero.

The state of technology at time $t+1$, A_{t+1}, is therefore

$$A_{t+1} = (1 + g_{t+1})A_t, \tag{12}$$

where the state of technology at time 0 is given at a level A_0.

Population The size of the adult population at time $t+1$, L_{t+1}, is

$$L_{t+1} = n_t L_t, \tag{13}$$

where L_t is the size the adult of population at time t and n_t is the number of children per person; L_0 is given. Hence, given (10), the evolution of the adult population over time is

$$L_{t+1} = \begin{cases} n^b(g_{t+1})L_t & \text{if } z_t \geqslant \tilde{z}, \\ n^a\big(g_{t+1}, z(e_t, g_t, x_t)\big)L_t & \text{if } z_t \leqslant \tilde{z}. \end{cases} \tag{14}$$

Effective resources The evolution of effective resources per worker, $x_t \equiv (A_t X)/L_t$, is determined by the evolution of population and technology. The level of effective resources per worker in period $t+1$ is

$$x_{t+1} = \frac{1 + g_{t+1}}{n_t} x_t, \tag{15}$$

where $x_0 \equiv A_0 X/L_0$ is given. Furthermore, as follows from (10) and (11)

$$x_{t+1} = \begin{cases} \dfrac{[1 + g(e_t, L_t)][\tau + e(g(e_t, L_t))]}{\gamma} x_t \equiv \phi^b(e_t, L_t)x_t & \text{if } z_t \geqslant \tilde{z}, \\[2ex] \dfrac{[1 + g(e_t, L_t)][\tau + e(g(e_t, L_t))]}{1 - [\tilde{c}/z(e_t, g_t, x_t)]} x_t \equiv \phi^a(e_t, g_t, x_t, L_t)x_t & \text{if } z_t \leqslant \tilde{z}, \end{cases} \tag{16}$$

where $\phi^b_e(e_t, L_t) > 0$ and $\phi^a_x(e_t, g_t, x_t, L_t) < 0$, $\forall e_t \geqslant 0$.

4.1.3. The dynamical system

The development of the economy is fully determined by a sequence $\{e_t, g_t, x_t, L_t\}_{t=0}^{\infty}$ that satisfies (9), (11), (14), and (16), in every period t and describes the joint evolution of education, technological progress, effective resources per capita, and population over time.

The dynamical system is characterized by two regimes. In the first regime the subsistence consumption constraint is binding and the evolution of the economy is governed by a four dimensional non-linear first-order autonomous system:

$$\begin{cases} x_{t+1} = \phi^a(e_t, g_t, x_t, L_t)x_t, \\ e_{t+1} = e\big(g(e_t, L_t)\big), \\ g_{t+1} = g(e_t, L_t), \\ L_{t+1} = n^a\big(g(e_t, L_t), z(e_t, g_t, x_t)\big)L_t \end{cases} \quad \text{for } z_t \leqslant \tilde{z} \tag{17}$$

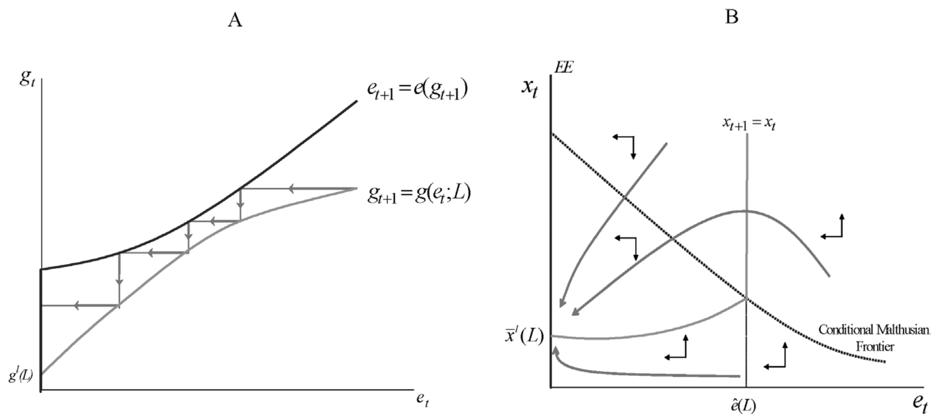

Figure 38. The evolution of technology, g_t, education, e_t, and effective resources, x_t: small population.

where the initial conditions e_0, g_0, x_0, and L_0 are historically given.

In the second regime the subsistence consumption constraint is not binding and the evolution of the economy is governed by a three-dimensional system:

$$\begin{cases} x_{t+1} = \phi^b(e_t, L)x_t, \\ e_{t+1} = e\big(g(e_t, L)\big), \\ L_{t+1} = n^b\big(g(e_t, L_t)\big)L_t \end{cases} \qquad \text{for } z_t \geqslant \tilde{z}. \tag{18}$$

In both regimes, however, the analysis of the dynamical system is greatly simplified by the fact that the evolution of e_t and g_t is independent of whether the subsistence constraint is binding, and by the fact that, for a given population size L, the joint evolution of e_t and g_t is determined independently of x_t. The education level of workers in period $t+1$ depends only on the level of technological progress expected between period t and period $t+1$, while given L, technological progress between periods t and $t+1$ depends only on the level of education of workers in period t. Thus, for a given population size L, the dynamics of technology and education can be analyzed independently of the evolution of resources per capita.

A. The dynamics of technology and education The evolution of technology and education, for a given population size L, is characterized by the sequence $\{g_t, e_t; L\}_{t=0}^{\infty}$ that satisfies in every period t the equations $g_{t+1} = g(e_t; L)$, and $e_{t+1} = e(g_{t+1})$. Although this dynamical sub-system consists of two independent one-dimensional, nonlinear first-order difference equations, it is more revealing to analyze them jointly.

In light of the properties of the functions $e(g_{t+1})$ and $g(e_t; L)$ this dynamical subsystem is characterized by three qualitatively different configurations, which are depicted in Figures 38A, 39A and 40A. The economy shifts endogenously from one configuration to another as population increases and the curve $g(e_t; L)$ shifts upward to account for the effect of an increase in population.

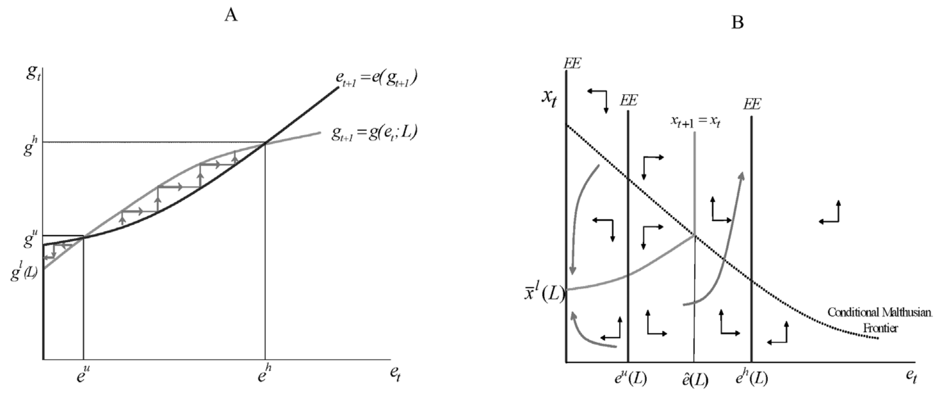

Figure 39. The evolution of technology, g_t, education, e_t, and effective resources, x_t: moderate population.

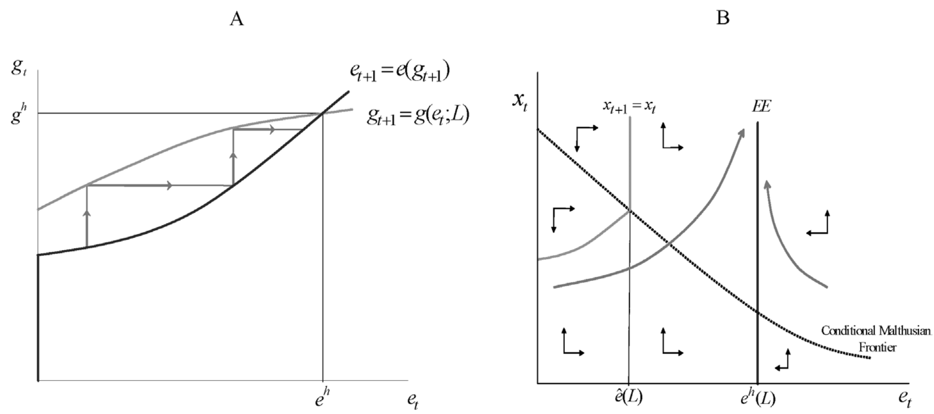

Figure 40. The evolution of technology, g_t, education, e_t, and effective resources, x_t: large population.

In Figure 38A, for a range of small population size, the dynamical system is characterized by globally stable steady-state equilibria, $(\bar{e}(L), \bar{g}(L)) = (0, g^l(L))$, where $g^l(L)$ increases with the size of the population while the level of education remains unchanged. In Figure 39A, for a range of moderate population size, the dynamical system is characterized by three steady-state equilibria, two locally stable steady-state equilibria: $(\bar{e}(L), \bar{g}(L)) = (0, g^l(L))$ and $(\bar{e}(L), \bar{g}(L)) = (e^h(L), g^h(L))$, and an interior unstable steady state $(\bar{e}(L), \bar{g}(L)) = (e^u(L), g^u(L))$, where $(e^h(L), g^h(L))$ and $g^l(L)$ increase monotonically with the size of the population. Finally, in Figure 40A, for a range of large population sizes, the dynamical system is characterized by globally stable steady-state equilibria, $(\bar{e}(L), \bar{g}(L)) = (e^h(L), g^h(L))$, where $e^h(L)$ and $g^h(L)$ increase monotonically with the size of the population.

B. Global dynamics This section analyzes the evolution of the economy from the Malthusian Regime, through the Post-Malthusian Regime, to the demographic transition and the Modern Growth Regime. The global analysis is based on a sequence of phase diagrams that describe the evolution of the system, within each regime, for a given population size, and the transition between these regimes as population increases in the process of development. Each of the phase diagrams is a two-dimensional projection in the plain $(e_t, x_t; L)$, of the three-dimensional system in the space $\{e_t, g_t, x_t; L\}$.

The phase diagrams, depicted in Figures 38B, 39B, and 40B contain three elements: the Malthusian Frontier, which separates the regions in which the subsistence constraint is binding from those where it is not; the *XX* locus, which denotes the set of all triplets $(e_t, g_t, x_t; L)$ for which effective resources per worker are constant; and the *EE* locus, which denotes the set of all pairs $(e_t, g_t; L)$ for which the level of education per worker is constant.

The Malthusian Frontier As was established in (17) and (18) the economy exits from the subsistence consumption regime when potential income, z_t, exceeds the critical level $\tilde{z}$. This switch of regime changes the dimensionality of the dynamical system from four to three.

Let the *Malthusian Frontier* be the set of all triplets of $(e_t, x_t, g_t; L)$ for which individuals' income equal $\tilde{z}$.[91] Using the definitions of z_t and $\tilde{z}$, it follows from (2) and (6) that the The Malthusian Frontier, $MM \equiv \{(e_t, x_t, g_t; L){:}\ x_t^{1-\alpha} h(e_t, g_t)^\alpha = \tilde{c}/(1-\gamma)\}$.

Let the *Conditional Malthusian Frontier* be the set of all pairs $(e_t, x_t; L)$ for which, conditional on a given technological level g_t, individuals incomes equal $\tilde{z}$. Following the definitions of z_t and $\tilde{z}$, Equations (2) and (6) imply that the Conditional Malthusian Frontier, $MM_{|g_t}$, is $MM_{|g_t} \equiv \{(e_t, x_t; L){:}\ x_t^{(1-\alpha)} h(e_t, g_t)^\alpha = \tilde{c}/(1-\gamma) \mid g_t\}$, where *$x_t$ is a decreasing strictly convex function of e_t* along the $MM_{|g_t}$ locus.

Hence, the Conditional Malthusian Frontier, as depicted in Figures 38B–40B, is a strictly convex, downward sloping, curve in the (e_t, x_t) space. Furthermore, it intersects the x_t axis and approaches asymptotically the e_t axis as x_t approaches infinity. The frontier shifts upward as g_t increases in the process of development.

The XX locus Let *XX* be the locus of all triplets $(e_t, g_t, x_t; L)$ such that the effective resources per worker, x_t, is in a steady state: $XX \equiv \{(e_t, x_t, g_t; L){:}\ x_{t+1} = x_t\}$.

As follows from (15), along the *XX* locus the growth rates of population and technology are equal. Above the Malthusian frontier, the fraction of time devoted to child-rearing is independent of the level of effective resources per worker. In this case, the growth rate of population will just be a negative function of the growth rate of technology, since for higher technology growth, parents will spend more of their resources

[91] Below the Malthusian Frontier, the effect of income on fertility will be positive, while above the frontier there will be no effect of income on fertility. Thus, the Malthusian Frontier separates the Malthusian and Post-Malthusian Regimes, on the one hand, from the Modern Growth regime, on the other, and crossing this frontier is associated with the demographic transition.

on child quality and thus less on child quantity. Thus there will be a particular level of technological progress which induces an equal rate of population growth. Since the growth rate of technology is, in turn, a positive function of the level of education, this rate of technology growth will correspond to a particular level of education, denoted $\hat{e}$. Below the Malthusian Frontier, the growth rate of population depends on the level of effective resources per capita, x, as well as on the growth rate of technology. The lower is x, the smaller the fraction of the time endowment devoted to child-rearing, and so the lower is population growth. Thus, below the Malthusian frontier, a lower value of effective resources per capita would imply that lower values of technology growth (and thus education) would be consistent with population growth being equal to technology growth. Thus, as drawn in Figures 38B, 39B, and 40B, lower values of x are associated with lower values of e on the part of the XX locus that is below the Malthusian frontier.

If the subsistence consumption constraint is not binding, it follows from (16) that for $z_t \geqslant \tilde{z}$, there exists a unique value $0 < \hat{e}(L) < e^h(L)$, such that $x_t \in XX$.[92]

$$x_{t+1} - x_t \begin{cases} > 0 & \text{if } e_t > \hat{e}(L), \\ = 0 & \text{if } e_t = \hat{e}(L), \\ < 0 & \text{if } e_t < \hat{e}(L). \end{cases} \tag{19}$$

Hence, the XX Locus, as depicted in Figures 38B, 39B, and 40B is a vertical line above the Conditional Malthusian Frontier at a level $\hat{e}(L)$.

If the subsistence constraint is binding, the evolution of x_t is based upon the rate of technological change, g_t, the effective resources per-worker, x_t as well as the quality of the labor force, e_t. Let $XX_{|g_t}$ be the locus of all pairs $(e_t, x_t; L)$ such that $x_{t+1} = x_t$, for a given level of g_t. That is, $XX_{|g_t} \equiv \{(e_t, x_t; L)\colon\ x_{t+1} = x_t \mid g_t\}$. It follows from (16) that *for* $z_t \leqslant \tilde{z}$, *and for* $0 \leqslant e_t \leqslant \hat{e}(L)$, *there exists a single-valued function* $x_t = x(e_t)$ *such that* $(x(e_t), e_t) \in XX_{|g_t}$.

$$x_{t+1} - x_t \begin{cases} < 0 & \text{if} \quad (e_t, x_t) > \big(e_t, x(e_t)\big) \ \text{for } 0 \leqslant e_t \leqslant \hat{e}(L), \\ = 0 & \text{if} \quad x_t = x(e_t) \qquad\qquad\quad\ \text{for } 0 \leqslant e_t \leqslant \hat{e}(L), \\ > 0 & \text{if} \quad \big[(e_t, x_t) < \big(e_t, x(e_t)\big) \ \text{for } 0 \leqslant e_t \leqslant \hat{e}(L)\big], \ \text{or } \big[e_t > \hat{e}(L)\big]. \end{cases} \tag{20}$$

Hence, without loss of generality, the locus $XX_{|g_t}$ is depicted in Figure 38 as an upward slopping curve in the space (e_t, x_t), defined for $e_t \leqslant \hat{e}(L)$. $XX_{|g_t}$ is strictly below the Conditional Malthusian Frontier for value of $e_t < \hat{e}(L)$, and the two coincides at $\hat{e}(L)$. Moreover, the Conditional Malthusian Frontier, the XX locus, and the $XX_{|g_t}$ locus, coincide at $(\hat{e}(L), \hat{x}(L))$.

[92] In order to simplify the exposition without affecting the qualitative nature of the dynamical system, the parameters of the model are restricted so as to assure that the XX locus is non-empty when $z_t \geqslant \tilde{z}$. That is, $\hat{g} < (\gamma/\tau) - 1 < g(e^h(L_0), L_0)$.

The EE locus Let *EE* be the locus of all triplets $(e_t, g_t, x_t; L)$ such that the quality of labor, e_t, is in a steady state: $EE \equiv \{(e_t, x_t, g_t; L)\colon\ e_{t+1} = e_t\}$.

As follows from (9) and (11), $e_{t+1} = e(g(e_t; L))$ and thus, for a given population size, the steady-state values of e_t are independent of the values of x_t and g_t. The locus *EE* evolves through three phases in the process of development, corresponding to the three phases that describe the evolution of education and technology, as depicted in Figures 38A, 39A, and 40A.

In early stages of development, when population size is sufficiently small, the joint evolution of education and technology is characterized by a globally stable temporary steady-state equilibrium, $(\bar{e}(L), \bar{g}(L)) = (0, g^l(L))$, as depicted in Figure 38A. The corresponding *EE* locus, depicted in the space $(e_t, x_t; L)$ in Figure 38B, is vertical at the level $e = 0$, for a range of small population sizes. Furthermore, for this range, the global dynamics of e_t are given by:

$$e_{t+1} - e_t \begin{cases} = 0 & \text{if } e_t = 0, \\ < 0 & \text{if } e_t > 0. \end{cases} \tag{21}$$

In later stages of development as population size increases sufficiently, the joint evolution of education and technology is characterized by multiple locally stable temporary steady-state equilibria, as depicted in Figure 39A. The corresponding *EE* locus, depicted in the space $(e_t, x_t; L)$ in Figure 39B, consists of three vertical lines corresponding to the three steady-state equilibria for the value of e_t. That is, $e = 0$, $e = e^u(L)$, and $e = e^h(L)$. The vertical line $e = e^u(L)$ shifts leftward, and $e = e^h(L)$ shifts rightward as population size increases. Furthermore, the global dynamics of e_t in this configuration are given by:

$$e_{t+1} - e_t \begin{cases} < 0 & \text{if } 0 < e_t < e^u(L) \text{ or } e_t > e^h(L), \\ = 0 & \text{if } e_t = \big(0, e^u(L), e^h(L)\big), \\ > 0 & \text{if } e^u(L) < e_t < e^h(L). \end{cases} \tag{22}$$

In mature stages of development when population size is sufficiently large, the joint evolution of education and technology is characterized by a globally stable steady-state equilibrium, $(\bar{e}(L), \bar{g}(L)) = (e^h(L), g^h(L))$, as depicted in Figure 40A. The corresponding *EE* locus, as depicted in Figure 40B in the space $(e_t, x_t; L)$, is vertical at the level $e = e^h(L)$. This vertical line shifts rightward as population size increases. Furthermore, the global dynamics of e_t in this configuration are given by:

$$e_{t+1} - e_t \begin{cases} > 0 & \text{if } 0 \leqslant e_t < e^h(L), \\ = 0 & \text{if } e_t = e^h(L), \\ < 0 & \text{if } e_t > e^h(L). \end{cases} \tag{23}$$

Conditional steady-state equilibria In early stages of development, when population size is sufficiently small, the dynamical system, as depicted in Figure 38B, is characterized by a unique and globally stable conditional steady-state equilibrium.[93] It is

[93] Since the dynamical system is discrete, the trajectories implied by the phase diagrams do not necessarily approximate the actual dynamic path, unless the state variables evolve monotonically over time. As shown,

given by a point of intersection between the *EE* locus and the $x_{t+1} = x_t$ locus. That is, conditional on a given technological level, g_t, the Malthusian steady state $(0, \bar{x}(L))$ is globally stable.[94] In later stages of development as population size increases sufficiently, the dynamical system as depicted in Figure 39B is characterized by two conditional steady-state equilibria. The Malthusian conditional steady-state equilibrium is locally stable, whereas the steady-state equilibrium $(e^u(L), x^u(L))$ is a saddle point.[95] For education levels above $e^u(L)$ the system converges to a stationary level of education $e^h(L)$ and possibly to a steady-state *growth rate* of x_t. In mature stages of development when population size is sufficiently large, the system convergences globally to an educational level $e^h(L)$ and possibly to a steady-state *growth rate* of x_t.

4.1.4. From Malthusian stagnation to sustained growth

The economy evolves from an epoch of Malthusian stagnation through the Post-Malthusian Regime to the demographic transition and a Modern Growth Regime. This pattern and the prime driving forces in this transition emerge from the phase diagrams depicted in Figures 38–40.

Consider an economy in early stages of development. Population size is relatively small and the implied slow rate of technological progress does not provide an incentive to invest in the education of children. As depicted in Figure 38A, the interaction between education, e_t, and the rate of technological change, g_t, for a constant small population, L, is characterized by a globally stable steady-state equilibrium $(0, g^l(L))$, where education is zero and the rate of technological progress is slow. This steady-state equilibrium corresponds to a globally stable conditional Malthusian steady-state equilibrium, depicted in Figure 38B. For a constant small population, L, and for a given rate of technological progress, effective resources per capita, as well as the level of education are constant, and output per capita is therefore constant as well. Moreover, shocks to population or resources will be resolved in a Malthusian fashion.

As population grows slowly in reaction to technological progress, the $g(e_{t+1}, L)$ locus, depicted in Figure 38A, gradually shifts upward. The steady-state equilibrium shifts vertically upward reflecting small increments in the rate of technological progress, while the level of education remains constant at a zero level. Similarly, the conditional Malthusian steady-state equilibrium drawn in Figure 38B shifts vertically upward, as the *XX*

the evolution of e_t is monotonic, whereas the evolution and convergence of x_t may be oscillatory. Non-monotonicity in the evolution of x_t may arise only if $e < \hat{e}$ and it does not affect the qualitative description of the system. Furthermore, if $\phi^a_x(e_t, g_t, x_t)x_t > -1$ the conditional dynamical system is locally non-oscillatory. The phase diagrams in Figures 38A–40A are drawn under the assumptions that assure that there are no oscillations.

[94] The local stability of the steady-state equilibrium $(0, \bar{x}(g_t))$ can be derived formally. The eigenvalues of the Jacobian matrix of the conditional dynamical system evaluated at the conditional steady-state equilibrium are both smaller than one (in absolute value).

[95] Convergence to the saddle point takes place only if the level of education is e^u. That is, the saddle path is the entire vertical line that corresponds to $e_t = e^u$.

locus shifts upward. However, output per capita remains initially constant at the subsistence level and eventually creeps forward at a miniscule rate.

Over time, the slow growth in population that takes place in the Malthusian Regime raises the rate of technological progress and shifts the $g(e_{t+1}, L)$ locus in Figure 38A sufficiently upward, generating a qualitative change in the dynamical system depicted in Figure 39A.

The dynamical system of education and technology, for a moderate population, is characterized by multiple, history-dependent, stable steady-state equilibria: the steady-state equilibria $(0, g^l(L))$ and $(e^h(L), g^h(L))$ are locally stable, whereas $(e^u(L), g^u(L))$ is unstable. Given the initial conditions, in the absence of large shocks, the economy remains in the vicinity of the low steady-state equilibrium $(0, g^l(L))$, where education is still zero but the rate of technological progress is moderate. These steady-state equilibria correspond to a multiple locally stable conditional Malthusian steady-state equilibrium, depicted in Figure 39B: Malthusian steady state, characterized by constant resources per capita, slow technological progress, and no education, and a modern-growth steady state, characterized by a high level of education, rapid technological progress, growing income per capita, and moderate population growth. However, since the economy starts in the vicinity of Malthusian steady state, it remains there.[96]

As the rate of technological progress continues to rise in reaction to the increasing population size, the $g(e_{t+1}, L_t)$ locus shifts upward further and ultimately, as depicted in Figure 40, the dynamical system experiences another qualitative change. The Malthusian steady-state equilibrium vanishes, and the economy is characterized by a unique globally stable modern steady-state equilibrium $(e^h(L), g^h(L))$ characterized by high levels of education and technological progress.

Increases in the rate of technological progress and the level of education feed back on each other until the economy converges rapidly to the stable modern steady-state equilibrium. The increase in the pace of technological progress has two opposing effects on the evolution of population. On the one hand, it eases households' budget constraints, allowing the allocation of more resources for raising children. On the other hand, it induces a reallocation of these additional resources toward child quality. In the Post-Malthusian Regime, due to the limited demand for human capital, the first effect dominates and the rise in real income permits households to increase their family size as well the quality of each child. The interaction between investment in human capital and technological progress generates a virtuous circle: human capital formation prompts faster technological progress, further raising the demand for human capital, inducing further investment in child quality, and eventually, as the economy crosses the Malthusian frontier, triggering a demographic transition. The offsetting effect of population

[96] Large shocks to education or technological progress would permit the economy to jump to the modern-growth steady state, but this possibility appears inconsistent with the evidence.

growth on the growth rate of income per capita is eliminated and the interaction between human capital accumulation and technological progress permits a transition to a state of sustained economic growth.

In the Modern Growth Regime, resources per capita rise as technological progress outstrips population growth. Provided that population size is constant (i.e., population growth is zero), the levels of education and technological progress and the growth rates of resources per capita and thus output per capita are constant in the modern-growth steady-state equilibrium.[97]

4.1.5. Major hypotheses and their empirical assessment

The theory generates several hypotheses about the evolution of population, human capital and income per capita in the process of development, underlying the roles of the inherent interaction between population and technology in the Malthusian epoch, as well as the formation of human capital in the second phase of industrialization and the associated demographic transition, in the emergence of a state of sustained economic growth.

Main hypotheses:

(H1) During the initial phases of the Malthusian epoch the growth rate of output per capita is nearly zero and the growth rate of population is miniscule, reflecting the sluggish pace of technological progress and the full adjustment of population to the expansion of resources. In the later phases of the Malthusian epoch, the increasing rate of technological progress, along with the inherent delay in the adjustment of population to the rise in income per capita, generated positive but very small growth rates of output per capita and population.

The hypothesis is consistent with the evidence, provided in Section 2.1, about the evolution of the world economy in the Malthusian epoch. In particular, the infinitesimal pace of resource expansion in the first millennium was reflected in a miniscule increase of the Western European population (from 24.7 million people in 1 AD to 25.4 million in 1000 AD), along with a zero average growth rate of output per capita. The more rapid, but still very slow expansion of resources in the period 1000–1500, permitted the Western European population to grow at a slow average rate of 0.16% per year (from 25 million

[97] If population growth is positive in the Modern Growth Regime, then education and technological progress continue to rise. Similarly, if population growth is negative, they fall. In fact, the model makes no firm prediction about what the growth rate of population will be in the Modern Growth Regime, other than that population growth will fall once the economy exits from the Malthusian region. If the growth rate of technology is related to the growth rate of population, rather than to its level, then there exists a steady state characterized by modern-growth in which the growth rates of population and technology would be constant. Further, such a steady state would be stable: if population growth fell, the rate of technological progress would also fall, inducing a rise in fertility.

in 1000 to 57 million in 1500), along with a slow average growth rate of income per capita at a rate of about 0.13% per year. Resource expansion over the period 1500–1820 had a more significant impact on the Western European population that grew at an average pace of 0.26% per year (from 57 million in 1500 to 133 million in 1820), along with a slightly faster average growth rate of income per capita at a rate of about 0.15% per year.

(H2) The reinforcing interaction between population and technology during the Malthusian epoch increased the size of the population sufficiently so as to support a faster pace of technological progress, generating the transition to the Post-Malthusian Regime. The growth rates of output per capita increased significantly, but the positive Malthusian effect of income per capita on population growth was still maintained, generating a sizable increase in population growth, and offsetting some of the potential gains in income per capita. Moreover, human capital accumulation did not play a significant role in the transition to the Post-Malthusian Regime and thus in the early take-off in the first phase of the Industrial Revolution.

The hypothesis is consistent with the evidence, provided in Section 2.2, about the evolution of the world economy in the Post-Malthusian Regime. In particular, the acceleration in the pace of resource expansion in the period 1820–1870, increased the Western European population from 133 million people in 1820 to 188 million in 1870, while the average growth rate of output per capita over this period increased significantly to 0.95% per year. Furthermore, historical evidence suggests that the industrial demand for human capital increased only in the second phase of the Industrial Revolution. As shown by Clark (2003), human capital formation prior to the Industrial Revolution, as well as in its first phase, occurred in an era in which the market rewards for skill acquisition were at historically low levels.[98]

(H3) The acceleration in the rate of technological progress increased the industrial demand for human capital in the later part of Post-Malthusian Regime (i.e., the second phase of industrialization), inducing significant investment in human capital, and triggering the demographic transition and a rapid pace of economic growth.

This hypothesis is consistent with the evidence, provided in Section 2.3, and partly depicted in Figure 41, about the significant rise in the industrial demand for human capital in the second phase of the Industrial Revolution, the marked increase in educational attainment, and the decline in fertility rates, that occurred in association with the acceleration in the growth rate of output per capita. In particular, the predicted timing of the acceleration in the growth rate of output per capita, is consistent with the revisionist

[98] The rise in human capital formation over this period may reflect religious, cultural and social forces, as well as the rise in valuation for offspring quality due to the forces of natural selection, as discussed in Section 5.2.

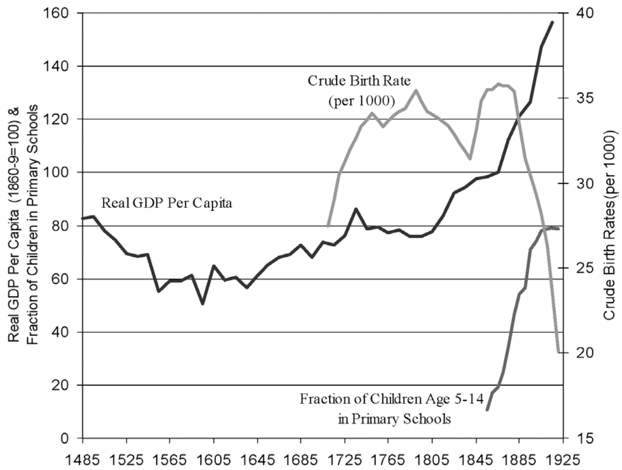

Figure 41. The sharp rise in the growth rate of real GDP per capita and its association with investment in education and fertility decline: England 1485–1920. Sources: Clark (2001), Feinstein (1972), Flora, Kraus and Pfenning (1983), Wrigley and Schofield (1981).

view on the British Industrial Revolution [e.g., Crafts and Harley (1992), Clark (2001), and Voth (2003)] that suggests that the first phase of the Industrial Revolution in England was characterized by a moderate increase in the growth rate of output per capita, whereas the "take-off", as depicted in Figure 41, occurred only in the 1860s.

Furthermore, quantitative analysis of unified growth theories by Doepke (2004), Fernandez-Villaverde (2005), Lagerlof (2006), and Pereira (2003) indeed suggest that the rise in the demand for human capital was a significant force behind the demographic transition and the emergence of a state of sustained economic growth.[99]

Moreover, the theory is consistent with the observed simultaneous onset of the demographic transition across Western European countries that differed significantly in their income per capita. It suggests that a technologically-driven universal rise in the demand for human capital in Western Europe (as documented in Section 2.3.3) generated this simultaneous transition. It should be noted that the lack of clear evidence about the increase in the return to human capital in the second phase of the Industrial Revolution does not indicate the absence of a significant increase in the demand for human capital over this period. The sizable increase in schooling that took place in the 19th century and in particular the introduction of public education that lowered the cost of educa-

[99] The rise in the demand for human capital in Fernandez-Villaverde (2005) is based on capital-skill complementarity, and is indistinguishable from the complementarity between technology and skills (in the short run) that is maintained by Galor and Weil (2000).

tion (e.g., The Education Act of 1870), generated significant increase in the supply of educated workers that may have prevented a rise in the return to education.[100]

(H4) The growth process is characterized by stages of development and it evolves non-linearly. Technological leaders experienced a monotonic increase in the growth rates of their income per capita. Their growth was rather slow in early stages of development, it increased rapidly during the take-off from the Malthusian epoch, and it continued to rise, often stabilizing at higher levels. In contrast, technological followers that made the transition to sustained economic growth, experienced a non-monotonic increase in the growth rates of their income per capita. Their growth rates was rather slow in early stages of development, it increased rapidly in the early stages of the take-off from the Malthusian epoch, boosted by the adoption of technologies from the existing technological frontier. However, once these economies reached the technological frontier, their growth rates dropped to the level of the technological leaders.

(H5) The differential timing of the take-off from stagnation to growth across economies generated convergence clubs characterized by a group of poor countries in the vicinity of the Malthusian equilibrium, a group of rich countries in the vicinity of the sustained growth equilibrium, and a third group in the transition from one club to another.[101]

These hypotheses are consistent with Maddison's (2001) evidence about the growth process in the last 250 years, as well as with contemporary cross section evidence. These studies suggest that the growth process is characterized by multiple growth regimes [e.g., Durlauf and Johnson (1995)] and thus with non-linearities in the evolution of growth rates [e.g., Durlauf and Quah (1999), Bloom, Canning and Sevilla (2003), and Graham and Temple (2004)]. Moreover, this research demonstrates that the evolution of income per-capita across countries is characterized by divergence in the past two centuries along with a tendency towards the emergence of a twin peak distribution [Quah (1996, 1997), Jones (1997), and Pritchett (1997)].[102]

4.2. Complementary theories

Subsequent theories of economic growth in the very long run demonstrate that the unified theory of economic growth can be augmented and fortified by additional characteristics of the transition from stagnation to growth without altering the fundamental

[100] Some of this supply response was a direct reaction of the potential increase in the return to human capital, and thus may only operate to partially offset the increase in the return to human capital, but the reduction in the cost of education via public schooling, generated an additional force that operated towards a reduction in the return to human capital.

[101] For the definition of club convergence see Azariadis (1996) and Galor (1996).

[102] Other studies that focused on nonlinearity of the growth process include Fiaschi and Lavezzi (2003), and Aghion, Howitt and Mayer-Foulkes (2005), whereas other research on the emergence of twin peak includes Feyrer (2003).

hypothesis regarding the central roles played by the emergence of human capital formation and the demographic transition in this process.

Various qualitative and quantitative unified theories explore plausible mechanisms for the emergence of human capital in the second stage of industrialization and the onset of the demographic transition. These theories focus on the rise in the demand for human capital (due to: technological acceleration, capital-skill complementarity, skilled biased technological change, and reallocation of resources towards skilled-intensive sectors), the decline in child and infant mortality, the rise in life expectancy, the emergence of public education, the decline in child labor, as well as cultural and genetic evolution in the valuation of human capital. The theories suggest that indeed the emergence of human capital formation, and the onset of the demographic transition played a central role in the shift from stagnation to growth.

4.2.1. Alternative mechanisms for the emergence of human capital formation

The emergence of human capital formation and its impact on the demographic transition and the technological frontier is a central element in the transition from the Post-Malthusian Regime to the state of sustained economic growth in all unified theories of economic growth in which population, technology and income per capita are endogenously determined.[103] Various complementary mechanisms that generate or reinforce the rise in human capital formation have been proposed and examined quantitatively, demonstrating the robustness and the empirical plausibility of this central hypothesis.

The rise in the industrial demand for human capital The rise in industrial demand for human capital in advanced stages of industrialization, as documented in Section 2.3.3, and its impact on human capital formation led researchers to incorporate it as a central feature in unified theories of economic growth.

The link between industrial development and the demand for human capital have been modeled in various complementary ways. Galor and Weil (2000) modeled the rise in the demand for human capital as an outcome of the acceleration in technological progress, underlying the role of educated individuals in coping with a rapidly changing technological environment. Their mechanism is founded on the premise that the introduction of new technologies increases the demand for skilled labor in the short-run, although in some periods the characteristics of new technologies may be complementarity to unskilled labor, as was the case in the first phase of the Industrial Revolution.[104]

Subsequent unified theories of economic growth have demonstrated that the rise in the demand for human capital in association with advanced stages of industrialization could emerge from alternative mechanisms, without altering the fundamental insights of

[103] Even in the multiple-regime structure of Lucas (2002) a shock to the return to human capital is suggested in order to generate the switch from the Malthusian Regime to the Modern Growth Regime.

[104] Evidence for the complementarity between technological progress (or capital) and skills is provided by Goldin and Katz (1998) and Duffy, Papageorgiou and Perez-Sebastian (2004).

the theory. Doepke (2004) constructs his unified theory on the basis of a rising *level* of skilled-intensive industrial technology, Fernandez-Villaverde (2005) bases his quantitative unified theory on capital-skill complementarity, and Galor and Mountford (2003) generate the rise in the demand for human capital via an increased specialization in the production of skilled-intensive goods, due to international trade.

The rise in the demand for human capital stimulated public policy designed to enhance investment in human capital [Galor and Moav (2006)]. In particular, as established in the quantitative unified theory of Doepke (2004), educational policy and child labor laws in England played an important role in human capital formation and the demographic transition.

Mortality decline, the rise in life expectancy, and human capital formation Several unified theories of economic growth demonstrate that the basic mechanism for the emergence of human capital proposed by Galor and Weil (2000) can be augmented and reinforced by the incorporation of the effect of the decline in mortality rates and the rise in life expectancy (as documented in Section 2.3.2) on the rise in human capital formation, the decline in the desirable number of surviving offspring, and thus on the transition from stagnation to growth.[105]

The significant decline in mortality rates in developed countries since the 18th century, as depicted in Figure 24, and the recent decline in mortality rates in less developed countries, as depicted in Figure 25, corresponded to an acceleration in the rise in life expectancy and a significant rise in human capital formation, towards the end of the 19th century in developed countries (Figures 26 and 28), and towards the middle of the 20th century in less developed countries (Figures 27 and 31). The rise in the expected length of the productive life may have increased the potential rate of return to investments in children's human capital, and thus could have induced an increase in human capital formation along with a decline in fertility. However, despite the gradual rise in life expectancy in developed and less developed countries, investment in human capital has been insignificant as long as the industrial demand for human capital has not emerged. Thus, it appears that the industrial demand for human capital, as documented in Section 2.3.3, provided the inducement for investment in education and the associated reduction in fertility rates, whereas the prolongation of life may have re-enforced and complemented this process.

Galor and Weil (1999) argue that the Malthusian interaction between technology and population accelerated the pace of technological progress, improving industrial technology as well as medical and health technologies. Consistent with the historical evidence provided in Section 2.3.3, the improvements in the industrial technology increased the demand for human capital, whereas the development of medical technology and health infrastructure generated a significant rise in life expectancy. The expected rate of return

[105] The effect of an increase in life expectancy on the incentive of individuals to invest in their human capital is well established since Ben Porath (1967).

to human capital investment increased therefore due to the prolongation of life, as well as the rise in industrial demand for human capital, enhancing the positive interaction between schooling and technological progress, bringing about a demographic transition and the state of sustained economic growth.

Various theories formally examined mechanisms that capture the interaction between human capital formation, the decline in mortality rate, and the rise in life expectancy, in the process of development.[106] Cervellati and Sunde (2005) and Boucekkine, de la Croix and Licandro (2003) focus on the plausible role of the reinforcing interaction between life expectancy and human capital formation in the transition from stagnation to growth, abstracting from its effect on fertility decisions. Others suggest that a decline in mortality rates increased the return to investment in human capital via: (a) prolongation of life [Soares (2005)], (b) increased population density and thus the efficiency of the transmission of human capital [Lagerlof (2003a)], (c) increased population growth and the advancement of skill-biased technologies [Weisdorf (2004)], and (d) improved healthiness and thus the capacity to absorb human capital [Hazan and Zoabi (2004)], generating a substitution of quality for quantity, a demographic transition and a transition to a state of sustained economic growth.[107]

Capital-skill complementarity and the emerging incentives for capitalists to support education reforms The accumulation of physical capital in the early stages of industrialization enhanced the importance of human capital in the production process and generated an incentive for the capitalists to support the provision of public education for the masses.[108] Consistent with the evidence provided in Section 2.3.3, Galor and Moav (2006) argue that due to capital-skill complementarity, the accumulation of physical capital by the capitalists in the first phase of the Industrial Revolution increased the importance of human capital in sustaining their rate of return to physical capital, inducing capitalists to support the provision of public education for the masses.[109]

[106] As argued in Section 3.3.1, qualitative and quantitative evidence do not lend credence to the theory that a decline in infant and child mortality rates *triggered* the decline in the number of surviving offspring and the increase in the investment in offspring's human capital.

[107] See Iyigun (2005) as well.

[108] Alternatively, others argued that increased polarization induced the elite to enact costly educational reforms. Grossman and Kim (1999) argue that education decreases predation, and Bowles and Gintis (1975) suggest that educational reforms are designed to *sustain* the existing social order, by displacing social problems into the school system. In contrast, Bourguignon and Verdier (2000) suggest that if political participation is determined by the education (socioeconomic status) of citizens, the elite may not find it beneficial to subsidize universal public education despite the existence of positive externalities from human capital.

[109] Since firms have limited incentive to invest in the general human capital of their workers, in the presence of credit market imperfections, the level of education would be suboptimal unless it would be financed publicly [Galor and Zeira (1993), Durlauf (1996), Fernandez and Rogerson (1996), Benabou (2000), Mookherjee and Ray (2003), and Galor and Moav (2004a)]. Moreover, a mixture of vocational and general education would be enacted [Bertocchi and Spagat (2004)].

The decline in child labor Other theories that focused on the transition from stagnation to growth suggest that the central role of human capital formation and the demographic transition can be augmented and reinforced by the incorporation of the adverse effect of the rise in the demand for human capital on child labor. Hazan and Berdugo (2002) suggest that technological change increased the wage differential between parental labor and child labor inducing parents to reduce the number of their children and to further invest in their quality, stimulating human capital formation, a demographic transition, and a shift to a state of sustained economic growth.[110] Alternatively, the rise in the importance of human capital in the production process, as documented in Section 2.3.3, induced industrialists to support laws that abolish child labor [Doepke and Zilibotti (2005)], inducing a reduction in child labor, and stimulating human capital formation and a demographic transition.

Cultural and genetic evolution of the valuation of human capital Human capital formation and its impact on the decline in the desirable number of surviving offspring may have been reinforced by cultural or genetic evolution in the attitude of individuals towards human capital formation. Consistent with the gradual rise in literacy rates prior to the Industrial Revolution, Galor and Moav (2002) argue that during the epoch of Malthusian stagnation that had characterized most of human existence, individuals with a higher valuation for offspring quality generated an evolutionary advantage and their representation in the population gradually increased. The increase in the rate of return to human capital along with the increase in the bias towards quality in the population reinforced the substitution towards child quality, setting the stage for a significant increase in human capital formation along with a rapid decline in fertility.

4.2.2. Alternative triggers for the demographic transition

The demographic transition that separated the Post-Malthusian Regime and the Sustained Growth Regime is a central element in quantitative and qualitative unified theories of economic growth in which population, technology, and income per capita are endogenously determined. As discussed in Section 2.3.2, the demographic transition brought about a reversal in the unprecedented increase in population growth that occurred during the Post-Malthusian Regime, leading to a significant reduction in fertility rates and population growth in various regions of the world, and enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of output per capita.[111] The demographic transition enhanced the growth process reducing the dilution of the stock of capital and land, enhancing the investment

[110] The decline in the relative wages of children is documented empirically [e.g., Horrell and Humphries (1995)].

[111] Demographic shocks generate a significant effect on economic growth in Connolly and Peretto (2003) as well.

in the human capital of the population, and altering the age distribution of the population, increasing temporarily the size of the labor force relative to the population as a whole.[112]

Various complementary mechanisms for the demographic transition have been proposed in the context of unified growth theories, establishing, theoretically and quantitatively the importance of this central hypothesis in the understanding of the transition from stagnation to growth.[113]

The emergence of human capital formation The gradual rise in the demand for human capital in the process of industrialization, as documented in Section 2.3.3, and its close association with the timing of the demographic transition, has led researchers to argue that the increasing role of human capital in the production process induced households to increase their investment in the human capital of their offspring, eventually leading to the onset of the demographic transition.

The link between the rise in the demand for human capital and the demographic transition has been modeled in various complementary ways. Galor and Weil (2000) argue that the gradual rise in the demand for human capital induced parents to invest in the human capital of their offspring. In the early stages of the transition from the Malthusian Regime, the effect of technological progress on parental income permitted the rise in population growth as well as the average population quality. Further increases in the rate of technological progress ultimately induced a reduction in fertility rates, generating a demographic transition in which the rate of population growth declined along with an increase in the average level of education. Thus, consistent with historical evidence, the theory suggests that prior to the demographic transition, population growth increased along with investment in human capital, whereas the demographic transition brought about a decline in population growth along with a further increase in human capital formation.

Other theories examine mechanisms that could have reinforced the effect of the rise in the demand for human capital on the demographic transition and the emergence of sustained economic growth, via the decline in benefits from child labor [Hazan and Berdugo (2002), Doepke (2004), and Doepke and Zilibotti (2005)], the decline in mortality rates and the rise in life expectancy [Jones (2001), Lagerlof (2003a), Weisdorf (2004), and Tamura (2004)], and the evolution of preferences for offspring quality [Galor and Moav (2002)], as discussed in Section 3.3. The quantitative examination of Doepke (2004), Fernandez-Villaverde (2005), and Lagerlof (2006) confirm the significance of these channels in originating the demographic transition and the shift from stagnation to growth.

112 Bloom and Williamson (1998) suggest that the cohort effect played a significant role in the growth "miracle" of East Asian countries in the time period 1960–1990.

113 As established in Section 3.3, some mechanisms that were proposed for the demographic transition, such as the decline in infant and child mortality, as well as the rise in income, are inconsistent with the evidence. These mechanisms were therefore excluded in the formulation of unified growth theory.

The decline in the gender gap The observed decline in the gender gap in the process of development, as discussed in Section 3.3.4, is an alternative mechanism that could have triggered a demographic transition and human capital formation, as elaborated in other unified theories.

A unified theory based upon the decline in the gender wage gap, the associated increase in female labor force participation, and fertility decline was explored by Galor and Weil (1996, 1999), as elaborated in Section 3.3.4. They argue that technological progress and capital accumulation complemented mental intensive tasks and substituted for physical-intensive tasks in the industrial production process. In light of the comparative physiological advantage of men in physical-intensive tasks and women in mental-intensive tasks, the demand for women's labor input gradually increased in the industrial sector, decreasing monotonically the wage deferential between men and women. In early stages of industrialization, wages of men and women increased, but the rise in female's relative wages was insufficient to induce a significant increase in women's labor force participation. Fertility, therefore increased due to the income effect that was generated by the rise in men's absolute wages. Ultimately, however, the rise in women's relative wages was sufficient to induce a significant increase in labor force participation, increasing the cost of child rearing proportionally more than households' income and triggering a demographic transition and a shift from stagnation to growth.

Similarly, a transition from stagnation to growth based upon a declining gender gap in human capital formation was proposed by Lagerlof (2003b). He argues that the process of development permitted a gradual improvement in the relative level of female education, raising the opportunity cost of children and initiating a fertility decline and a transition from stagnation to growth.[114]

4.2.3. Alternative modeling of the transition from agricultural to industrial economy

The shift from agriculture to industry that accompanied the transition from stagnation to growth, as described in Section 2.2.3, influenced the specifications of the production structure of most unified theories of economic growth. In some unified theories [e.g., Galor and Weil (2000)] the structure of the aggregate production function and its interaction with technological progress, reflects implicitly a transition from an agricultural to an industrial economy in the process of development. In other theories [e.g., Hansen and Prescott (2002), Kogel and Prskawetz (2001), Hazan and Berdugo (2002),

[114] Alternatively, one could have adopted the mechanism proposed by Fernandez, Fogli and Olivetti (2004) and Greenwood, Seshadri and Yorukoglu (2005) for the gradual decline in the education gap and labor force participation between men and women. The former suggests that it reflects a dynamic process in which the home experience of sons of working, educated mothers makes them more likely to prefer educated and working wives, inducing a gradual increase in investment in education as well as in labor force participation among women. The latter suggests that it reflects the reduction in the cost of machines that could substitute for women's labor at home.

Tamura (2002), Doepke (2004), Galor and Mountford (2003), Bertocchi (2003), and Galor, Moav and Vollrath (2003)] the process of development generates explicitly a transition from an agricultural sector to an industrial sector.

In Galor and Weil (2000) production occurs according to a constant returns to scale technology that is subject to endogenous technological progress. The output produced at time t, is $Y_t = H_t^{\alpha}(A_t X)^{1-\alpha}$, where H_t is the aggregate quantity of efficiency units of labor employed in period t, X is land employed in production in every period t, and A_t represents the endogenously determined technological level in period t. Hence $A_t X$ are the "effective resources" employed in production in period t. In early stages of development, the economy is agricultural (i.e., the fixed amount of land is a binding constraint on the expansion of the economy). Population growth reduces labor productivity since the rate of technological progress is not sufficiently high to compensate for the land constraint. However, as the rate of technological progress intensifies in the process of development, the economy becomes industrial. Technological progress counterbalances the land constraint, the role of land gradually diminishes, and "effective resources" are expanding at a rate that permit sustained economic growth.

Hansen and Prescott (2002) develop a model that captures explicitly the shift from an agricultural sector to an industrial sector in the transition from stagnation to growth. In early stages of development, the industrial technology is not sufficiently productive and production takes place solely in an agricultural sector, where population growth (that is *assumed* to increase with income) offsets increases in productivity. An *exogenous* technological progress in the latent constant returns to scale industrial technology ultimately makes the industrial sector economically viable and the economy gradually shifts resources from the agricultural sector to the industrial one. Assuming that the positive effect of income on population is reversed in this transition, the rise in productivity in the industrial sector is not counterbalanced by population growth, permitting the transition to a state of sustained economic growth.

Unlike most unified theories in which the time paths of technological progress, population growth, and human capital formation are endogenously determined on the basis on explicit micro-foundations, in Hansen and Prescott (2002) technological progress is exogenous, population growth is assumed to follow the hump-shaped pattern that is observed over human history, and human capital formation (that appears central for the transition) is absent. Based upon this reduced-form approach, they demonstrate that there exists a rate of technological progress in the latent industrial sector, and a well specified reduced-form relationship between population and output, under which the economy will shift from Malthusian stagnation to sustained economic growth. This reduced-form analysis, however, does not advance us in identifying the underlying micro-foundations that led to the transition from stagnation to growth – the ultimate goal of unified growth theory.

In accordance with the main hypothesis of Galor and Weil (2000), the transition from stagnation to growth in Hansen and Prescott (2002) is associated with an increase in productivity growth in the economy as a whole. Although productivity growth within each sector is constant, a shift towards the higher productivity growth sector, that is associated with the transition, increases the productivity in the economy, permitting the take-off to a state of sustained economic growth. Moreover, although formally the transition from stagnation to growth in Hansen and Prescott (2002) does not rely on the forces of human capital, if micro-foundations for the critical factors behind the transition would have been properly established, human capital would have played a central role in sustaining the rate of technological progress in the industrial sector and in generating the demographic transition. The lack of an explicit role for human capital in their structure is an artifact of the reduced-form analysis that does not identify the economic factors behind the process of technological change in the latent industrial technology, as well as the forces behind the assumed hump-shaped pattern of population dynamics.[115] Thus, Hansen–Prescott's explicit modeling of the transition from agriculture to industry does not alter the basic insights from the framework of Galor and Weil – a rise in productivity as well as a rise in the demand for human capital is critical for the transition from stagnation to growth.

A two-sector framework is instrumental in the exploration of the effect of international trade on the differential timing of the transition from stagnation to growth and the associate phenomenon of the great divergence [Galor and Mountford (2003)], as discussed in Section 6.1. Moreover, a two-sector setting would be necessary in order to examine the incentives of land owners to block education reforms and the process of industrialization [Galor, Moav and Vollrath (2003)], as well as the evolution of property rights and their impact on political reforms [Bertocchi (2003)].

5. Unified evolutionary growth theory

5.1. Human evolution and economic development

This section explores the dynamic interaction between human evolution and the process of economic development. It focuses on a recent development of a unified evolutionary growth theory that, based on historical evidence, generates innovative hypotheses about the interplay between the process of development and human evolution, shedding new

[115] The demographic pattern assumed by Hansen and Prescott (2002) is critical for the transition from Malthusian stagnation to sustained economic growth. Moreover, human capital appears to be the implicit underlaying force behind their transition as well. In order to generate the features of the Malthusian economy, they set the pace of population growth during this epoch at a level that would generate zero growth rate of output per capita. In the absence of change in this pattern of population growth, output per capita growth is not feasible. Thus, in order to generate output growth along with population growth during the take-off, they assume that at a certain stage the rise in population growth did not fully offset the rise in output (suggesting that parental resources were channeled partly towards child quality in light of a rising demand for human capital). It should be noted that a biological upper bound on the level of fertility that could have generated a take-off mechanically (in an environment characterized by technological change) is inconsistent with the evidence that show that in Western Europe fertility rates continued to increase for nearly a century after the initial take-off.

light on the origin of modern economic growth and the observed intricate evolution of health, life expectancy, human capital, and population growth since the Neolithic Revolution.

Unified evolutionary growth theory advances an analytical methodology that is designed to capture the complexity of the dynamic interaction between the economic, social, and behavioral aspects of the process of development and evolutionary processes in the human population. The proposed hybrid between Darwinian methodology and the methodology of unified theories of economic growth permits the exploration of the dynamic reciprocal interaction between the evolution of the distribution of genetic traits and the process of economic development. It captures potential non-monotonic evolutionary processes that were triggered by major socioeconomic transitions, and may have played a significant role in the observed time path of health, life expectancy, human capital, and population growth.[116]

Humans were subjected to persistent struggle for existence for most of their history. The Malthusian pressure affected the size of the population (as established in Section 2.1.2), and conceivably via natural selection, the composition of the population as well. Lineages of individuals whose traits were complementary to the economic environment generated higher income, and thus a larger number of surviving offspring, and the representation of their traits in the population gradually increased, contributing significantly to the process of development and the take-off from an epoch of Malthusian stagnation to a state of sustained economic growth.

Evidence suggests that evolutionary processes in the composition of existing genetic traits may be rather rapid and the time period between the Neolithic Revolution and the Industrial Revolution that lasted about 10,000 years is sufficient for significant evolutionary changes. There are numerous examples of rapid evolutionary changes among various species.[117] In particular, evidence establishes that evolutionary changes occurred in the Homo sapiens within the time period that is the focus of the analysis. For instance, lactose tolerance was developed among European and Near Easterners since

[116] The conventional methodology of *evolutionary stable strategies* that has been employed in various fields of economics, ignores the dynamics of the evolutionary process, and is thus inappropriate for the understanding of the "short-run" interaction between human evolution and the process of development since the Neolithic revolution. As will become apparent the dynamics of the evolutionary process are essential for the understanding of the interaction between human evolution and economic growth since the Neolithic revolution – a period marked by fundamental non-monotonic evolutionary processes.

[117] The color change that peppered moths underwent during the 19th century is a classic example of evolution in nature [see Kettlewell (1973)]. Before the Industrial Revolution light-colored English peppered moths blended with the lichen-covered bark of trees. By the end of the 19th century a black variant of the moth, first recorded in 1848, became far more prevalent than the lighter varieties in areas in which industrial carbon removed the lichen and changed the background color. Hence, a significant evolutionary change occurred within a time period which corresponds to only hundreds of generations. Moreover, evidence from Daphne Major in the Galapagos suggests that significant evolutionary changes in the distribution of traits among Darwin's Finches occurred within few generations due to a major drought [Grant and Grant (1989)]. Other evidence, including the dramatic changes in the color patterns of guppies within 15 generations due to changes in the population of predators, are surveyed by Endler (1986).

the domestication of dairy animals in the course of the Neolithic revolution, whereas in regions that were exposed to dairy animals in later stages, a larger proportion of the adult population suffers from lactose intolerance. Furthermore, genetic immunity to malaria provided by the sickle cell trait is prevalent among descendants of Africans whose engagement in agriculture improved the breeding ground for mosquitoes and thereby raised the incidence of malaria, whereas this trait is absent among descendants of nearby populations that have not made the transition to agriculture.[118]

Despite the existence of compelling evidence about the interaction between human evolution and the process of economic development, only few attempts have been made to explore the reciprocal interaction between the process of development and human evolution – an exploration that is likely to revolutionize our understanding of the process of economic development as well as the process of human evolution.[119] Galor and Moav (2002) explore the effect of the Malthusian epoch on the evolution of valuation for offspring quality and its role in the transition from stagnation to growth. Ofek (2001) and Saint-Paul (2003) examine the effect of the emergence of markets on the evolution of heterogeneity in the human population. Clark and Hamilton (2003) analyze the relationship between the evolution of time preference and the process of development. Borghans, Borghans and ter-Weel (2004) explore the effect of human cooperation on the evolution of Major Histocompatibility Complex (MHC), and Galor and Moav (2004b) examine the effect of the process of development on the evolution of life expectancy.

5.2. Natural selection and the origin of economic growth

The first evolutionary growth theory that captures the interplay between human evolution and the process of economic development in various phases of development, was developed by Galor and Moav (2002). The theory suggests that during the epoch of Malthusian stagnation that had characterized most of human existence, traits of higher valuation for offspring quality generated an evolutionary advantage and their representation in the population gradually increased. This selection process and its effect on investment in human capital stimulated technological progress and initiated a reinforcing interaction between investment in human capital and technological progress that brought about the demographic transition and the state of sustained economic growth.[120]

[118] See Livingston (1958), Weisenfeld (1975) and Durham (1982).

[119] The evolution of a wide range of attributes such as time preference, risk aversion, and altruism, in a *given* economic environment, has been extensively explored in the economic literature, as surveyed by Bowles (1998) and Robson (2001).

[120] The theory is applicable for either social or genetic intergenerational transmission of traits. A cultural transmission is likely to be more rapid and may govern some of the observed differences in fertility rates across regions. The interaction between cultural and genetic evolution is explored by Boyd and Richardson (1985) and Cavalli-Sforza and Feldman (1981), and a cultural transmission of preferences is examined by Bisin and Verdier (2000).

The theory suggests that during the Malthusian epoch, the distribution of valuation for quality lagged behind the evolutionary optimal level. The evolution of the human brain in the transition to Homo sapiens and the complementarity between brain capacity and the reward for human capital has increased the evolutionary optimal investment in the quality of offspring (i.e., the level that maximizes reproduction success).[121] Moreover, the increase in the return to human capital in the aftermath of the Neolithic Revolution increased the evolutionary optimal level of investment in child quality. The agricultural revolution facilitated the division of labor and fostered trade relationships across individuals and communities, enhancing the complexity of human interaction and raising the return to human capital. Thus, individuals with traits of higher valuation for offspring's quality generated higher income and, in the Malthusian epoch when child rearing was positively affected by aggregate resources, a larger number of offspring. Traits of higher valuation for quality gained the evolutionary advantage and their representation in the population increased over time.

The Malthusian pressure increased the representation of individuals whose preferences are biased towards child quality, positively affecting investment in human capital and ultimately the rate of technological progress. In early stages of development, the proportion of individuals with higher valuation for quality was relatively low, investment in human capital was minimal, resources above subsistence were devoted primarily to child rearing, and the rate of technological progress was rather slow. Technological progress therefore generated proportional increases in output and population and the economy was in the vicinity of a Malthusian equilibrium, where income per capita is constant, but the proportion of individuals with high valuation for quality was growing over time.[122]

As the fraction of individuals with high valuation for quality continued to increase, technological progress intensified, raising the rate of return to human capital. The increase in the rate of technological progress generated two effects on the size and the quality of the population. On the one hand, improved technology eased households' budget constraints and provided more resources for quality as well as quantity of children. On the other hand, it induced a reallocation of these increased resources toward child quality. In the early stages of the transition from the Malthusian Regime, the

[121] The evolutionary process in valuation for quality that was triggered by the evolution of the human brain has not reached a new evolutionary stable state prior to the Neolithic period because of the equality that characterized resource allocation among hunter-gatherers tribes. Given this tribal structure, a latent attribute of preferences for quality, unlike observable attributes such as strength and intelligence, could not generate a disproportionate access to sexual mates and resources that could affect fertility rates and investment in offspring's quality, delaying the manifestation of the potential evolutionary advantage of these traits. It was the emergence of the nuclear family in the aftermath of the agricultural revolution that fostered intergenerational links, and thereby enhanced the manifestation of the potential evolutionary advantage of this trait.

[122] Unlike Galor and Weil (2000) in which the adverse effect of limited resources on population growth delays the process of development, in the proposed theory the Malthusian constraint generates the necessary evolutionary pressure for the ultimate take-off.

effect of technological progress on parental income dominated, and the rate of population growth as well as the average quality increased, further accelerating technological progress. Ultimately, the rate of technological progress induced a universal investment in human capital along with a reduction in fertility rates, generating a demographic transition in which the rate of population growth declined along with an increase in the average level of education. The positive feedback between technological progress and the level of education reinforced the growth process, setting the stage for the transition to a state of sustained economic growth.[123]

During the transition from the Malthusian epoch to the sustained growth regime, once the economic environment improved sufficiently, the significance of quality for survival declined, and traits of higher valuation for quantity gained the evolutionary advantage. Namely, as technological progress brought about an increase in income, the Malthusian pressure relaxed and the domination of wealth in fertility decisions diminished. The inherent advantage of higher valuation for quantity in reproduction has started to dominate, and individuals whose preferences are biased towards child quantity gained the evolutionary advantage. Nevertheless, the growth rate of output per worker has remained positive since the high rate of technological progress sustained an attractive return to investment in human capital even from the viewpoint of individuals whose valuation for quality is relatively low.

The transition from stagnation to growth is an inevitable by-product of the interaction between the composition of the population and the rate of technological progress in the Malthusian epoch. However, for a given composition of population, the timing of the transition may differ significantly across countries and regions due to historical accidents, as well as variation in geographical, cultural, social and institutional factors, trade patterns, colonial status, and public policy.

5.2.1. Primary ingredients

The theory is based upon the interaction between several building blocks: the Darwinian elements, the Malthusian elements, the nature of technological progress, the determinants of human capital formation, and the factors that affect parental choice regarding the quantity and quality of offspring.

The Darwinian elements. The theory incorporates the main ingredients of Darwinian evolution (i.e., variety, intergenerational transmission of traits, and natural selection) into the economic environment. Inspired by fundamental components of the Darwinian theory [Darwin (1859, 1871)], individuals do not operate consciously so as to assure their evolutionary advantage. Nevertheless, their preferences (or strategies) assure that

[123] The theory suggests that waves of rapid technological progress in the Pre-Industrial Revolution era did not generate sustained economic growth due to the shortage of preferences for quality in the population. Although in these previous episodes technological progress temporarily increased the return to quality, the level of human capital that was generated by the response of the existing population to the incentive to invest in human capital, was insufficient to sustain technological progress and economic growth.

those individuals whose operations are most complementary to the environment would eventually dominate the population.

Individuals' preferences are defined over consumption above subsistence as well as over the quality and the quantity of their children.[124] These preferences capture the Darwinian survival strategy as well as the most fundamental trade-offs that exist in nature – the trade-off between the resources allocated to the parent and the offspring, and the trade-off between the number of offspring and resources allocated to each offspring.[125] The economy consists of a variety of types of individuals distinguished by the weight given to child quality in their preferences.[126] This trait is assumed to be transmitted intergenerationally. The economic environment determines the type with the evolutionary advantage (i.e., the type characterized by higher fertility rates), and the distribution of preferences in the population evolves over time due to differences in fertility rates across types.[127]

The significance that individuals attribute to child quantity as well as to child quality reflects the well-known variety in the quality-quantity survival strategies (or in the K and r strategies) that exists in nature [e.g., MacArthur and Wilson (1967)]. Human beings, like other species, confront the basic trade-off between offspring's quality and quantity in their implicit Darwinian survival strategies. Although a quantity-biased preference has a positive effect on fertility rates and may therefore generate a direct evolutionary advantage, it adversely affects the quality of offspring, their income, and their fitness and may therefore generate an evolutionary disadvantage. "Increased bearing is bound to be paid for by less efficient caring" [Dawkins (1989, p. 116)]. As was established in the evolutionary biology literature since the seminal work of Lack (1954), the allocation of resources between offspring "caring" and "bearing" is subjected to evolutionary changes.[128]

124 The subsistence consumption constraint is designed to capture the fact that the physiological survival of the parent is a pre-condition for the survival of the lineage (dynasty). Resources allocated to parental consumption beyond the subsistence level may be viewed as a force that rises parental productivity and resistance to adverse shocks (e.g., famine and disease), generating a positive effect on the fitness of the parent and the survival of the lineage. This positive effect, however, is counterbalanced by the implied reduction in resources allocated to the offspring, generating a negative effect on the survival of the lineage.

125 Resources allocated to quality of offspring in different stages of development take different forms. In early stages of development it is manifested in investment in the durability of the offspring via better nourishment and parental guidance, whereas in mature stages, investment in quality may capture formal education.

126 The analysis abstracts from heterogeneity in the degree of the trade-off between resources allocated to parent and offspring. The introduction of this element would not alter the qualitative results.

127 Recent research across historical and modern data from the United States and Europe suggests that fertility behavior has a significant hereditary component [Rodgers et al. (2001a)]. For instance, as established recently by Kohler et al. (1999) and Rodgers et al. (2001b), based on the comparison of fertility rates among identical and fraternal twins born in Denmark during the periods 1870–1910 and 1953–1964, slightly more than one-quarter of the variance in completed fertility is attributable to genetic influence. These findings are consistent with those of Rodgers and Doughty (2000) based on kinship data from the United States.

128 Lack (1954) suggests that clutch sizes (i.e., number of eggs per nest), among owls and other predatory vole-eating birds, for instance, are positively related to food abundance. He argues that the clutch size is

The Malthusian elements. Individuals are subjected to subsistence consumption constraint and as long as the constraint is binding, an increase in income results in an increase in population growth along with an increase in the average quality of a minor segment of the population. Technological progress, which brings about temporary gains in income per capita, triggers therefore an increase in the size of the population that offsets the gain in income per capita due to the existence of diminishing returns to labor. Growth in income per capita is generated ultimately, despite decreasing returns to labor, since technological progress induces investment in human capital among a growing minority.

The determinants of technological progress. The average level of human capital as reflected by the composition of the population is the prime engine of technological progress.[129]

The origin of human capital formation. Technological change raises the demand for human capital. Technological progress reduces the adaptability of existing human capital for the new technological environment and educated individuals (and thus offspring of parent with high valuation for quality) have a comparative advantage in adapting to the new technological environment.[130]

The determination of paternal decision regarding offspring quantity and quality. Individuals choose the number of children and their quality based upon their preferences for quality as well as their time constraint.[131] The rise in the (genetic or cultural) bias

selected such that under any feeding conditions fertility rates ensure the maximal reproductive success. Furthermore, Cody (1966) documents the existence of significant differences between clutch sizes of the same bird species on islands and nearby mainland localities of the same latitude. In temperate regions where food is more abundant in the mainland than on islands, the average clutch size is smaller on the islands. For instance, for *Cyanoramphus novaezelandeae*, the average mainland clutch is 6.5 whereas the average in the island is 4.

[129] This link between education and technological change was proposed by Nelson and Phelps (1966) and is supported empirically by Easterlin (1981), Doms et al. (1997), as well as others. In order to focus on the role of the evolutionary process, the model abstracts from the potential positive effect of the size of the population on the rate of technological progress. Adding this scale effect would simply accelerate the transition process [e.g., Galor and Weil (2000)]. Consistently with Mokyr (2002) who argues that the effect of human capital accumulation on technological progress becomes significant only in the course of the Scientific Revolution that preceded the Industrial Revolution, the effect of human capital accumulation on the rate of technological progress need not be significant prior to the scientific revolution, as long as it becomes significant prior to the Industrial Revolution.

[130] See Schultz (1964) and Nelson and Phelps (1966). If the return to education rises with the level of technology rather than with the rate of technological progress, the qualitative analysis would not be affected. However, this alternative would imply that changes in technology were skill-biased throughout human history in contrast to those periods in which technological change was skilled-saving, notably, in the first phase of the Industrial Revolution.

[131] Anthropological evidence suggests that fertility control was indeed exercised even prior to the Neolithic Revolution. Reproductive control in hunter-gatherer societies is exemplified by "pacing birth" (e.g., birth every four years) conducted by tribes who live in small, semi nomadic bands in Africa, Southeast Asia, and New Guinea in order to prevent the burden of carrying several children while wandering. Similarly, Nomadic women of the Kung use no contraceptives but nurse their babies frequently, suppressing ovulation and menstruation for two to three years after birth, and reaching a mean interval between births of 44 months.

towards quality, as well as the rise in the demand for human capital, induce parents to substitute quality for quantity of children.

5.2.2. Main hypotheses and their empirical assessment

The theory generates several hypotheses about human evolution and the process of development, underlying the role of natural selection in: (i) the gradual process of human capital formation and thus technological progress prior to the Industrial Revolution, and (ii) the acceleration of the interaction between human capital and technological progress in the second phase of the Industrial Revolution, the associated demographic transition, and the emergence of a state of sustained economic growth.

The main hypotheses

(H1) During the initial phases of the Malthusian epoch, the growth rate of output per capita is nearly zero and the growth rate of population and literacy rates is minuscule, reflecting the sluggish pace of technological progress, the low representation of individuals with high valuation for child quality, and the slow pace of the evolutionary process.

This hypothesis is consistent with the characteristics of the Malthusian epoch, as described in Section 2.1.

(H2) In the pre-demographic transition era, traits for higher valuation for offspring quality generated an evolutionary advantage. Namely, individuals with higher valuation for the quality of children had a larger number of surviving offspring and their representation in the population increased over time. In contrast, in the post-demographic transition era, when income per capita has no longer been the binding constraint on fertility decisions, individuals with higher valuation for offspring quantity have an evolutionary advantage, bearing a lager number of surviving offspring. Thus, in the pre-demographic transition era, the number of surviving offspring was affected positively by parental education and parental income whereas in the post-demographic transition era this pattern is reversed and more educated, higher income individuals have a smaller number of surviving offspring.

Clark and Hamilton (2003) examine empirically this hypothesis on the basis of data from wills written in England in the time period 1620–1636. The wills were written in a closed proximity to the death of a person, in urban and rural areas, and across a large variety of occupations and wealth. They contain information about the number of surviving offspring, literacy of testator (measured by whether the will was signed), occupation of testator (if male), the amount of money bequeathed and to whom (spouse, children, the poor, unrelated persons), and houses and land that were bequeathed. Based on this data, Clark and Hamilton find a positive and statistically significant effect of literacy (and wealth) on the number of surviving offspring.[132] They confirm the hypothesis that literate people (born, according to the theory, to parents with quality-bias) had an evolutionary advantage in this (pre-demographic transition) period.[133] The negative relationship between education and fertility within a country in the post-demographic transition era was documented extensively.[134]

(H3) The increased the representation of individuals with higher valuation for quality, gradually increased the average level of investment in human capital,[135] permitting a slow growth of output per capita.

The prediction about the rise in human capital prior to the Industrial Revolution is consistent with historical evidence. Various measures of literacy rates demonstrate a significant rise in literacy rates during the two centuries that preceded the Industrial Revolution in England.[136] As depicted in Figure 42, male literacy rates increased gradually in the time period 1600–1760. Literacy rates for men doubled over this period, rising from about 30% in 1600 to over 60% in 1760. Similarly, as reported by Cipolla (1969), literacy rates of women more than tripled from less than 10% in 1640 to over 30% in 1760.[137]

Moreover, as argued by Clark (2003), human capital accumulation in England began in an era when the market rewards for skill acquisition were at historically low levels, consistent with the argument that the rise in human capital reflected a rise in the preference for quality offspring.

[132] In addition, Boyer (1989) argues that in early 19th century England, agricultural laborers' income had a positive effect on fertility: birth rates increased by 4.4% in response to a 10% increase in annual income. Further evidence is surveyed by Lee (1997).

[133] Interestingly, in New France, where land was abundant, and thus fertility decisions were not constraint by the availability of resources, the number of surviving offspring was higher among less educated individuals. These findings are consistent with the theory as well. If resource constraint is not binding for fertility decisions (e.g., in the post-demographic transition era, or due to a positive shock to income in the Malthusian era), individuals with higher valuation for quantity gain an evolutionary advantage.

[134] See, for instance, Kremer and Chen (2002).

[135] In contrast to Galor and Weil (2000) in which the inherent positive interaction between population and technology during the Malthusian Regime is the force behind the increase in the rate of technological progress that induced investments in human capital and led to further technological progress, a demographic transition, and sustained economic growth, Galor and Moav (2002) is structured such that the gradual change in the composition of the population (rather than the size of the population) brings about the take-off from stagnation to growth. Thus, a scale effect is not needed for the take-off. However, this is just a simplifying modeling devise and both forces could operate simultaneously in triggering the take-off.

[136] Moreover, this hypothesis appears consistent with the increase in the number and size of universities in Europe since the establishment of the first university in Bologna in the 11th century, significantly outpacing the growth rate of population.

[137] This pattern is robust and is observed in various dioceses over this period. For instance Cressy (1981, Table 6.3, p. 113) reports a gradual rise in average literacy rate of average of yeomen, husbandmen and tradesmen in Norwich from 30% in 1580 to nearly 61% in 1690, and Cressy (1980, Table 7.1, p. 143) reports a gradual rise in Gentle literacy in the diocese of Durham between 1565 and 1624.

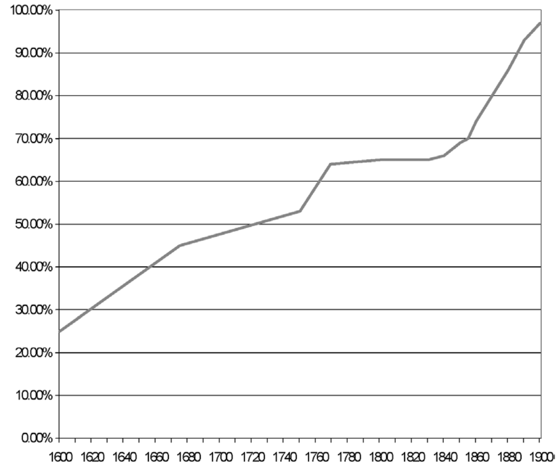

Figure 42. The rise in male literacy rates prior and during the industrial revolution: England: 1600–1900. Sources: Cipolla (1969), Stone (1969), and Schofield (1973).

(H4) The acceleration in the rate of technological progress that was reinforced by the investment in human capital of individuals with high valuation for offspring quality, increased the demand for human capital in the later part of the Post-Malthusian Regime, generating a universal investment in human capital, a demographic transition and a rapid pace of economic growth.

The hypothesis is consistent with the evidence, provided in Section 2.3 and depicted partly in Figure 41, about the significant rise in the industrial demand for human capital in the second phase of the Industrial Revolution, the marked increased in educational attainment, the emergence of universal education towards the end of the 19th century in association with a decline in fertility rates, and a transition to a state of sustained economic growth.

5.3. Complementary mechanisms

The theory suggests that during the Malthusian epoch hereditary human traits, physical or mental, that generate higher earning capacity, and thereby potentially larger number of offspring, would generate an evolutionary advantage and would dominate the population. Hereditary traits that stimulate technological progress or raise the incentive to invest in offspring's human capital (e.g., ability, longevity, and a preference for quality), may trigger a positive feedback loop between investment in human capital and technological progress that would bring about a take-off from an epoch of Malthusian stagnation, a demographic transition, and a shift to a state of sustained economic growth. Hence, the struggle for existence that had characterized most of human history stimulated natural selection and generated an evolutionary advantage to individuals whose characteristics are complementary to the growth process, eventually triggering a take-off from an epoch of stagnation to sustained economic growth. Galor and Moav (2002) focus on the evolution of the trade-off between resources allocated to the quantity and the quality of offspring. Their framework of analysis can be modified to account for the interaction between economic growth and the evolution of other hereditary traits.

5.3.1. The evolution of ability and economic growth

Suppose that individual's preferences are defined over consumption above a subsistent level and over child quality and quantity. Individuals are identical in their preferences, but differ in their hereditary innate ability. Suppose further that offspring's level of human capital is an increasing function of two complementary factors: innate ability and investment in quality. Thus, since the marginal return to investment in child quality increases with ability, higher-ability individuals and hence dynasties would allocate a higher fraction of their resources to child quality.

In the Malthusian era, individuals with a higher ability generate more income and hence are able to allocate more resources for child quality and quantity. High ability individuals, therefore, generate higher income due to fact that their innate ability as well as their quality are higher. In the Malthusian era fertility rates are positively affected by the level of income and (under plausible configurations) the high ability individuals have therefore an evolutionary advantage over individuals of lower ability. As the fraction of individuals of the high ability type increases, investment in quality rises, and technological progress intensifies. Ultimately the dynamical system changes qualitatively, the Malthusian temporary steady state vanishes endogenously and the economy takes off from the Malthusian trap. Once the evolutionary process generates a positive feedback between the rate of technological progress and the level of education, technological progress is reinforced, the return to human capital increases further, setting the stage for the demographic transition and the shift to a state of sustained economic growth.

5.3.2. The evolution of life expectancy and economic growth

Suppose that individuals differ in their level of health due to hereditary factors. Suppose further that there exists a positive interaction between the level of health and economic well-being. Higher income generates a higher level of health, whereas higher level of health increases labor productivity and life expectancy. Parents that are characterized by high life expectancy, and thereby expect their offspring to have a longer productive life, would allocate more resources toward child quality. In the Malthusian era, fertility rates are positively affected by the level of income and individuals with higher life expectancy, and therefore higher quality and higher income, would have (under plausible configurations) an evolutionary advantage. Natural selection therefore, increases the level of health as well as the quality of the population. Eventually, this process generates a positive feedback loop between investment in child quality, technological progress and health, bringing about a transition to a sustained economic growth with low fertility rates and high longevity.

Alternatively, Galor and Moav (2004b) develop an evolutionary growth theory that captures the intricate time path of life expectancy in the process of development, shedding new light on the origin of the remarkable rise in life expectancy since the Agricultural Revolution. The theory argues that social, economic and environmental changes that were associated with the transition from hunter-gatherer tribes to sedentary agricultural communities, and ultimately to urban societies, affected the nature of the environmental hazards confronted by the human population, triggering an evolutionary process that had a significant impact on the time path of human longevity. The theory suggests that the deterioration in the health environment enhanced the genetic potential for longer life expectancy thereby playing a significant role in the dramatic impact of recent improvements in health infrastructure on the prolongation of human life.

The rise in population density, the domestication of animals, and the increase in work effort in the course of the Agricultural Revolution, increased the exposure and the vulnerability of humans to environmental hazards such as infectious diseases and parasites, increasing the extrinsic mortality risk and leading to the observed temporary decline in life expectancy during the Neolithic period.[138] The theory suggests, however, that the evolutionary optimal allocation of parental resources towards somatic investment, repairs, and maintenance (e.g., enhanced immune system, DNA repairs, accurate gene regulation, tumor suppression, and antioxidants) was altered in the face of the fundamental trade-off between current and future reproduction. The rise in the extrinsic morality risk generated an evolutionary advantage to individuals who were genetically pre-disposed towards higher somatic investment leading to the observed increase in life expectancy in the post-Neolithic period.

Galor and Moav (2004b) suggest, therefore, that the increase in the *extrinsic morality risk* (i.e., risk associated with environmental factors) in the course of the Agricultural Revolution triggered an evolutionary process that gradually altered the distribution of genes in the human population that are associated with the *intrinsic mortality risk* (i.e., physiological and biochemical decay over lifetime). Individuals that were characterized by a higher genetic predisposition towards somatic investment, repairs, and maintenance gained the evolutionary advantage during this transition, and their representation in the population increased over time.[139] Despite the increase in the extrinsic mortality risk

[138] Most comparisons between hunter-gatherers and farmers [e.g., Cohen (1989)] suggest that, in the same locale, farmers suffered higher rates of infection due to the increase in human settlements, poorer nutrition due to reduced meat intake and greater interference with mineral absorption by the cereal-based diet. Consequently, Neolithic farmers were shorter and had a lower life expectancy relative to Mesolithic hunter-gatherers. Although it is difficult to draw reliable conclusion about relative life expectancy in these periods, because skeletal samples are often distorted and incomplete, available evidence suggests that prehistoric hunter-gatherers often fared relatively well in comparison to later populations, particularly with reference to the survival of children. The Illinois Valley provides life tables for hunter-gatherers which confirm the fact that their life expectancies matched or exceeded those of later groups.

[139] For the effect of somatic maintenance system on longevity see Kirkwood (1998).

that brought about a temporary decline in life expectancy, longevity eventually increased beyond the peak that existed in the hunter-gatherer society, due to the changes in the distribution of genes in the human population. This evolutionary process in life expectancy reinforced the interaction between investment in human capital, life expectancy, and technological progress thereby expediting the demographic transition and enhancing the economic transition from stagnation to growth.[140] Moreover, the biological upper bound of longevity gradually increased, generating the biological infrastructure that contributed significantly to the impact of recent improvements in medical technology on the dramatic prolongation of life expectancy.

6. Differential takeoffs and the great divergence

The last two centuries have witnessed dramatic changes in the distribution of income and population across the globe. The differential timing of the take-off from stagnation to growth across countries and the corresponding variations in the timing of the demographic transition have led to a great divergence in income, as depicted in Figure 32, and to significant changes in the distribution of population around the globe, as depicted in Figure 33. Some regions have excelled in the growth of income per capita, while other regions have been dominant in population growth.

Inequality in the world economy had been insignificant until the 19th century. The ratio of GDP per capita between the richest region and the poorest region in the world was only 1.1 : 1 in 1000 AD, 2 : 1 in 1500 and 3 : 1 in 1820. In contrast, the past two centuries have been characterized by a 'Great Divergence' in income per capita among countries and regions. In particular, the ratio of GDP per capita between the richest and the poorest regions has widened considerably from a modest 3 : 1 ratio in 1820, to a large 18 : 1 ratio in 2001. An equally impressive transformation occurred in the distribution of world population across regions, as depicted in Figure 33. The earlier take-off of Western European countries generated a 16% increase in the share of their population in the world economy within the time period 1820–1870. However, the early onset of the Western European demographic transition, and the long delay in the demographic transitions of less developed regions, well into the second half of the 20th century, led to a 55% decline in the share of Western European population in the world in the time period 1870–1998. In contrast, the prolongation of the Post-Malthusian period of less developed regions and the delay in their demographic transitions, generated a 84% increase in Africa's share of world population, from 7% in 1913 to 12.9% in 1998, an 11% increase in Asia's share of world population from 51.7% in 1913 to 57.4% in 1998, and a four-fold increase in Latin American's share in world population from 2% in 1820 to 8.6% in 1998.

[140] The evolution of the human brain along with the evolution of life expectancy prior to the Neolithic revolution is examined by Robson and Kaplan (2003).

The phenomenon of the Great Divergence in income per capita across regions of the world over the past two centuries, that was associated with the take-off from the epoch of near stagnation to a state of sustained economic growth, presents intriguing questions about the growth process. How does one account for the sudden take-off from stagnation to growth in some countries in the world and the persistent stagnation in others? Why has the positive link between income per capita and population growth reversed its course in some economies but not in others? Why have the differences in per capita incomes across countries increased so markedly over the last two centuries? Has the transition to a state of sustained economic growth in advanced economies adversely affected the process of development in less-developed economies?

6.1. Non-unified theories

The origin of the Great Divergence has been a source of controversy. The relative roles of geographical and institutional factors, human capital formation, ethnic, linguistic, and religious fractionalization, colonialism and globalization have been at the center of a debate about the origins of this remarkable change in the world income distribution in the past two centuries.

The role of institutional and cultural factors has been the focus of influential hypotheses regarding the origin of the great divergence. North (1981), Landes (1998), Mokyr (1990, 2002), Hall and Jones (1999), Parente and Prescott (2000), and Acemoglu, Johnson and Robinson (2002) have argued that institutions that facilitated the protection of property rights and enhanced technological research and the diffusion of knowledge, have been the prime factors that enabled the earlier European take-off and the great technological divergence across the globe.[141]

The effect of geographical factors on economic growth and the great divergence have been emphasized by Jones (1981), Diamond (1997) and Gallup, Sachs and Mellinger (1998).[142] The geographical hypothesis suggests that advantageous geographical conditions made Europe less vulnerable to the risk associated with climate and diseases, leading to the early European take-off, whereas adverse geographical conditions in disadvantageous regions (e.g., harsh climate, prevalence of diseases, scarcity of natural resources, high transportation costs, limited regional diffusion of knowledge and technology), generated permanent hurdles for the process of development, contributing to the great divergence.[143]

The exogenous nature of the geographical factors and the endogenous nature of the institutional factors lead researchers to hypothesize that initial geographical conditions

[141] Barriers to technological adoption that may lead to divergence are explored by Caselli and Coleman (2002), Howitt and Mayer-Foulkes (2005) and Acemoglu, Aghion and Zilibotti (2004).

[142] See also Hall and Jones (1999), Masters and McMillan (2001) and Hibbs and Olson (2005).

[143] Bloom, Canning and Sevilla (2003) cross section analysis rejects the geographical determinism, but maintains nevertheless that favorable geographical conditions have mattered for economic growth since they increase the likelihood of an economy to escape a poverty trap. See Przeworski (2003) as well.

had a persistent effect on the quality of institutions, leading to divergence and overtaking in economic performance. Engerman and Sokoloff (2000) provide descriptive evidence that geographical conditions that led to income inequality, brought about oppressive institutions designed to preserve the existing inequality, whereas geographical characteristics that generated an equal distribution of income led to the emergence of growth promoting institutions. Acemoglu, Johnson and Robinson (2002) provide evidence that reversals in economic performance across countries have a colonial origin, reflecting institutional reversals that were introduced by European colonialism across the globe.[144] "Reversals of fortune" reflect the imposition of extractive institutions by the European colonialists in regions where favorable geographical conditions led to prosperity, and the implementation of growth enhancing institutions in poorer regions.[145] Furthermore, the role of ethnic, linguistic, and religious fractionalization in the emergence of divergence and "growth tragedies" has been linked to their effect on the quality of institutions. Easterly and Levine (1997) and Alesina et al. (2003) demonstrate that geopolitical factors brought about a high degree of fractionalization in some regions of the world, leading to the implementation of institutions that are not conducive for economic growth and thereby to diverging growth paths across regions.

The role of human capital in the great divergence is underlined in the unified growth theories of Galor and Weil (2000), Galor and Moav (2002), Doepke (2004), Fernandez-Villaverde (2005), Lagerlof (2006), as well as others. These theories establish theoretically and quantitatively that the rise in the technologically-driven demand for human capital in the second phase of industrialization and its effect on human capital formation and on the onset of the demographic transition have been the prime forces in the transition from stagnation to growth and thus in the emergence of the associated phenomena of the great divergence. In particular, they suggests that once the technologically-driven demand for human capital emerged in the second phase of industrialization, the prevalence of human capital promoting institutions determined the extensiveness of human capital formation, and therefore the rapidity of technological progress, the timing of the demographic transition, the pace of the transition from stagnation to growth, and thus the distribution of income in the world economy.

Empirical research is inconclusive about the significance of human capital rather than institutional factors in the process of development. Some researchers suggest that initial geographical conditions affected the current economic performance primarily via their effect on institutions. Acemoglu, Johnson and Robinson (2002), Easterly and Levine (2003), and Rodrik, Subramanian and Trebbi (2004) provide evidence that variations in the contemporary growth processes across countries can be attributed to institutional factors whereas geographical factors are secondary, operating primarily via variations in institutions.

144 Additional aspects of the role of colonialism in comparative developments are analyzed by Bertocchi and Canova (2002).

145 Brezis, Krugman and Tsiddon (1993) attribute technological leapfrogging to the acquired comparative advantage (via learning by doing) of the current technological leaders in the use of the existing technologies.

Glaeser et al. (2004) revisit the debate whether political institutions cause economic growth, or whether, alternatively, growth and human capital accumulation lead to institutional improvement. In contrast to earlier studies, they find that human capital is a more fundamental source of growth than are the institutions. Moreover, they argue that poor countries emerge from poverty through good policies (e.g., human capital promoting policies) and only subsequently improve their political institutions.

A theory that unifies the geographical and the human capital paradigms, capturing the transition from the domination of the geographical factors in the determination of productivity in early stages of development, to the domination of human capital promoting institutions in mature stages of development has been proposed by Galor, Moav and Vollrath (2003). The theory identifies and establishes the empirical validity of a channel through which favorable geographical conditions, that were inherently associated with inequality, affected the emergence of human capital promoting institutions (e.g., public schooling, child labor regulations, abolishment of slavery, etc.), and thus the pace of the transition from an agricultural to an industrial society.[146] They suggest that the distribution of land within and across countries affected the nature of the transition from an agrarian to an industrial economy, generating diverging growth patterns across countries. The accumulation of physical capital in the process of industrialization raised the importance of human capital in the growth process, reflecting the complementarity between capital and skills. Investment in human capital, however, was sub-optimal due to credit market imperfections, and public investment in education was growth-enhancing. Nevertheless, human capital accumulation did not benefit all sectors of the economy. Due to a low degree of complementarity between human capital and land, universal public education increased the cost of labor beyond the increase in average labor productivity in the agricultural sector, reducing the return to land. Landowners, therefore, had no economic incentives to support these growth enhancing educational policies as long as their stake in the productivity of the industrial sector was insufficient. Land abundance, which was beneficial in early stages of development, brought about a hurdle for human capital accumulation and economic growth among countries that were marked by an unequal distribution of land ownership.[147]

6.2. Unified theories

Unified theories of economic growth generate direct hypotheses about the factors that determine the timing of the transition from stagnation to growth and thus the causes of the Great Divergence. The timing of the transition may differ significantly across

[146] As established by Chanda and Dalgaard (2003), variations in the structural composition of economies and in particular the allocation of scarce inputs between the agricultural and the non-agricultural sectors are important determinants of international differences in TFP, accounting for between 30% and 50% of these variations.

[147] Berdugo, Sadik and Sussman (2003) explore an alternative theory of divergence and overtaking that links natural resources abundance, the quality of learning institutions, and retardation in technology adoption.

countries and regions due to historical accidents, as well as variations in geographical, cultural, political, social and institutional factors that affected the vital interaction between population and technology in the Malthusian epoch, and the fundamental links between technological progress, human capital formation, and the demographic transition, in the Post-Malthusian Regime as well as in the Modern Growth Regime.[148]

6.2.1. Human capital promoting institutions

The role of human capital in the take-off from stagnation to growth and thus in the great divergence was underlined in the unified theories of Galor and Weil (2000), Galor and Moav (2002), Doepke (2004), Fernandez-Villaverde (2005), Lagerlof (2006), as well as others, as explored in Section 4. These theories establish theoretically and quantitatively that the rise in the demand for human capital in the second phase of industrialization, and its effect on human capital formation, and the onset of the demographic transition that swept the world in the course of the last century, have been the prime forces in the transition from stagnation to growth and thus in the emergence of the associated phenomena of the Great Divergence. Furthermore, they suggest that variations in the timing of the transition from stagnation to growth (e.g., England's earlier industrialization in comparison to China), and thus differences in economic performance across countries, may reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, demographic, and cultural factors, trade patterns, colonial status, and public policy.

Consistently with the findings of Glaeser et al. (2004), these unified theories suggest that once the technologically-driven demand for human capital emerged in the second phase of industrialization, the prevalence of human capital promoting institutions determined the swiftness of human capital formation, the timing of the demographic transition, the pace of the transition from stagnation to growth, and thereby the observed distribution of income in the world economy.

6.2.2. Globalization and the great divergence

This subsection explores a unified growth theory that generates a transition from stagnation to growth along with a great divergence, focusing on the asymmetric effect of globalization on the timing of the transition of developed and less developed countries from Malthusian stagnation to sustained economic growth. Galor and Mountford

[148] Related to the unified paradigm, Pomeranz (2000) suggest that the discovery of the New World, enabled Europe, via Atlantic trade, to overcome 'land constraints' and to take off technologically. The inflow of grain and other commodities as well as the outflow of migrants during the 19th century may have played a crucial role in Europe's development. By easing the land constraint at a critical point – when income per capita had begun to rise rapidly, but before the demographic transition had gotten under way – the "ghost acres" of the New World provided a window of time which allowed Europe to pull decisively away from the Malthusian equilibrium.

(2003) suggest that sustained differences in income and population growth across countries could be attributed to the contrasting effect of international trade on industrial and non-industrial nations. Consistent with the evidence provided in Section 2, their theory suggests that the expansion of international trade in the 19th century and its effect on the pace of individualization has played a major role in the timing of demographic transitions across countries and has thereby been a significant determinant of the distribution of world population and a prime cause of the 'Great Divergence' in income levels across countries in the last two centuries. International trade had an asymmetrical effect on the evolution of industrial and non-industrial economies**.** While in the industrial nations the gains from trade were directed primarily towards investment in education and growth in output per capita, a significant portion of the gains from trade in non-industrial nations was channeled towards population growth.[149]

In the second phase of the Industrial Revolution, international trade enhanced the specialization of industrial economies in the production of industrial, skilled intensive, goods. The associated rise in the demand for skilled labor induced a gradual investment in the quality of the population, expediting a demographic transition, stimulating technological progress and further enhancing the comparative advantage of these industrial economies in the production of skilled intensive goods. In non-industrial economies, in contrast, international trade has generated an incentive to specialize in the production of unskilled intensive, non-industrial, goods. The absence of significant demand for human capital has provided limited incentives to invest in the quality of the population, and the gains from trade have been utilized primarily for a further increase in the size of the population, rather than in the income of the existing population. The demographic transition in these non-industrial economies has been significantly delayed, increasing further their relative abundance of unskilled labor, enhancing their comparative disadvantage in the production of skilled intensive goods, and delaying their process of development. The research suggests, therefore, that international trade affected persistently the distribution of population, skills, and technologies in the world economy, and has been a significant force behind the 'Great Divergence' in income per capita across countries.[150]

[149] In contrast to the recent literature on the dynamics of comparative advantage [e.g., Findlay and Keirzkowsky (1983), Grossman and Helpman (1991), Matsuyama (1992), Young (1991), Mountford (1998), and Baldwin, Philippe and Ottaviano (2001)] the focus on the interaction between population growth and comparative advantage as well as the persistent effect that this interaction may have on the distribution of population and income in the world economy, generates an important new insight regarding the distribution of the gains from trade. The theory suggests that even if trade affects output growth of the trading countries at the same rate (due to the terms of trade effect), income *per capita* of developed and less developed economies will diverge since in less developed economies growth of total output will be generated partly by population growth, whereas in developed economies it will be generated primarily by an increase in output per capita.

[150] Consistent with the thesis that human capital has reinforced the existing patterns of comparative advantage, Taylor (1999) argues that human capital accumulation during the late 19th century was not a source of convergence even among the advanced 'Greater Atlantic' trading economies. The richer economies – the US and Australia – had greater levels of school enrollments than the poorer ones, Denmark and Sweden.

The historical evidence described in Section 2 suggests that the fundamental hypothesis of this theory is consistent with the process of development over the last two centuries. As implied by the trade patterns reported in Table 1, and the evolution of industrialization depicted in Figure 14, trade over this period induced the specialization of industrialized economies in the production of industrial goods, whereas non-industrial economies specialize in the production of primary goods. The asymmetric effect of international trade on the process of industrialization of developed and less developed economies, as depicted in Figure 14, affected the demand for human capital as analyzed in Section 2.3.3, and thus the timing of the demographic transition in developed and less-developed economies, generating a great divergence in output per capita as well as significant changes in the distribution of world population, as depicted in Figure 33.[151]

The diverging process of development of the UK and India since the 19th century in terms of the levels of income per capita and population growth is consistent with the theory of Galor and Mountford (2003) and provides an interesting case study. During the 19th century the UK traded manufactured goods for primary products with India.[152] Trade with Asia constituted over 20% of UK total exports and 23.2% of total imports throughout the 19th century [Bairoch (1974)].[153] Consistent with the proposed hypothesis, as documented in Figure 14, industrialization in the UK accelerated, leading to a significant increase in the demand for skilled labor in the second phase of the Industrial Revolution, a demographic transition and a transition to a state of sustained economic growth.

For India, however, international trade played the reverse role. The period 1813–1850 was characterized by a rapid expansion in the volume of exports and imports which gradually transformed India from being an exporter of manufactured products – largely textiles – into a supplier of primary commodities [Chaudhuri (1983)]. Trade with the UK was fundamental in this process. The UK supplied over two thirds of its imports for most of the 19th century and was the market for over a third of India's exports. As depicted in Figure 14, the rapid industrialization in the UK in the 19th century was associated with a decline in the per capita level of industrialization in India.[154] The

[151] Consistent with the viewpoint that trade has not been uniformly beneficial across time and regions, recent research by Rodriguez and Rodrik (2001) has indicated that the relationship between openness and growth changed in the last century. Moreover, Clemens and Williamson (2004) find a positive relationship between average tariff levels and growth for the period 1870–1913 and a negative relationship for the period 1970–1998. Similarly Vamvakadis (2002) finds a positive relationship between several measures of openness and growth after 1970 and some evidence of a negative relationship in the period 1870–1910.

[152] The colonial power of the UK may have encouraged the specialization of India in the production of primary goods beyond the degree dictated by market forces. However, these forces would have just reinforced the adverse effects described in their theory.

[153] In contrast, trade with Asia constituted only 5% or less of French, German or Italian exports and 12.1% of total imports of continental Europe.

[154] Furthermore, Bairoch (1974) found that industries that employed new technologies made up between 60% and 70% of the UK manufacturing industry in 1860 but less than 1% of manufacturing industries in the developing countries.

setback in the process of industrialization and consequently the lack of demand for skilled labor, delayed the demographic transition and the process of development.[155] Thus, while the gains from trade were utilized in the UK primarily towards an increase in output per capita, in India they were significantly channeled towards an increase in the size of the population. The ratio of output per capita in the UK relative to India grew from 3 : 1 in 1820 to 11 : 1 in 1998, whereas the ratio of India's population relative to the UK's population grew from 8 : 1 in 1870 to 16 : 1 in 1998.[156]

7. Concluding remarks

The transition from stagnation to growth and the associated phenomenon of the great divergence have been the subject of an intensive research in the growth literature in recent years. The discrepancy between the predictions of exogenous and endogenous growth models and the process of development over most of human history, induced growth theorists to advance an alternative theory that would capture in a single unified framework the contemporary era of sustained economic growth, the epoch of Malthusian stagnation that had characterized most of human history, and the fundamental driving forces of the recent transition between these distinct regimes.

The advancement of unified growth theory was fueled by the conviction that the understanding of the contemporary growth process would be limited and distorted unless growth theory would be based on micro-foundations that would reflect the qualitative aspects of the growth process in its entirety. In particular, the hurdles faced by less developed economies in reaching a state of sustained economic growth would remain obscured unless the origin of the transition of the currently developed economies into a state of sustained economic growth would be identified and its implications would

155 Unlike the rise in the industrial demand for education in the UK, education was not expanded to a similar degree in India in the 19th century. As noted by Basu (1974), during the 19th century the state of education in India was characterized by a relatively large university sector, aimed at producing skilled bureaucrats rather than industrialists, alongside widespread illiteracy of the masses. The literacy rate was very low, (e.g., 10% in Bengal in 1917–1918) but nevertheless, attempts to expand primary education in the 20th century were hampered by poor attendance and high drop out rates, suggesting that demand for education was relatively low. The lack of broad based education in India can also be seen using the data of Barro and Lee (2000). Despite an expansion of education throughout the 20th century Barro and Lee report that in 1960 72.2% of Indians aged 15 and above had "no schooling" compared with 2% in the UK.

156 Another interesting case study providing supporting evidence for the proposed hypothesis is the economic integration of the Israeli and the West Bank economies in the aftermath of the 1967 war. Trade and factor mobility between the skilled abundant economy of Israel and the unskilled abundant economy of the West Bank, shifted the West Bank economy towards further specialization in the production of primary goods, and possibly triggered the astonishing increase in crude birth rates from 22 per 1000 people in 1968 to 42 per 1000 in 1990, despite a decline in mortality rates. The gains from trade and development in the West Bank economy were converted primarily into an increase in population size, nearly doubling the population in those two decades. Estimates of the growth rates of output per capita over this period are less reliable and suggest that the increase was about 30%.

be modified to account for the additional economic forces faced by less developed economies in an interdependent world.

Unified growth theory suggests that the transition from stagnation to growth is an inevitable outcome of the process of development. The inherent Malthusian interaction between the level of technology and the size and the composition of the population accelerated the pace of technological progress, and ultimately raised the importance of human capital in the production process. The rise in the demand for human capital in the second phase of industrialization and its impact on the formation of human capital, as well as on the onset of the demographic transition, brought about significant technological advancements along with a reduction in fertility rates and population growth, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita, and paving the way for the emergence of sustained economic growth. Moreover, the theory suggests that differences in the timing of the take-off from stagnation to growth across countries contributed significantly to the Great Divergence and to the emergence of convergence clubs.

Variations in the timing of the transition from stagnation to growth and thus in economic performance across countries (e.g., England's earlier industrialization in comparison to China) reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, demographic, and cultural factors, trade patterns, colonial status, and public policy. In particular, once a technologically driven demand for human capital emerged in the second phase of industrialization, the prevalence of human capital promoting institutions determined the extensiveness of human capital formation, the timing of the demographic transition, and the pace of the transition from stagnation to growth. Thus, unified growth theory provides the natural framework of analysis in which variations in the economic performance across countries and regions could be examined based on the effect of variations in educational, institutional, geographical, and cultural factors on the pace of the transition from stagnation to growth.

Further advancements of unified growth theory would necessitate refinements of some of the central building blocks of the theory as well as additional empirical and quantitative examinations of the fundamental hypothesis based on contemporary and historical data. In particular, while the micro foundations for fertility decisions, population growth, and to a lesser extent human capital formation, appears profound in existing unified theories, the modeling of the factors that govern technological progress could be enhanced using recent insights from the theory of endogenous technological change as well as from the recent advancements in the study of the role of human capital and institutional factors in technological progress. Moreover, unified growth theory provides a new set of testable predictions that could guide economic historians in their data collection, as well as in revising their past interpretations of existing historical evidence, enhancing the refinements of the main hypotheses of unified growth theory.

The most promising and challenging future research in the field of economic growth in the next decades would be the exploration of the interaction between human evolution and the process of economic development. This research will revolutionize our understanding of the process of economic development as well as the process of human evolution, establishing socio-biological evolutionary foundations to the growth process.

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