Trade, Demographic Transition, and the Great Divergence: Why are a Third of People Indian or Chinese?

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Abstract

This research argues that the rapid expansion of international trade in the second phase of the industrial revolution has played a significant role in the timing of demographic transitions across countries and has thereby been a major determinant of the distribution of world population and a prime cause of the Great Divergence in income per capita across countries in the last two centuries. The theory suggests that international trade affected the evolution of economies asymmetrically. The gains from trade were channeled towards population growth in non-industrial nations while in the industrial nations they were directed towards investment in education and growth in output per capita. International trade enhanced the specialization of industrial economies in the production of skilled intensive goods. The rise in the demand for skilled labor induced an investment in the quality of the population, expediting the 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, the specialization in the production of unskilled intensive goods that was brought about by international trade reduced the demand for skilled labor and provided limited incentives to invest in population quality. The gains from trade were utilized primarily for an increase in the size of the population. The demographic transition was therefore delayed, increasing further the abundance of unskilled labor in these economies and enhancing their comparative disadvantage in the production of skilled intensive goods. 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.

Keywords: International Trade , Demographic Transition, Industrial Revolution, Growth, Human Capital

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1 Introduction

The last two centuries have been characterized by dramatic changes in the distribution of income and population across the globe. A 'Great Divergence' in income per capita across countries and regions has emerged along with a momentous transformation in the distribution of world population.[1] Some regions have drifted apart in their income per capita, whereas others gained prominence in their population size. While Western European economies have tripled their domination in income per capita over Asian economies, significant resources in Asian countries have been channeled to double their lead over Western Europe in the population dimension.[2]

The Great Divergence in income per capita across regions (depicted in Figure 1), that accompanied the take-off from an epoch of stagnation to sustained economic growth is the most significant, unresolved mystery in 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 have the differences in per capita incomes across countries increased so markedly in the last two centuries? Why has the link between income per capita and population growth been so dramatically reversed in some economies but not in others? Has the pace of transition to sustained economic growth in advanced economies adversely affected the process of development in less-developed economies?

The origin of the Great Divergence has been a source of controversy among economic historians. Institutional and cultural factors that facilitated the protection of property rights and enhanced technological research and the diffusion of knowledge have been advocated by David Landes (1998) and Joel Mokyr (2002) as the prime factors that permitted the European take-off. Eric L. Jones (1981,1988) has emphasized geographical factors that made Europe less vulnerable to the risk associated with climate and diseases. Others, notably Kenneth Pomeranz (2000), have suggested that the discovery of the New World enabled Europe, via Atlantic trade, to overcome 'land constraints' and to take-off technologically.

This research argues that the rapid expansion of international trade in the second phase of the industrial revolution 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

[1] In the time period 1820-1998, the ratio between income per capita in the richest region in the world (i.e., Western offshoots - the United States, Canada, Australia and New Zealand) and the poorest regions in the world (i.e., Africa) has increased from about 3 to 19 [Maddison, 2001].

[2] Over the period 1820-1998, Western European income per capita grew 2.9 times more rapidly than the Asian one (excluding Japan), whereas the Asian population (excluding Japan) grew 1.7 as rapidly as the Western European population.[Maddison, 2001].

and a prime cause of the 'Great Divergence' in income levels across countries in the last two centuries. The analysis suggests that 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.

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 has 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 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.

The historical evidence described in the next section suggests that indeed the asymmetric effect of international trade on the timing of the demographic transition in developed and less-developed economies, and its persistent effect therefore on the initial patterns of comparative advantage may be a important element behind the Great Divergence. An interesting case study of the proposed theory is the process of development of the UK and India over the last two centuries. During the nineteenth century the UK traded manufactured goods for primary products with India.[3] As documented in Table 1, industrialization in India regressed over this century whereas industrialization in the UK accelerated. The process of industrialization in the UK lead to a

[3]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 this paper..

significant increase in the demand for skilled labor in the second phase of the industrial revolution, triggering a demographic transition and a transition to a state of sustained economic growth. In India, in contrast, the lack of demand for skilled labor delayed the demographic transition and the process of development. Thus, while the gains from trade were utilized in the UK primarily towards an increase in output per capita, in India they were channeled towards an increase in the size of the population.[4]

This paper develops a unified growth theory that captures the asymmetric role that international trade may have played in expediting the transition to sustained economic growth in technologically advanced economies and in delaying the transition in technologically inferior economies. The theory suggests that sustained differences in income and population growth across countries may be attributed to the contrasting role that international trade had on industrial and non-industrial nations.

Unlike the recent literature on the transition of economies from an epoch of Malthusian stagnation to state of sustained economic growth (Oded Galor and David N. Weil, 1999, 2000) that abstracted from the emergence Great Divergence and focused on the evolution of the world economy from stagnation to growth,[5] the proposed theory examines the differential patterns of takeoffs across regions in the world and the emergence of the Great Divergence.[6]

In contrast to the recent literature on the dynamics of comparative advantage,[7] the proposed theory focuses on the interaction between the population growth and comparative advantage and the persistent effect that this interaction may have on the distribution of population and income

[4]The theory further suggests that the near abstention of China from international trade during this period, delayed its demographic transition, increased the level of its population and derailed its relative position in the world income distribution. As documented in Table 1 and argued by David Landes (1998), the degree of industrialization in China, which was in the midst of an epoch of isolationism and discouragement of international trade, was declining in this period, despite being quite technologically advanced.

[5]In particular, Oded Galor and David N. Weil (1999, 2000) argue that the inherent positive interaction between population and technology during the Malthusian regime increased the rate of technological progress sufficiently so as to induce investment in human capital that led to further technological progress, a demographic transition, and sustained economic growth. Oded Galor and Omer Moav (2002) argue that natural selection is the origin of economic growth. Gary Hansen and Edward Prescott (2002) suggests that the transition from stagnation to growth reflects a transition from a stagnating agricultural economy to a growing industrial economy. Other recent growth models that capture some aspects of the long transition from stagnation to growth include Marvin Goodfriend and John McDermott (1995), Robert Lucas (2002), Tomas Kogel and Alexia Prskawetz (2001), McDermott (2002), Nils Lagerlof (2003), among others.

[6]Krugman and Venables (1995) and Baldwin et al. (2001) argued that the reduction in transportation and the associated expansion in trade, generated geographically based industrialization and divergence. Peter Howitt and David Mayer-Foulkes (2002) suggests that the that deferential timing in the introduction of the R&D labs across countries is a source of divergence.

[7]See , Ronald Findlay and Henryk Kierzkowski (1983) Gene Grossman and Elhanan Helpman (1991) and Kiminori Matsuyama, Alwyn Young (1991), among others.

in the world economy.[8] Furthermore, it generates a new insight regarding the distribution of the gains from trade. It demonstrates that even if trade affects output growth of the trading countries at the same rate, (due to the terms of trade effect),[9] output per capita may diverge since in one of the countries the growth of output will be generated primarily by population growth.

The theory is based on several fundamental elements. The interaction between these elements generates a dynamic pattern that is consistent with the observed asymmetrical evolution of the world economy from the epoch of Malthusian stagnation to the current era of sustained growth, characterized by widened international differences in income per capita and population growth rates, as well as by persistent patterns of comparative advantage.

Economies are initially in a Malthusian epoch in which the growth rate of output per capita is rather small and population growth is positively related to the level of income per capita. Technological progress leads ultimately to the adoption of more advanced agricultural and industrial technologies which paves the way for the take-off from the Malthusian epoch.

International trade induces technologically advanced economies to specialize in the production of skilled intensive manufactured goods whereas technologically inferior economies specialize in the production of unskilled intensive agricultural goods. The increase in the demand for human capital in the technologically advanced economies that is brought about by international trade induces investment in the human capital[10] and expedites the demographic transition, whereas the reduction in the demand for human capital in less advanced economies delays the demographic transition and investment in human capital.[11]

The analysis demonstrates that the acceleration of the demographic transition in the technologically advanced economies increases their formation of human capital and brings about sustained technological progress,[12] that enhances their comparative advantage in the production of

[8]Deardorff (1994, 1999) examine the effect of differing population growth rates on the world distribution of income in an international context. These papers show how diverging (exogenous) population growth rates can lead to widening international inequality.

[9]See for example Acemoglu and Ventura (2002).

[10]Consistent with empirical evidence, the increased demand for human capital has not resulted necessarily in an increase in the equilibrium rate of return to human capital due to a massive supply response generated by (a) the increase in the incentive for investment in education (for a given cost), and (b) institutional changes (e.g., the provision of public education) that lowered the cost of investment in human capital. See, Goldin and Katz (1998) for evidence regarding technology-skill complementarity during the 20th century.

[11]Unlike Becker [1981]'s hypothesis that a high level of income induces parents to switch to having fewer, higher quality children, the substitution of quality for quantity in this paper is in response to technological progress. The fact that demographic transitions occurred around the same period in Western European countries that differed in their income per capita, but shared a similar pattern of future technological progress, supports our technological approach.

[12]This link between education and technological change was proposed by Richard R. Nelson and Edmund S. Phelps [1966]. For supportive evidence see Easterlin (1981) and Mark Doms, Timothy Dunne, and Kenneth R.

skilled intensive industrial goods.[13] In contrast, the delay in the demographic transition in the less advanced economies increases the supply of unskilled workers and enhances the comparative advantage of these economies in the production of unskilled intensive goods. Thus, the historical patterns of international trade reinforced the initial patterns of comparative advantage and has generated a persistent effect on the distribution of population in the world economy and a great divergence in income per capita across countries and regions. The evidence indicates that the rapid transition of the currently developed economies into a state of sustained economic growth may have been related to the slow transition of less developed economies into a state of sustained economic growth.

2 Historical Evidence

This section provides some historical evidence that demonstrates that the fundamental hypothesis of this research is consistent with the process of development of the last two centuries, with particular reference to the experience of the UK and India and since the 19th century and their divergence, depicted in Figure 2.

2.1 Trade and Industrialization

During the 19th century, world 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.[Antoni Estavadeordal, Brian Frantz and Alan M. Taylor, 2002)] At the end of 19th Century 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. [Ronald Findlay and Kevin O'Rourke, 2001)]. As shown in Table 2, 40% of manufactured exports during this period was to non-European and North American economies

The expansion of international trade played an important contributory role in the process of industrialization in the UK and Europe (Joel Mokyr, 1985 and Nicholas Crafts, 1985). For the UK, the proportion of foreign trade to national income grew from about 10% in the 1780's

Troske (1997).

[13] 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 Nineteenth Century was not a source of convergence even among the advanced ' Greater Atlantic' trading economies. The richer economies - U.S.A. and Australia – had greater levels of school enrollments than the poorer ones, Denmark and Sweden.

to about 26% in the period 1837-45, and 51.5% in the period 1909-13. [Simon 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. [Simon 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 1870's [Mokyr, 1985]. Thus while 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. Kenneth Pomeranz (2000), however, 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. Clark and Feenstra (2001) establish that most of the Great Divergence occurred in the last two centuries and it is originated by differences in labor efficiency across countries. Moreover, they argue that international trade patterns reflected these differences in labor efficiency.

Non-industrialized economies were an important market for the export of the industrial economies, as exhibited in Table 2. Trade with Asia was especially significant for Britain. According to Paul Bairoch (1974) trade with Asia constituted over 20% of UK total exports throughout the nineteenth century. In contrast, trade with Asia was only 5% or less of French, German or Italian exports. UK imports from Asia were also much more important for the UK than for Europe. Bairoch estimates that 23.2% of UK imports were originated in Asian countries in 1860 as compared with 12.1% for continental Europe.

For India, however, international trade may well have played a vital role in the delay of the industrial revolution. As Chaudhuri (1983) argues "In India's case we know that external trade was of far greater importance for her in the past than it was later". This is especially the case in the period following the abolition of the East India Company's monopoly on Indian external trade in 1813. Chaudhuri (1983) describes 1813-1850 as a period of 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. Trade with the UK was fundamental in this process as Table 3 demonstrates.

Bairoch's (1974, 1982) analysis of international levels of industrialization and international trade supports the viewpoint that international trade was associated with a decrease in the per capita level of industrialization in India. As Table 1 suggests, the rapid industrialization in the UK in the nineteenth century was associated with a decline in the per capita level of industrialization in India. Furthermore, Bairoch (1974) found that industries that employed new technologies made up between 60 and 70 percent of the UK manufacturing industry in 1860 but less than 1 percent of manufacturing industries in the developing countries.[14]

China during the period was in the midst of a policy of self-imposed isolation and was also, as Table 1 shows, experiencing decreases in its level of per capita industrialization. After a brief period of interest in foreign exploration at the start of the fifteenth century during which huge fleets were built, the position had turned around by the end of the fifteenth century. As described by Landes (1998) "By 1500, anyone who built a ship of more than two masts was liable to the death penalty, and in 1525 coastal authorities were enjoined to destroy all ocean-going ships and arrest their owners. Finally in 1551 it became a crime to go to sea on a multimasted ship, even for trade". This era of isolationism was to last over four hundred years during which European technological advances left China far behind.

2.2 Industrialization and Demographic Transition

For the major part of human existence economies appear to have been in a state of Malthusian stagnation. Diminishing returns to labor along with a positive effect of the standard of living on the growth rate of population provided a self equilibrating role for the size of the population in a stationary economic environment. Changes in the technological environment or in the availability of land led to larger but not richer population. The growth rate of output per capita had been negligible over time and the standard of living had not differed greatly across countries. For instance, the average growth rate of GDP per capita in Western Europe in the years 0-1000 was nearly zero and only 0.14% in the years 1000-1820 (Angus Maddison, 2001). Similarly, the pattern of population growth over this era followed the Malthusian pattern. The average annual rate of population growth in Western Europe was 0% between the years 0 and 1000 and 0.1% in the years 1000-1820 (Maddison, 2001), and world population grew at an average pace of less than 0.1% per year from the year 1 to 1750 (Massimo Livi-Bacci, 1997), reflecting the slow pace of resource expansion and technological progress. Fluctuations in population and wages also reflected the structure of the Malthusian regime. Negative shocks to population, such as the Black Death, were reflected in higher real wages and faster population growth. Finally, differences in technology

[14] This contrasts with the experience of the non-UK European economies which produced more of the 'new technology' goods and which traded with themselves to a greater extent, (Bairoch, 1974).

were reflected in population density but not in standards of living. Prior to 1800 differences in standard of living between countries were relatively small despite the existence of wide differences in technology (Richard Easterlin, 1981, and Lucas, 2002).

The emergence from Malthusian stagnation in Europe was initially very slow, (Maddison, 2001). During this slow transition, the Malthusian mechanism linking higher income to higher population growth continued to function, but the reduction in resources per capita caused by higher population was counteracted by technological progress, which allowed per capita income to keep rising. The average growth of output per capita over the period 1820-1870 rose to an annual rate of 1.0 percent along with an impressive increase in education.[15] As depicted in Figure 3, during this time interval, fertility rates increased in most of Western Europe until the second half of the nineteenth century, peaking in England and Wales in 1871 and in Germany in 1875. (Tim Dyson and Mike Murphy, 1985, and Ansley J. Coale and Roy Treadway, 1986).[16] Furthermore, the acceleration in technological progress increased the return to human capital and ultimately triggered a demographic transition in which fertility rates declined rapidly, paving the way to an era of sustained economic growth.[17] The level of resources invested in each child increased and population growth fell, bringing about a sustained average annual increase in income per capita of 2.2 percent over the period 1929-1990.

Figure 4 shows that in the UK, population growth increased rapidly during the industrial revolution before declining sharply in the twentieth century. Western Europe has a similar although less dramatic pattern. In contrast India and China have not until recently experienced a rapid increase in industrialization and have seen population growth increase with income in a Malthusian manner (see Landes (1998) and McEvedy and Jones (1978)).

2.3 Industrialization and Human Capital Accumulation

The process of industrialization in the UK was characterized by a gradual increase in the relative importance of human capital accumulation. In the first phase of the Industrial Revolution (1760-

[15] See the next section, but for example, 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 1852-56 and 9.1 for the cohort born 1897-1906. (Robert C. O. Matthews, Charles H. Feinstein, and John C. Odling-Smee, 1982).

[16] In addition, as living standards rose, mortality fell. Between the 1740s and the 1840s, life expectancy at birth rose from 33 to 40 in England and from 25 to 40 in France (Livi-Bacci, 1997). Mortality reductions led to growth of the population both because more children reached breeding age and because each person lived for a larger number of years.

[17] The reduction in fertility was most rapid in Europe around the turn of the century. In England, for example, live births per 1000 women aged 15-44 fell from 153.6 in 1871-80 to 109.0 in 1901-10 (Wrigley, 1969). The exception was France, where fertility started to decline in the early 19th century.

1830), capital accumulation as a fraction of GNP increased significantly whereas literacy rates remained largely unchanged. Skills and literacy requirements had been minimal and the state devoted virtually no resources to raise the level of literacy of the masses, and economic growth was not impeded by educational retardation.[18]. Workers developed skills primarily through on-the-job training, and child labor was highly valuable. Consequently, literacy rates had not increased during the period 1750-1830 (Sanderson, 1995, pp. 2-10). The requirements for technical skills in that period, were slight and adequately met by traditional means (Green, 1990, pp. 293-294). 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."[19]

In the second phase of the industrial revolution, industrialization causes an increase in the demand for human capital by the industrial sector.[20] Capital accumulation subsided, the education of the labor force markedly increased and skills became necessary for production.[21] The investment ratio increased from 6 percent in 1760 to 11.7 percent in the year 1831, but it remained around 11% on average in the period 1856-1913 (Crafts 1985, p. 73 and Matthews et al 1982, p. 137).[22] In contrast, the second half of the nineteenth century was marked by a great expansion of education in the UK. The average years of schooling of the male labor force of England which did not change significantly until 1830s, tripled by the beginning of the twentieth century [Matthews et al (1982), p 573] and school enrollment at the age of 10 increased from 40% in 1870 to 100% in 1900.[West, 1985]. This increase in human capital investment was in part a response to an increase in demand for skilled labor by industrialists. The British government

[18]As argued by Mitch (1992 pp. 14-15), during the first stages of the Industrial Revolution, literacy was largely a cultural skill or a hierarchy symbol that had limited value in the labor market. 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.

[19]Furthermore, some have argued that the low skill requirements have even declined over this period. For instance, Sanderson (1972, p. 89) suggests that "One thus finds the interesting situation of an emerging economy creating a whole range of new occupations which require even less literacy and education than the old ones."

[20]The increased demand for human capital has not resulted necessarily in an increase in the return to human capital due to a supply response generated by (a) the increase in the incentive for investment in education (for a given cost), and (b) institutional changes (e.g., the provision of public education) that lowered the cost of investment in human capital. Hence the lack of non-controversial evidence about the increase in the return to skilled labor in the second phase of the industrial revolution should not raise doubts about the validity of the theory.

[21]From the 1850s, job advertisements suggest that literacy has become an increasingly desired characteristic for employment (Mitch, 1993, p. 292).

[22]The emergence of human capital as a prime engine of economic growth in the second phase of the Industrial Revolution, channeled resources towards investment in human capital as well as investment in physical capital. Consequently, although aggregate investment in human and physical capital had increased, measured saving rates (where national accounts consider investment in education as expenditure) remained constant.

responded to this demand by setting up in 1868 the Parliamentary Select Committee on Scientific Education which lead to the 1870 Education Act and the 1902 Balfour Act - the education reform in England that marked the consolidation of a national education system and the creation of a publicly supported secondary school system.

A similar pattern occurred in other European countries as well as in the USA and Canada. As argued by Abramovitch (1993 p.224) "In the nineteenth century, technological progress was heavily biased in a physical capital-using direction. ... In the twentieth century, however, the physical capital-using bias weakened; it may have disappeared altogether. The bias shifted in an intangible (human and knowledge) capital-using direction and produced the substantial contribution of education and other intangible capital accumulation to this century's productivity growth...". Indeed, evidence provided by Goldin and Katz (2001) and Abramovitz and David (2000) suggest that over the period 1890-1999 in the United States the contribution of human capital accumulation to the growth process has nearly doubled whereas the contribution of physical capital has declined significantly.[23]

Education was not expanded to a similar degree in India in the 19th Century. As noted by Aparna Basu (1974), during the nineteenth 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 1917-8) but nevertheless, attempts to expand primary education in the twentieth century were hampered by poor attendance and high drop out rates, which may suggest that the rate of return to 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 twentieth century Barro and Lee report that in 1960 72.2 percent of Indians aged 15 and above had "no schooling" compared with 2 percent in the UK.

[23]Goldin and Katz (2001) show that the rate of growth of educational productivity was 0.29% per year over the period 1890-1915, accounting for about 11% of the 1.8% annual growth rate of output per capita over this period. In the period 1915-1999, the rate of growth of educational productivity was 0.53% per year accounting for about 20% of the 1.8% annual growth rate of output per capita over this period. (The labor share is assumed to be 0.7 over the entire 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 has declined from an average of 56% in the period 1800-1890 to 31% in 1890-1927 and 21% in the period 1929-1966. Similarly, Denison (1962, p 270) suggests that the contribution of capital accumulation accounted for 22% of the growth rate in output per capita in the period 1909 - 1929 and 9% in the period 1929-1957, whereas the contribution of human capital accounted for 15% and 21%, respectively.

3 An Autarkic Economy

This section analyzes the path of a closed economy from its Malthusian pre-industrial state through a transitional state of increased fertility, investment in human capital and economic growth to a modern state with high investment in human capital, low population growth, and sustained economic growth.

Consider an overlapping generations economy in which economic activity extends over infinite discrete time. In every period t two goods, a manufactured good, Y_t^m, and an agricultural good Y_t^a, may be produced using up to three factors of production, skilled labor, H_t, unskilled labor, L_t, and land, X. The supply of skilled and unskilled labor are endogenously determined and evolve over time, whereas the quantity of land is exogenously determined and remains constant over time.

3.1 Production

In each of the sectors of the economy production may take place with either an old technology or a new one. In early stages of development the new production technologies are latent and production is conducted using the old technologies. However, in the process of development the productivity of the new technologies grows faster than those of the old technologies and ultimately the new technologies become economically viable. In the agricultural sector the introduction of the new technology represents the escape from the Malthusian trap, where wages do not fall despite an increase in population. In the industrial sector the introduction of the new technology reflects an increase in the skill-intensity of the production process in the second phase of the industrial revolution and the associated increase in the demand for human capital.

3.1.1 Production of the Agricultural Good

The agricultural good can be produced by either an old technology or a new one. The output of the agricultural good produced with the old technology in period t, $Y_t^{a,0}$, is

$$Y_t^{a,0} = a_t^a (L_t^{a,0})^\gamma X^{1-\gamma}; \qquad\qquad 0 < \gamma < 1, \tag{1}$$

where $L_t^{a,0}$ is the amount of unskilled labor and X is the amount of land employed in period t in the production of the agricultural good using the old technology, and a_t^a is the level of productivity of the old technology in period t. For simplicity the amount of land is normalized such that $X = 1$.

The output of the agricultural good produced with the new technology in period t, $Y_t^{a,N}$, is governed by a constant returns to scale production technology[24]

$$Y_t^{a,N} = A_t^a L_t^{a,N}, \tag{2}$$

where $L_t^{a,N}$ is the amount of unskilled labor employed in the production of the agricultural good in period t using the new technology, and A_t^a is the level of productivity of the new technology in period t. Appendix B demonstrates that the qualitative analysis remains intact if the agricultural sector remains land-intensive.

As will become apparent, in the early stages of development when the productivity of the new technology, A_t^a, is low relative to the productivity of the old technology, a_t^a, only the old technology will be employed. However in later stages of development, when A_t^a rises sufficiently relative to a_t^a, the new technology becomes economically viable.

3.1.2 Production of the Manufactured Good

The manufactured good can be produced by either an old technology or a new one. The output of the manufactured good produced with the old technology in period t, $Y_t^{m,0}$, is

$$Y_t^{m,0} = a_t^m L_t^{m,0}, \tag{3}$$

where $L_t^{m,0}$ is the amount of unskilled labor employed in period t in the production of the manufactured good using the old technology, and a_t^m is the level of productivity of the old industrial technology in period t.[25]

The output of the manufactured good produced with the modern technology in period t, $Y_t^{m,N}$, is governed by a neoclassical constant returns to scale production function,

$$Y_t^{m,N} = A_t^m F(H_t^m, L_t^{m,N}) = A_t^m f(h_t^m) L_t^{m,N}, \tag{4}$$

where $h_t^m \equiv H_t^m / L_t^{m,N}$, A_t^m is the level of productivity of the new industrial technology in period t, and $L_t^{m,N}$ and H_t^m are the amounts of unskilled labor and skilled labor employed in the production of the industrial good in period t using the new technology.

As will become apparent, in early stages of development when the technological level A_t^m is low relative to a_t^m only the old industrial technology is economically viable. However in the process of development as A_t^m rises sufficiently relative to a_t^m, it becomes profitable for producers to employ the new industrial technology.

[24] This production function is designed to capture the decline in the importance of land in mature state of development. However, the qualitative analysis would remain intact if the agricultural technology remains land-intensive, as established in Appendix B. Some economic historians have argued the Industrial Revolution was preceded by an agricultural revolution (e.g., Allen, Robert C., 1999) and the that total factor productivity in English agriculture at least tripled between 1300 and 1850 (Clark, 1991).

[25] The incorporation of capital would not affect the qualitative results, but will complicate the analysis considerably.

3.1.3 Factor Prices and Goods' Prices

Producers operate in perfectly competitive markets for final goods and for labor. In the absence of property rights to land, the return to land is zero and workers in the agricultural sector who use the old technology receive their average products.[26]

The inverse demand for unskilled labor in the agricultural sector, given (1) and (2), is therefore

$$w_t^u = \begin{cases} p_t a_t^a (L_t^{a,0})^{\gamma-1} & \text{if} \quad Y_t^{a,0} > 0 \\ \\ p_t A_t^a & \text{if} \quad Y_t^{a,N} > 0, \end{cases} \tag{5}$$

where w_t^u is the wage of an unskilled labor in terms of the manufactured good, and p_t as the relative price of the agricultural good in terms of the manufactured good in period t.

The inverse demand for skilled and unskilled labor in the manufactured sector, given (3) and (4), is therefore

$$w_t^u = \begin{cases} a_t^m & \text{if} \quad Y_t^{m,0} > 0 \\ \\ A_t^m[f(h_t^m) - h_t^m f'(h_t^m)] \equiv A_t^m w^u(h_t^m) & \text{if} \quad Y_t^{m,N} > 0, \end{cases} \tag{6}$$

and

$$w_t^s = A_t^m f'(h_t^m) \equiv A_t^m w^s(h_t^m) \quad \text{if} \quad Y_t^{m,N} > 0. \tag{7}$$

Moreover,

$$\frac{w_t^s}{w_t^u} = \frac{f'(h_t^m)}{f(h_t^m) - h_t^m f'(h_t^m)} = \omega(h_t^m) \quad \text{if} \quad Y_t^{m,N} > 0, \tag{8}$$

where as follows from the neoclassical properties of $f(h_t^m)$, $\omega'(h_t^m) < 0$.

Since unskilled workers are mobile between the agricultural and the industrial sectors, the wages of unskilled labor in both sectors are equal if both goods are produced. As follows from (5) and (6), p_t, the relative price of the agricultural good in terms of the manufactured good in period

[26] Since the fundamental mechanism explored in this paper focuses on the role of human capital accumulation and the demographic transition, rather than the role of capital and asset accumulation, in the process of development and in the emergence of sustained economic growth, this is a natural simplifying assumption. (See Galor and Weil (2000)). One could alternatively assume that the economy uses capital as a factor of production in agriculture and is small and open or that land is collectively owned and the proceeds distributed lump sum across the population. Allowing for capital accumulation and property rights to land in a closed economy context would complicate the model to the point of intractability.

t, is therefore

$$p_t = \begin{cases} \frac{a_t^m}{a_t^a (L_t^{a,0})^{\gamma-1}} & \text{if} \quad Y_t^{a,0} > 0 \text{ and } Y_t^{m,0} > 0 \\ \frac{a_t^m}{A_t^a} & \text{if} \quad Y_t^{a,N} > 0 \text{ and } Y_t^{m,0} > 0 \\ \frac{A_t^m w^u(h_t^m)}{a_t^a (L_t^{a,0})^{\gamma-1}} & \text{if} \quad Y_t^{a,0} > 0 \text{ and } Y_t^{m,N} > 0 \\ \frac{A_t^m w^u(h_t^m)}{A_t^a} & \text{if} \quad Y_t^{a,N} > 0 \text{ and } Y_t^{m,N} > 0. \end{cases} \tag{9}$$

3.2 Individuals: Fertility, Human Capital and Consumption

Individuals live for two periods. In their first period of life they consume a fraction of their parental unit time endowment; educated offspring require a larger fraction of parental time. In their second period of life they are endowed with one unit of time which they optimally allocate between child rearing and labor force participation.

3.2.1 Preferences and Budget Constraints

Individuals make optimal decisions over fertility, consumption and the training of their offspring (Becker (1976)). Individuals face subsistence consumption constraint that they must consume a subsistence level of the agricultural good, $\widetilde{c}$.[27]

Individual's preferences are defined over consumption and the potential aggregate income of their children. The preferences of a member of generation t (i.e. an individual who is born in period $t-1$) are represented by the utility function,[28]

$$u_t = (c_t^a)^\alpha (c_t^m)^\beta [w_{t+1}^s n_t^s + w_{t+1}^u n_t^u]^{1-\alpha-\beta}, \tag{10}$$

where c_t^a and c_t^m are the consumption of the agricultural good and the consumption of the manufactured good respectively. $\Sigma_{\{i=s,u\}} w_{t+1}^i n^i$ is the total potential income of the individual's offspring where n_t^s is the number of offspring trained to be skilled workers, n_t^u is the number of offspring trained to be unskilled workers, and w_{t+1}^s, and w_{t+1}^u are the wages paid to skilled and unskilled

[27] As will become apparent, the presence of a subsistence consumption constraint generates the Malthusian positive income elasticity of population growth at low income levels.

[28] A Stone-Geary utility function of the form: $u_t = (c_t^a - \widetilde{c})^\alpha (c_t^m)^\beta [w_{t+1}^s n_t^s + w_{t+1}^u n_t^u]^{1-\alpha-\beta}$ would generate identical qualitative results. The second component of the utility function may represent either intergenerational altruism, or implicit concern about potential support from children in old age. The interpretation that emphasizes intergenerational altruism reflects an implicit bounded rationality on the part of the parent. Alternative formulations according to which individuals generate utility from the utility of their children, or from the actual aggregate income of their offspring would require parental predictions about fertility choices of their dynasty. These approaches would greatly complicate the model and we conjecture that they would not affect the qualitative results.

offspring in period $t+1$.[29]

Individuals optimally allocate their time between labor force participation and child rearing. They further optimally choose both the number and quality of children and the amount of each good to consume. Denoting the time required to bring up a skilled offspring as, τ^s, and the time required to bring up unskilled offspring as, τ^u, where $\tau^s > \tau^u$, the budget constraint of a member i of generation t, $i = s, u$, is

$$p_t c_t^a + c_t^m + w_t^i(n_t^s \tau^s + n_t^u \tau^u) \leq w_t^i.$$

3.2.2 Optimization

A member i of generation t chooses $\{c_t^a, c_t^m, n_t^s, n_t^u\}$ so as to maximize the utility function.

$$\{c_t^a, c_t^m, n_t^s, n_t^u\} = \arg\max (c_t^a)^\alpha (c_t^m)^\beta [w_{t+1}^s n_t^s + w_{t+1}^u n_t^u]^{1-\alpha-\beta}$$

such that, for $i = s, u,$:

$$p_t c_t^a + c_t^m + w_t^i(n_t^s \tau^s + n_t^u \tau^u) \leq w_t^i;$$

$$c_t^a \geq \widetilde{c}.$$

The optimization depends on whether the subsistence consumption constraint is binding. If income was high enough, the constraint would not bind and the log-linearity of the utility function would imply that fixed shares of potential income are devoted to child rearing and consuming each of the two goods. However if the subsistence consumption constraint binds then a greater share of potential income must be devoted to agricultural consumption.

The consumption of the agricultural good, c_t^a, by a member i of generation t is

$$c_t^a = \begin{cases} \widetilde{c} & \text{if} \quad \alpha \frac{w_t^i}{p_t} < \widetilde{c} \\ \\ \alpha \frac{w_t^i}{p_t} & \text{if} \quad \alpha \frac{w_t^i}{p_t} \geq \widetilde{c}. \end{cases} \tag{11}$$

The consumption of the manufactured good, c_t^m, by a member i of generation t is therefore

$$c_t^m = \begin{cases} \frac{\beta}{1-\alpha}(w_t^i - p_t \widetilde{c}) & \text{if} \quad \alpha \frac{w_t^i}{p_t} < \widetilde{c} \\ \\ \beta w_t^i & \text{if} \quad \alpha \frac{w_t^i}{p_t} \geq \widetilde{c}. \end{cases} \tag{12}$$

Furthermore, the number of educated and uneducated offspring will be determined such that the aggregate time devoted by a member i of generation t to child rearing is

[29] Modeling education as a discrete variable is a natural assumption given the two-sector international trade structure of model. Alternatively education could be modeled as a continuous choice variable, as in Galor and Weil (2002). This would result in an optimal level of education that all agents would choose. Countries would differ in this level of skill-intensity and hence in their productivity and their comparative advantage.

$$(n_t^s\tau^s + n_t^u\tau^u) = \begin{cases} \frac{1-\alpha-\beta}{1-\alpha}\frac{(w_t^i - p_t\widetilde{c})}{w_t^i} & \text{if} \quad \alpha\frac{w_t^i}{p_t} < \widetilde{c} \\ (1-\alpha-\beta) & \text{if} \quad \alpha\frac{w_t^i}{p_t} \geq \widetilde{c}, \end{cases} \tag{13}$$

where,

$$\begin{aligned} n_t^u = 0 \quad & \text{if} \quad w_{t+1}^s/w_{t+1}^u \geq \tau^s/\tau^u \\ n_t^s > 0 \text{ and } n_t^u > 0 \quad & \textit{only if} \quad w_{t+1}^s/w_{t+1}^u = \tau^s/\tau^u \\ n_t^s = 0 \quad & \text{if} \quad w_{t+1}^s/w_{t+1}^u < \tau^s/\tau^u. \end{aligned} \tag{14}$$

3.3 Education and Fertility Decisions

This section demonstrates that in early stages of development, when the technological level is relatively low, individuals do not have an incentive to invest in the human capital of their offspring. However, as the level of technology improves in the process of development, the new industrial technology will ultimately become economically viable, human capital will be demanded and individuals will have an incentive to invest in the human capital of their offspring.

Lemma 1 *Consider the new industrial sector. There exists a unique ratio of skilled to unskilled labor,* $(h^m)^*$, *such that*

$$\frac{w_t^s}{w_t^u} = \omega((h^m)^*) = \frac{\tau^s}{\tau^u}.$$

where,

$$n_t^u = 0 \quad \textit{if} \quad h_t^m < (h^m)^*$$

$$n_t^s = 0 \quad \textit{if} \quad h_t^m > (h^m)^*.$$

Proof. As established in (8), $\omega'(h_t^m) < 0$ and the uniqueness of $(h^m)^*$ follows. The remaining part is a Corollary of (14). □

Hence, if $h_{t+1}^m < (h^m)^*$ then individuals would not have an incentive to raise unskilled offspring and the skilled to unskilled ratio will increase, whereas if $h_{t+1}^m > (h^m)^*$ then individuals would not have an incentive to raise skilled offspring and the skilled to unskilled ratio will decline till $h_{t+1}^m = (h^m)^*$.

Corollary 1 *If the new industrial technology is employed then* $h_t^m = (h^m)^*$ *and there is an incentive to produced skilled and unskilled offspring, i.e.,*

$$h_t^m = (h^m)^* \quad \textit{if} \quad Y_t^{m,N} > 0,$$

and therefore

$$w_t^u = A_t^m w^u((h^m)^*) \quad if \qquad Y_t^{m,N} > 0;$$

$$p_t = \frac{A_t^m w^u((h^m)^*)}{A_t^a} \quad if \quad Y_t^{a,N} > 0 \text{ and } Y_t^{m,N} > 0.$$

3.4 Aggregate Labor Allocation

Since preferences are such that both goods are consumed in every period, in autarky both goods must be produced in every period. Hence an equilibrium in the goods market requires that, in a given technological state, the demand for the agricultural and the industrial goods given by (11) and (12) equal the supply of the two goods given by (1)-(4).

Lemma 2 *If both goods are produced with the old technology*

(a) The employment of labor in the agricultural sector is

$$L_t^{a,0} = \begin{cases} [\frac{\widetilde{c}}{a_t^a} N_t]^{1/\gamma} & if \quad \alpha \frac{w_t^u}{p_t} < \widetilde{c} \\ \alpha N_t & if \quad \alpha \frac{w_t^u}{p_t} \geq \widetilde{c}. \end{cases}$$

(b) The employment of labor in the industrial sector is

$$L_t^{m,0} = \begin{cases} \frac{\beta}{1-\alpha}(N_t - [\frac{\widetilde{c}}{a_t^a} N_t]^{1/\gamma}) & if \quad \alpha \frac{w_t^u}{p_t} < \widetilde{c} \\ \beta N_t & if \quad \alpha \frac{w_t^u}{p_t} \geq \widetilde{c}. \end{cases}$$

(c) The aggregate time devoted to child rearing is

$$n_t^u \tau^u = \begin{cases} \frac{(1-\alpha-\beta)}{(1-\alpha)}(N_t - [\frac{\widetilde{c}}{a_t^a} N_t]^{1/\gamma}) & if \quad \alpha \frac{w_t^u}{p_t} < \widetilde{c} \\ (1-\alpha-\beta) N_t & if \quad \alpha \frac{w_t^u}{p_t} \geq \widetilde{c}. \end{cases}$$

Proof. Follows from (11)-(13), (1) and (3), noting that $w_t^u/p_t = a_t^a (L_t^{a,0})^{\gamma-1}$. □

3.5 Viability of the New Technologies

The new industrial technology will become economically viable if the value of the marginal product of unskilled workers who use this new technology, $A_t^m w^u((h^m)^*)$, is at least as high as that of unskilled workers who use the old industrial technology, a_t^m.

The new agricultural technology will become economically viable if the value of the marginal product of unskilled workers who use this new technology, $p_t A_t^a$ is at least as high as the return to unskilled workers who use the old industrial technology, $p_t a_t^a (L_t^{a,0})^{\gamma-1}$.

Lemma 3 *(a) The new industrial technology is economically viable if*[30]

$$\frac{A_t^m}{a_t^m} \geq 1/[w^u((h^m)^*)].$$

(b) The new agricultural technology is economically viable if

$$\frac{A_t^a}{a_t^a} \geq (L_t^{a,0})^{\gamma-1}.$$

where the $L_t^{a,0}$ *is given by Lemma 2.*

Proof. (a) $Y_t^{m,N} > 0$ if the marginal productivity of unskilled labor in the new industrial sector is at least as high as in the old industrial sector. Hence part (a) follows from (6) and Corollary 1.

(b) $Y_t^{a,N} > 0$ if the marginal productivity of unskilled labor in the new agricultural sector is at least as high as in the old agricultural sector. Hence part (b) follows from (5). □

4 The Time Path of Macroeconomic Variables

4.1 Technological Progress

Suppose that the technological progress, g_{t+1}, that takes place between periods t and $t+1$ is affected positively by the adult population size, N_t, and by its skill intensity (i.e., the ratio of educated adults, H_t, in the entire adult population, N_t), $h_t \equiv H_t/N_t$, in period t.

$$g_{t+1} \equiv \frac{\lambda_{t+1} - \lambda_t}{\lambda_t} = g(h_t, N_t), \tag{15}$$

where $g(h_t, N_t)$ is an increasing concave function ($g_i(h_t, N_t) > 0$ and $g_{ii}(h_t, N_t) < 0$, $i = e_t, N_t$), and $g(0, N_t) > 0 \quad \forall N_t > 0$.[31] Furthermore, consistent with historical evidence, it is assumed that in the post-industrial revolution era human capital contributes to technological progress significantly more than population size (i.e. $g_1(h_t, N_t) \gg g_2(h_t, N_t)$).[32] Hence, for a sufficiently large population size, the rate of technological progress between time t and $t+1$ is a positive, increasing, strictly concave function of the size and level of education of the working generation at

[30]When $A^m w^u(h_m^*) = a^m$ then there is indeterminacy in the choice of how many skilled and unskilled offspring to produce. This indeterminacy can be resolved by assuming that *ceteris paribus* parents prefer educated children. The indeterminacy resolves itself after one period in any case as technology progresses.

[31]It should be noted that we assume that, for a sufficiently small population, the rate of technological progress is strictly positive only every several periods. That is, for a sufficiently small $N_t > 0$, $g(0, N_t) \geq 0$, $g_i(e_t, N_t) \geq 0$, for all t, and $g(0, N_t) > 0$, $g_i(e_t, N_t) > 0$, for some t. 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 indeed in a Malthusian steady-state. Clearly, if technological progress occurred in every time period at a pace that increased with the size of population, the growth rate of output per capita would always be positive, despite the adjustment in the size of population.

[32]This formulation accords with the recent account of Mokyr (2002), that argues that a transition from luck based innovation to purposeful innovation took place after the period of Enlightenment. See Kremer (1993) as well

time t. Furthermore, the rate of technological progress is positive even if the proportion of skilled labor is zero.

Suppose that the productivity levels in each sector are functions of the technological level in the economy as a whole.[33] Namely, the productivity of the old and the new technologies in the agricultural sector, a, and the industrial sector, m, are

$$\begin{aligned} A_t^j &= A^j(\lambda_t) \\ a_t^j &= a^j(\lambda_t) \end{aligned} \qquad j = a, m \tag{16}$$

where, $dA^j/d\lambda > 0$ and $da^j/d\lambda > 0$, $j = a, m$.

The productivity parameters are restricted so as to assure that the process of technological progress is consistent with its historical patterns:

(a) The new industrial and agricultural technologies are not economically viable in period 0, i.e.,

$$\begin{aligned} \tfrac{A_0^m}{a_0^m} &< 1/[w^u((h^m)^*)]; \\ \tfrac{A_0^a}{a_0^a} &< (L_0^{a,0})^{\gamma-1} = (\tfrac{\tilde{c}N_0}{a_0^a})^{\frac{\gamma-1}{\gamma}} \end{aligned} \tag{A1}$$

where $N_0 > 0$ is the initial size of the adult population.[34]

(b) The advancement in the productivity of the industrial sector is higher than that in the agricultural sector,[35] and the new technologies advance more rapidly that the old one, i.e.,[36]

$$\tfrac{dA^m(\lambda_t)}{d\lambda_t} > \tfrac{dA^a(\lambda_t)}{d\lambda_t} > \tfrac{da^m(\lambda_t)}{d\lambda_t} > \tfrac{da^a(\lambda_t)}{d\lambda_t} > 0; \quad \lim_{\lambda_t \to \infty} \tfrac{A^j(\lambda_t)}{a^j(\lambda_t)} = \infty \;\; j = a, m. \tag{A2}$$

Condition A2 ensures that a more technologically advanced economy has a comparative advantage in the industrial good[37].

[33] This formulation of technological progress that captures the spirit of a GPT, simplifies the analysis considerably.

[34] The last equality follows from Lemma 2.

[35] These assumption is consistent with historical evidence that suggests that productivity in the agricultural sector grew less rapidly than in the industrial sector over the late part of the 18th century and the entire 19th century. In particular, sectoral productivity growth in the UK in the period 1780-1860 was estimated by Donald N McCloskey, (1981) to be 1.8% in the Modernized sector and 0.45% in the agricultural sector. The gap was revised downward by C. Knick Harley (1999) who estimated productivity growth in the Modernized sector to be 1.2% and 0.7% in the agricultural sector.

[36] Despite the fact that modern production technology is not employed over a certain period of time, the advancement in knowledge permits the advancement in the productivity of this potential technology to be faster than the older one. For instance, early vintages of the steam engines were very inefficient and thus were not used. However, advancement in knowledge permitted this technology to advance rather rapidly and to become effective. Hence, the advancement in the latent technology is via learning by doing in the laboratory rather than in the industry.

[37] As follows from (9), condition A2 also has the implication that the relative price of the agricultural good is monotonically increasing over time. Evidence suggests that the relative price of agricultural goods rose over the period 1880-1920 and declined over the period 1920-1990. (Caselli and Coleman (1999)). This pattern can be easily matched if the cost of acquiring skills would vary over time. In particular, if the cost of acquiring skills is increasing through time, (i.e. τ^s/τ^u is increasing with λ.), the relative price of agricultural goods could decrease over time. This, in the context of the current model, the assumption of a fixed τ^s/τ^u is a reasonable simplifying assumption that has no qualitative implication on the main thesis.

Let $(t^m)^*$ be the time period in which the new industrial technology becomes economically viable, i.e., .

$$\frac{A_t^m}{a_t^m} \geq 1/[w^u((h^m)^*)] \quad \forall t \geq (t^m)^*,$$

and let $(t^a)^*$ be the time period in which the new agricultural technology becomes economically viable, i.e.,

$$\frac{A_t^a}{a_t^a} \geq ((L_t^{a,0})^*)^{\gamma-1} \qquad \forall t \geq (t^a)^*,$$

where $(L_t^{a,0})^*$ which is the level of employment in the old agricultural sector necessary for the old agricultural sector alone to satisfy the total demand for agricultural products at time t.

The existence of time periods $(t^a)^*$ and $(t^m)^*$ is derived in the appendix. In order to simplify the determination of factor prices, the new agricultural technology is assumed to become economically viable before the new industrial technology, i.e.,

$$(t^a)^* < (t^m)^*, \tag{A3}$$

This assumption assures that the static structure of the model reassembles the Ricardo-Viner trade model. In any period wages of skilled and unskilled workers are determined by either the constant marginal productivity of unskilled labor in the old industrial sector (prior to the employment of the modern agricultural technology), or the constant marginal productivity of unskilled workers in the agricultural sector (once the modern agricultural technology is used). As established in Appendix B, the qualitative result would not be affected is this structure will not be imposed.

4.2 Human Capital Accumulation

The proportion of skilled labor in the adult population at time $t+1$, h_{t+1}, depends only on the technological level λ_{t+1}, as follows from (14), Lemma 2 and (A3). Parents' fertility decisions in the period t are based on their rational expectation of the relative wage rate of skilled and unskilled labor in the period $t+1$, w_{t+1}^u/w_{t+1}^s, which in turn depends on the level of technology in the period $t+1$, λ_{t+1}.[38] Hence,

$$h_{t+1} = h(\lambda_{t+1}), \tag{17}$$

[38] The qualitative analysis would not be altered if the growth rate of technology would affect the return to human capital. As is established in Appendix B, if the agricultural technology remains land-intensive then it is the rate of growth of technology that is vital. Although the threshold and the rate of growth models are theoretically distinct mechanisms, they are both consistent with the same set of facts i.e. a growing rate of technological change occurring alongside an increase in the rate of human capital accumulation and a non-monotonic relationship between population growth and income.

4.3 Population Dynamics

The size of the adult population in period $t+1$, N_{t+1}, depends on three variables: the adult population in period t, N_t, the income level and income distribution of the adult population in period t, which are determined by λ_t, and the demand for skilled and unskilled workers in period $t+1$, which are determined by λ_{t+1}. Hence,

$$N_{t+1} = n(\lambda_{t+1}, \lambda_t, N_t). \tag{18}$$

5 The Evolution of the Economy

The evolution of the economy is determined by dynamical system given by equations (15) and (18), noting (17). This section analyzes the evolution of the economy through qualitatively distinct stages as the new agricultural technology becomes economically viable and subsequently the new industrial technology becomes economically viable. As will become apparent in the first stage the economy is in a Malthusian epoch. Ultimately due to technological progress the economy experiences a take-off to a modern industrial stage, where the transition between the two stages population growth first rises and then falls.

5.1 The Malthusian Stage

In early stages of development (i.e., $t < (t^a)^*$) the new technology in both sectors is not economically viable. The economy is in a state where individuals are constrained in their choices by the subsistence consumption constraint. The share of the agricultural sector in production is thus higher than in subsequent stages and the budget share of manufactured goods is lower. Since the new industrial technology is not economically viable, there is no demand for skilled labor and there is thus no human capital accumulation. The rate of technological progress is therefore slow since $g_{t+1} = g(0, N_t)$. This accords with stylized facts for Europe before the industrial revolution, see Maddison (1982, 1995).

Population Dynamics in the Malthusian Stage

In the Malthusian stage since the new production technology in the industrial sector is not economically viable there is no demand for skilled labor. Parents therefore only rear unskilled children. The old agricultural production technology has a fixed factor of production - land - and so there are decreasing returns to scale to labor. Thus for a given level of technology, as population rises, the land-labor ratio falls, and wages fall. As stated in Lemma A1 in the appendix, under reasonable conditions this will be a stable process whereby population tends to a steady state level for a given level of technology.

Technological progress has no effect on the real wage rate, $w_t/p_t = a_t^a(L_t^{a,0})^{\gamma-1}$, and just allows for a larger level of population. Technological progress initially causes output per worker to increase which in turn increases wages and fertility and causes the population to rise. The average product of labor thus falls and in the absence of further technological progress, real wages fall back to the long run level of $\widetilde{c}(1-\alpha-\beta)/[(1-\alpha-\beta)-(1-\alpha)\tau^u]$.

5.2 The Population Expansion Stage

In intermediate stages of development (i.e., $(t^a)^* < t < (t^m)^*$) the new technology in the industrial sector is not economically viable and hence there is still no demand for skilled labor. Parents thus only rear unskilled offspring. The market equilibrium is very similar to that in the Malthusian stage except that in this stage the new agricultural production technology is economically viable and the wage rate of unskilled labor is therefore $p_t A_t^a$.

The important difference between this stage and its predecessor is that the Malthusian check on the economy is no longer present. In this stage increased population does not reduce the real wage and so from this point onwards the unskilled wage rises with the level of technology. As follows from (11), (12) and (13) the budget share devoted to fertility and manufactured goods will increase and the population increases throughout this stage according to the equation

$$N_{t+1} = \frac{(1-\alpha-\beta)}{(1-\alpha)\tau^u}(1-\frac{\widetilde{c}}{A_t^a})N_t.$$

5.3 Industrialization and Demographic Transition

In advanced stages of development (i.e., $t > (t^m)^* > (t^a)^*$) the new industrial technology is economically viable and there is a demand for skilled labor. The ratio of skilled to unskilled labor employed in the economy at time $t+1$, h_{t+1}, is determined by the fertility decisions of the adult agents in period t, which are based on the expected relative wage rates of skilled and unskilled labor in period $t+1$, w_{t+1}^u/w_{t+1}^s, and also by the demand side of the economy.

As established in Lemma A3 in the Appendix, there is a unique market clearing level of h_{t+1} for all values of λ_{t+1} and that the level of h_{t+1} is non-decreasing in λ_{t+1} The Lemma presents the initial case where λ_{t+1} is such that both skilled and unskilled workers will be constrained by the subsistence constraint. The analysis for the subsequent case where unskilled workers will be constrained by the subsistence constraint but skilled workers will not, follows trivially from this analysis.

In this stage there is thus a self-reinforcing relationship between technological progress and the human capital intensity of the economy which causes both the rate of technological progress and the level of human capital accumulation in the economy to rise. From equation (15) an increased level of h_t increases λ_{t+1} and from Lemma A4 an increase in λ_{t+1} increases h_{t+1}. This process creates two opposing forces on the population growth rate as the following section describes.

Population Dynamics in the Stage of Demographic Transition

The growing levels of technology and skill intensity apply two conflicting pressures on the rate of population growth. On the one hand they increase in the wage level which leads to an increase in the budget share of manufactured goods which in turn raises the demand for skilled workers and so tends to lower the fertility rate since $\tau^s > \tau^u$. However on the other hand increases in the wage level allows more resources to be devoted to raising children which exerts a positive influence on the fertility rate. The number of skilled and unskilled offspring produced in this stage is derived in the following Lemma whereas Corollary 2 establishes the conditions under which fertility has the inverted 'U' shaped relationship with income per capita as has been observed in many developed economies.

Lemma 4 *If the new technologies are economically viable in both sectors, and if the subsistence constraint is binding for skilled and unskilled workers in period* $t+1$, *then under symmetry, the number of skilled offspring,* $n_t^{i,s}$, *and unskilled offspring,* $n_t^{i,u}$ *of individual* i *in period* t *is determined by*

(i) The total number of offspring n_t^i, *of an individual* i, $i = u, s$, *is,*

$$n_t^i = \frac{(1-\alpha-\beta)(1-p_{t+1}\widetilde{c}/w_{t+1}^i)(1+h_{t+1})}{[(1-\alpha)(\tau^u + h_{t+1}\tau^s)]}.$$

(ii) The ratio of skilled to unskilled offspring of individual i, $n_t^{i,s}/n_t^{i,u}$, *is*

$$\frac{n_t^{i,s}}{n_t^{i,u}} = h_{t+1}.$$

Proof. The level of h_{t+1} together with the assumption of symmetry determines the ratio of $n_t^{i,s}$ to $n_t^{i,u}$ since $h_{t+1} = n_t^{i,s}/n_t^{i,u}$. This directly implies condition (ii) of the proposition. Thus $n_t^i = [1 + h_{t+1}]n_t^{i,u}$ and similarly $(n_t^{i,u}\tau^u + n_t^{i,s}\tau^s) = n_t^{i,u}[\tau^u + h_{t+1}\tau^s]$. This together with the first order condition, equation(13) implies condition (i) □

This Lemma demonstrates, as stated above, that there are two opposing forces on the population growth rate in this stage of development. On the one hand the increase in the wage level leads to an increase in the budget share of manufactured goods, which raises the demand for skilled workers. Since $\tau^s > \tau^u$, this exerts a negative influence on the fertility rate. On the other hand the increase in the wage level also allows more resources to be devoted to raising children which exerts a positive influence on the fertility rate. The following Corollary shows that it is possible to restrict parameters so that fertility has an inverted 'U' shaped relationship with income per capita over time.

Corollary 2 *If the new technology is economically viable in the manufacturing sector, the rate of population growth will eventually fall towards a lower level if* $(1-\alpha-\beta)(1+\widehat{h})/(\tau^u+\widehat{h}\tau^s)$ *is sufficiently small and positive, where* $\widehat{h} = (\beta h^m)^*/[(\alpha+\beta)(1+(h^m)^*)+\alpha(h^m)^*((\tau^s-\tau^u))/\tau^u)]$.

Proof. As λ_{t+1} increases real wages increase and eventually no agents will be bound by the subsistence constraint. In this case condition (ii) of Lemma 4 becomes $n_t^i = (1-\alpha-\beta)(1+\widetilde{h})/(\tau^u+\widetilde{h}\tau^s)$. □

5.4 The Modern Industrial Stage

When the level of technology rises sufficiently for the subsistence constraint not to bind for any agent, the economy reaches a state where the population growth rate and the skill intensity of the economy are constant. Since no agent is bound by the subsistence constraint, the budget share devoted to manufactured goods and the level of human capital accumulation will be higher than in the previous stages and from Corollary 2 the fertility rate will be low. This implies that growth will also, *ceteris paribus,* be higher given the properties of $g_{t+1} = g(h_t, N_t)$ given by Lemma (15).

Proposition 1 *If the new technologies are economically viable in both sectors and neither skilled nor unskilled workers are constrained by the subsistence constraint, the economy is in a state of balanced growth with a constant population growth rate and skill intensity.*

Proof. As follows from (11) and (12), the demand ratio $p_t c_t^a / c_t^m = \alpha/\beta$. Thus using the structure of the analysis in Lemma A2, the unique equilibrium level of h_{t+1} equals $\widetilde{h}$, where $\widetilde{h}$ is the constant defined above in Corollary 2. Furthermore, following the analysis in Lemma 4, using (13), the total fertility of all agents is given by $n = (1-\alpha-\beta)(1+\widetilde{h})/(\tau^u+\widetilde{h}\tau^s)$. □

Corollary 3 *If the new technologies are economically viable in both sectors and neither skilled nor unskilled workers are constrained by the subsistence constraint, the budget share devoted to manufactured goods and the level of human capital accumulation will be higher than in the previous stages and the fertility rate will be lower.*

Proof. This follows from the first order conditions, equations (11), (12) and (13), Lemma A4 and Corollary 2. □

6 International Trade and the Process of Development

This section analyzes the effect of international trade on the transition of economies from a Malthusian epoch, through a demographic transition, to state of sustained economic growth. The analysis demonstrates that international trade accelerates the transition of technologically advanced economies to a state of sustained growth, whereas it prolongs the transition of less advanced economies to a state of sustained economic growth, perhaps indefinitely.

6.1 Comparative Advantage

Suppose that the world economy consists of two economies that are identical in every respect except for their level of technology. In particular, economy A is more technologically advanced than economy B and therefore possesses better advanced technologies for the production of the industrial good as well as the agricultural good, i.e.,

$$\begin{aligned} [A_t^m]^A &> [A_t^m]^B; \\ [A_t^a]^A &> [A_t^a]^B. \end{aligned} \tag{19}$$

Furthermore, since technological progress in the industrial sector is faster than in the agricultural sector, the industrial technology is relatively more advanced in economy A, and the technologically advanced country has a comparative advantage, A, in the production of the industrial good,.i.e.,

$$\left\{\frac{A_t^m}{A_t^a}\right\}^A > \left\{\frac{A_t^m}{A_t^a}\right\}^B. \tag{20}$$

6.2 Autarkic and Trade Equilibrium

Suppose that international trade does not take place prior to the stage in which the new production technologies become economically viable. As established above, since technological advancement is biased towards the industrial sector, the autarkic relative price of the agricultural good, p^A, in the technologically advanced economy A, is higher than the autarkic relative price of the agricultural good, p^B, in the less technologically advanced economy B. That is, as follows from (9) and Corollary 1, once the two advanced technologies are economically viable in both economies, i.e., $[Y_t^{a,N}]^i > 0$ and $[Y_t^{m,N}]^i > 0$, for $i = a, b$,

$$\begin{aligned} p_t^A &= \frac{[A_t^m]^A w^u((h^m)^*)}{[A_t^a]^A}; \\ p_t^B &= \frac{[A_t^m]^B w^u((h^m)^*)}{[A_t^a]^B}, \end{aligned} \tag{21}$$

where as follows from (20),

$$p_t^A > p_t^B. \tag{22}$$

As international trade is established between the two countries, the international equilibrium relative price of the agricultural good, p_t^*, is determined in between the autarkic equilibrium prices, p_t^A and p_t^B of the two economies.

$$p_t^B \leq p_t^* \leq p_t^A. \tag{23}$$

6.3 Patterns of Specialization

International trade therefore causes each of the countries to specialize relative to their position in autarky. Furthermore, it follows from (20) and (21) that one of the economies completely specializes in production. (If $p_t^B < p_t^* < p_t^A$, the two economies completely specialize in production).[39] From the viewpoint of the technologically advanced economy, A, there is reduction in the relative price of the agricultural good, and producers are induced to produce more of the industrial good. From the viewpoint of the less advanced economy, B, there is an increase in the relative price of the agricultural good and producers are induced to produced more of the agricultural good. International trade, therefore induces Country A to specialize in the production of the industrial, skilled

[39] This determination of the patterns of comparative advantage by this semi-Ricardian structure is consistent with recent evidence provided by Antonio Estavadoerdal and Alan M. Taylor (2002) which shows that the Heckesher-Ohlin structure does not fit well the patterns of trade in 1913.

intensive, good, whereas Country B is induced to specialize in the production of the agricultural good.

6.4 Trade and Population Growth

The effect of international trade on the patterns of specialization in production in period t, affects the demand for skilled and unskilled labor in the two economies in period t, and generates an advanced supply response from parents who are taking decisions about the optimal number of skilled and unskilled children to raise in period $t-1$ in light of the expected rate of return for skilled and unskilled workers in period t.

Proposition 2 *If the world economy is opened to international trade:*

(a) The rate of population growth of the technologically advanced economy, A, is affected negatively

(b) The rate of population growth of the technologically less advanced economy, B is affected positively.

Proof.

(a) Since $p_t^B \leq p_t^* \leq p_t^A$, international trade increases necessarily the production of the skilled intensive industrial good in economy A (even if the economy remains diversified). The ratio of skilled workers in the economy $[h_t]^A$ would increase and since the production of skilled children requires more time, the rate of population growth declines. In particular, if $p_t^* < p_t^A$ then economy A completely specializes in the production of the industrial good, $[h_t^m]^A = (h^m)^*$ and as follows from Lemma 1, population growth decreases.

(b) Since $p_t^B \leq p_t^* \leq p_t^A$, international trade increases necessarily the production of the unskilled intensive agricultural good in economy B (even if the economy remains diversified). The ratio of skilled workers in the economy $[h_t]^B$ would decline and since the production of unskilled children requires less time, the rate of population growth rises. In particular, if $p_t^B < p_t^*$ then economy B completely specializes in the production of the agricultural good, $[h_t^m]^B = 0$ and as follows from Lemma 1, population growth increases. □

Population growth in the two economies prior to the demographic transition is affected positively by the aggregate resources of the economy and negatively by the rate of return to human capital. The effect of international trade expedites the demographic transition in the technological advanced economy, A, whereas it slows it down in the technologically less advanced economy, B.

Proposition 3 *If the world economy is opened to International trade*

(a) The demographic transition of the technologically advanced economy, A, is accelerated

(b) The demographic transition of the technologically less advanced economy, B, is delayed,, perhaps indefinitely,

Proof. As established below in Proposition 4, international trade widens the technological gap between the advanced and the less advanced economies. The relative income of economy B in the world economy depends on its rate population growth relative to that of the advanced economy A. If the share of income of economy B in the world economy falls over time then economy B could completely specialize in agricultural production, and the economy would never generate a demand for skilled workers and would therefore not experience a demographic transition. Alternatively if the relative share of income of economy B in the world economy rises over time then ultimately the output of the manufactured good from economy A will be insufficient to meet world demand, and economy B would begin demanding skilled workers and eventually would experience a demographic transition. For economy A international trade increases the rate of technological progress and thereby the demand for skilled labor, accelerating the demographic transition. □

6.5 Trade and the Technological Gap

This initial effect of international trade on population growth will persist, and the initially less advanced economy will become even relatively less advanced through time.

Proposition 4 *International trade widens the technological gap between the advanced and less advanced economies.*

Proof. As follows from (15), the increased in the proportion of skilled workers $[h_t]^A$ in the technologically advanced economy increases the rate of technological progress in the economy, whereas the reduction in the proportion of skilled workers $[h_t]^B$ in the technologically less advanced economy, decreases its rate of technological progress. Since $g_1(h_t, L_t) \gg g_2(h_t, L_t)$ the proposition follows. □

Corollary 4 *International trade reinforces the initial patterns of comparative advantage.*

7 Concluding Remarks

This research argues that the Great Divergence in income levels across countries as well as the current distribution of world population can be attributed, in part, to the contrasting effects that the rapid expansion of international trade in the second phase of the industrial revolution played in the timing of the demographic transition in industrial and non-industrial countries. In industrial economies international trade enhanced the specialization in the production of skilled intensive goods and stimulated technological progress. The rise in the demand for skilled labor induced an investment in the quality of the population, expediting the 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, the specialization in the production of unskilled intensive goods that was brought about by international trade reduced the demand for skilled labor and provided limited incentives to invest in population quality. The demographic transition was therefore delayed, increasing further the abundance of unskilled labor in these economies and enhancing their comparative disadvantage in the production of skilled intensive goods. International trade has therefore widened the gap between the technological level as well as the skill abundance of industrial and non-industrial economies, enhancing the initial patterns of comparative advantage and generating sustained differences in income per capita across countries. The gains from trade were channelled towards an increase in population in non-industrial economies and an increase in the income of the existing population in industrial economies.

The asymmetric effect of international trade on the timing of the demographic transition in developed and less-developed economies, and its persistent effect therefore on the initial patterns of comparative advantage, may suggest that the rapid transition of the currently developed economies into a state of sustained economic growth is associated with the slow transition of less developed economies into a state of sustained economic growth.

The economic history of the UK, India and China is consistent with the thesis that international trade played a significant role in the timing of the demographic transition and in the process of industrialization. Historical evidence suggests that during the nineteenth century the intensive trade relationship between India and the, technologically superior, UK led to a regression in industrialization in India and acceleration in industrialization in the UK. Whereas the UK experienced an impressive increase in the level of education throughout the 19th century and a demographic transition towards the end of the century, in India the demographic transition has been delayed and its comparative advantage in the production of labor-intensive goods has been enhanced.[40]

The proposed model abstracts from several factors that are relevant for the assessment of the effects of international trade on population growth and the process of development in less developed economies. Cultural and institutional differences between countries in the determination of population growth, public provision of education, and in the process of technological change would be reflected in the timing of their demographic transition and in their patterns of comparative advantage. Moreover, the adverse effect of international trade on industrialization and thus on the timing of the demographic transition could have been mitigated by the positive effect of trade on technological diffusion across countries (e.g., Ronald Findlay, 1996). However, as argued by Clark (1987) and Clark and Feenstra (2001), labor productivity in this period differed greatly across countries even among industries in which technologies were very similar across globe.[41] Moreover, since the rate of technological diffusion depends upon the appropriateness of factor endowments in the receiving country,[42] the adverse effect of trade on the factor endowment of less developed economies would slow down the rate of technological diffusion.

The near completion of the demographic transition in most countries in the world, along with the acceleration in technological diffusion and the changes in the nature of international trade and its effect on the return to human capital, suggest that although trade may have had an

[40]Furthermore, China could have taken advantage of superior technology by trading internationally. China's near abstention from international trade during this period, has apparently led to a decline in China's degree of industrialization over this period, and has subsequently delayed its demographic transition and has worsened its relative position in the world income distribution.

[41]In particular, Clark (1987) shows that despite the fact that in 1910 textile machinery was uniform around the world, labor productivity was ten times higher in advanced countries than in the less developed ones.

[42]See, Susanto Basu and David N. Weil, 1998, and Daron Acemoglu and Fabrizio Zilibotti, 2001)

adverse effect on the earlier process of industrialization in less developed countries, the conventional beneficial forces that are associated with international trade have denominated in recent decades.

Appendix A

Lemma A1 *In the Malthusian stage, if technology is stationary, the population will converge to a steady state level, if (i)* $(1-\alpha-\beta)/\tau^u > 1$, *(ii)* $\gamma > 1 - \frac{(1-\alpha)}{(1-\alpha-\beta)}\tau$, *and (iii)* $N_0 < (A_0^a/\widetilde{c})^{\frac{1}{1-\gamma}}$.

Proof. As follows from Lemma 2 and the individual's optimization, the population dynamic in the Malthusian stage is

$$N_{t+1} = \begin{cases} \frac{(1-\alpha-\beta)}{(1-\alpha)\tau^u}[1 - (\frac{\widetilde{c}}{A_t^a})^{\frac{1}{\gamma}} N_t^{\frac{1-\gamma}{\gamma}}]N_t & \text{if} \quad \alpha \frac{w_t^u}{p_t} < \widetilde{c} \\ \frac{(1-\alpha-\beta)}{\tau^u} N_t & \text{if} \quad \alpha \frac{w_t^u}{p_t} \geq \widetilde{c}, \end{cases}$$

Condition (i) of the Lemma ensures that when agents are unconstrained and are rearing only unskilled children, the population is rising. Noting the properties of the old agricultural production technology (1), the economy will eventually be in a state where its agents are constrained by the subsistence constraint. The steady state value of N, is

$$\bar{N} = (\frac{\widetilde{c}}{A_t^a})^{\frac{1}{\gamma-1}}[1 - \frac{(1-\alpha)\tau^u}{(1-\alpha-\beta)}]^{\frac{\gamma}{1-\gamma}}.$$

It is globally stable since as follows from condition (ii):

$$\frac{dN_{t+1}}{dN_t} |_{N_{t+1}=N_t} = \frac{(1-\alpha-\beta)}{(1-\alpha)\tau^u}[1 - \frac{1}{\gamma}[1 - \frac{(1-\alpha)\tau^u}{(1-\alpha-\beta)}]] \in (-1, 1),$$

provided that the initial level of population is not so large as to cause the initial average product of labor to be below the subsistence level, as guaranteed by condition (iii). □

Lemma A2 *Under A1, A2,*

(a) there exists a time period $(t^m)^*$ *in which the new industrial technology becomes economically viable, i.e.,*

$$A_t^m/a_t^m \geq 1/[w^u((h^m)^*)] \quad \forall t \geq (t^m)^*.$$

(b) there exists a time period $(t^a)^*$ *in which the new agricultural technology becomes economically viable, i.e.,*

$$A_t^a/a_t^a \geq (L_t^{a,0})^{\gamma-1} \quad \forall t \geq (t^a)^*.$$

Proof.

(a) Follows from (A1), (A2) and Lemma 3 noting that $g(0, N_t) > 0 \quad \forall N_t$.

(b) Lemma A1 shows that under the old technology the unskilled wage, $a_t^a(L_0^{a,0})^{\gamma-1}$ tends to the constant level of $\widetilde{c}(1-\alpha-\beta)/[(1-\alpha-\beta)-(1-\alpha)\tau^u] \equiv \tilde{w}^u$. However since A_t^a is rising over time, there exits a time period $(t^a)^*$ such that, $A_t^a > a_t^a(L_0^{a,0})^{\gamma-1}$. For $(t^a)^* < t < (t^m)^*$ it follows from (13) that population will be higher than it would have been in the Malthusian regime. Therefore the shadow Malthusian unskilled wage given by $a_t^a((L_t^{a,0})^*)^{\gamma-1}$,[43] will be below the level $\tilde{w}^u$. In contrast A^a will have continued rising. Thus $\frac{A_t^a}{a_t^a} > ((L_t^{a,0})^*)^{\gamma-1}$ still holds. For $(t^m)^* < t < (t^m)^{**}$, where $(t^m)^{**}$ is the start of the modern industrial stage, $\frac{A_t^a}{a_t^a} > ((L_t^{a,0})^*)^{\gamma-1}$ still holds since the demand for agricultural goods will be at least as high as it would have been without any new technologies[44], and thus the shadow Malthusian unskilled wage will be below the level $\tilde{w}^u$. Finally for $t > (t^m)^{**}$, the demand for agricultural goods will be growing at the rate of A^a, which is a greater rate than would be occurring under the Malthusian system. Thus again the shadow Malthusian unskilled wage will be below the level $\tilde{w}^u$ and $\frac{A_t^a}{a_t^a} > ((L_t^{a,0})^*)^{\gamma-1}$ still holds.□

Lemma A3 *When both sectors' new technology is economically viable and both skilled and unskilled workers will be constrained by the subsistence constraint in period $t+1$, there exists a unique market clearing level of h_{t+1} which will be rationally expected by agents making their period t fertility decisions*

Proof. Defining the number of unskilled agents working in agriculture as, N_t^A, and in manufacturing as, N_t^M, such that $L_t^{a,N} = l_t^u N_t^A$, $L_t^{m,N} = l_t^u N_t^M$ and $H_t^m = l_t^s H_t$, then for equilibrium at time t in the agricultural sector the following condition must hold,

$$A_t^a l_t^u N_t^A = \widetilde{c} N_t \tag{24}$$

or

$$\frac{N_t^A}{N_t} = \frac{\widetilde{c}/A_t^a}{l_t^u} \tag{25}$$

where we know from equation 13 that in equilibrium $l_t^u = \beta/(1-\alpha) + ((1-\alpha-\beta)/(1-\alpha))\widetilde{c}/A_t^a$, and $l_t^s = \beta/(1-\alpha) + (\tau^u/\tau^s)((1-\alpha-\beta)/(1-\alpha))\widetilde{c}/A_t^a$.

We also know from Corollary 1 that $H_t = (h^m)^*(l_t^u/l_t^s)N_t^M$ and that by definition $N_t^A + N_t^M + H_t = N_t$. Thus we can write that

$$h_t \equiv \frac{H_t}{N_t} = \frac{(h^m)^*(l_t^u/l_t^s)}{1+(h^m)^*(l_t^u/l_t^s)}(1 - \frac{N_t^A}{N_t}) \tag{26}$$

Given A_t^a this expression is a constant. Since A_{t+1}^a is a function of λ_{t+1} which is forecastable given period t information, the Lemma follows. □

[43] Where as defined above, the variable $(L_t^{a,0})^*$ is the level of employment in the old agricultural sector necessary for the old agricultural sector alone to satisfy the total demand for agricultural products at time t.

[44] For some parameter specifications the fall in fertility caused by the introduction of the new industrial technology may reduce fertility so much and for so long that the population falls below the level it would have attained if the economy had continued on its Malthusian path without the new technologies. If this occurs then we cannot rule out the possibility that $a_t^a((L_t^{a,0})^*)^{\gamma-1}$ rises above A^a. We regard this as a highly unlikely and very counterfactual. Based on McEvedy and Jones's (1978), the population of the British Isles grew from 5 million in 1500 to 10 million in 1750. If growth continued at this rate then the current population of the British Isles would have been 20 million, much below its current actual level of approximately 60 million). Hence, the population at the beginning of the modern industrial stage is assumed to be greater than it would have without the existence of the new production technologies.

Lemma A4 *The proportion of skilled workers in the adult population in the economy at time t, h_t, is non-decreasing in the level of technology, λ_t. When some agents are constrained in their decisions by the subsistence constraint h_t is increasing in the level of λ_t. When no agent is constrained by the subsistence constraint h_t is a constant and is unaffected by the level of λ_t.*

Proof. This follows from the agents first order conditions, equations (11), (12) and (13). They imply that for all constrained agents the higher their wage the larger their budget share devoted to manufactured goods. Thus an increase in λ_t implies that the equilibrium ratio of the value of manufactured goods to agricultural goods produced must also increase, i.e. the following ratio must rise

$$\frac{Y_t^m}{p_t Y_t^a} = \frac{A_t^m f((h^m)^*) l_t^u N_t^M}{p_t A_t^a l_t^u N_t^A} = \frac{f((h^m)^*) N_t^M}{w^u((h^m)^*) N_t^A}$$

where N_t^A and N_t^M are defined above in Lemma A3. Thus for a given N_t, the level of N_t^M must rise which also implies an increase in the level of H_t since l_t^s is non-increasing in λ.

When agents aren't constrained equations (11), (12) and (13) show that the budget share of manufactured goods is unaffected by λ_t and so increases in λ_t have no effect on h_t. □

8 Appendix B

This appendix demonstrates that the qualitative results would not alter if the production technology in the agricultural section remains land-intensive.

If the economy is characterized by 3 production technologies: an old agricultural technology, described in (1) and an old and new industrial technologies described in (3-4) one would need to replace Assumption A1-A3 with a stronger set of assumptions so as to assure that the technologically advanced economy would have a comparative advantage in the production of industrial goods.

In the three-technology model, the relative price of the agricultural good in terms of the manufactured good in period t, is

$$p_t = \begin{cases} \frac{a_t^m}{A_t^a (L_t^{a,O})^{\gamma-1}} & \text{if} \quad Y_t^{m,0} > 0 \\ \\ \frac{A_t^m w^u(h_t^m)}{A_t^a (L_t^{a,O})^{\gamma-1}} & \text{if} \quad Y_t^{m,N} > 0 \end{cases} \qquad \text{((9‘))}$$

The productivity parameters are restricted such that in addition to (A1) and (A2)

The productivity of the new industrial technology advances more rapidly than that in the agricultural technology,namely i.e.,

$$\frac{A^m(\lambda)}{A^a(\lambda)} = K^\lambda \text{ where } K > 1 \text{ and so } \lim_{\lambda_t \to \infty} \frac{A^m(\lambda_t)}{A^a(\lambda_t)} = \infty \qquad \text{((A3'))}$$

This implies that the technologically advanced economy will have a comparative advantage in the industrial sector if K is sufficiently large.

The advancement in the productivity of the agricultural sector, A_t^a,with λ_t is such that, at some point $\widetilde{t}$ where $N_t = \widetilde{N}$ and $h_t = \widetilde{h}$ the rate of technological progress rises sufficiently high so that the subsistence constraint will not bind in the future, i.e.,

$$\frac{A_{t+1}^a(\lambda_{t+1})}{A_t^a(\lambda_t)} > [(1-\alpha-\beta)/\tau^u]^{(1-\gamma)} \text{ for all } \frac{\lambda_{t+1}}{\lambda_t} = \phi(h_t, N_t) \text{ where } h_t \geq \widetilde{h} \text{ and } N_t \geq \widetilde{N} \quad \text{((A4'))}$$

In order to assure that the pattern of trade is consistent with historical patterns will assume that K is sufficiently large for $p_t^A > p_t^B$, when the two economies begin to trade.

Lemma A5 *Economy A has a comparative advantage in the industrial good if K is sufficiently large.*

Proof. From equation (9), $p_t^A > p_t^B$ implies that

$$[\frac{A_t^m}{A_t^a}]^A/[\frac{A_t^m}{A_t^a}]^B = K^{(\lambda_t^A - \lambda_t^B)} > (\frac{[L_t^{a,O}]^B}{[L_t^{a,O}]^A})^{1-\gamma}$$

Thus the inequality will hold for a sufficiently large value of K. □

The rest of the results are established straightforwardly subject to (A1), (A2), (A3') and (A4').

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Per Capita Industrialization Levels					
	1800	1860	1913	1953	1980
UK	16	64	115	210	325
Europe	8	17	45	90	267
India*	6	3	2	5	16
China	6	4	3	5	24

Table 1. Per capita industrialization levels.

Source: Bairoch (1982)
Notes:
India is measured using its boundaries in 1913
(The Index is normalized at 100 = UK at 1900)

Regional Shares of World Trade in Manufactures						
Region	Percent					
	1876-1880		1896-1900		1913	
	Exports	Imports	Exports	Imports	Exports	Imports
U.K. 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 2. Percentage Regional Shares of World Trade in Manufactures.

Source: Yates (1959)

Share of the Value of British Trade in Total Value of Indian Trade								
	1828-9	1839-40	1850-1	1860-1	1880-1	1900-1	1920-1	1940-1
Exports	48.2	57.1	44.6	43.1	41.6	29.8	22.1	34.7
Imports	65.0	75.7	72.1	84.8	82.9	65.6	60.9	22.9

Table 3. Share of the Value of British Trade in the Total Value of Indian Trade.

Source: K.N. Chaudhuri (1983)

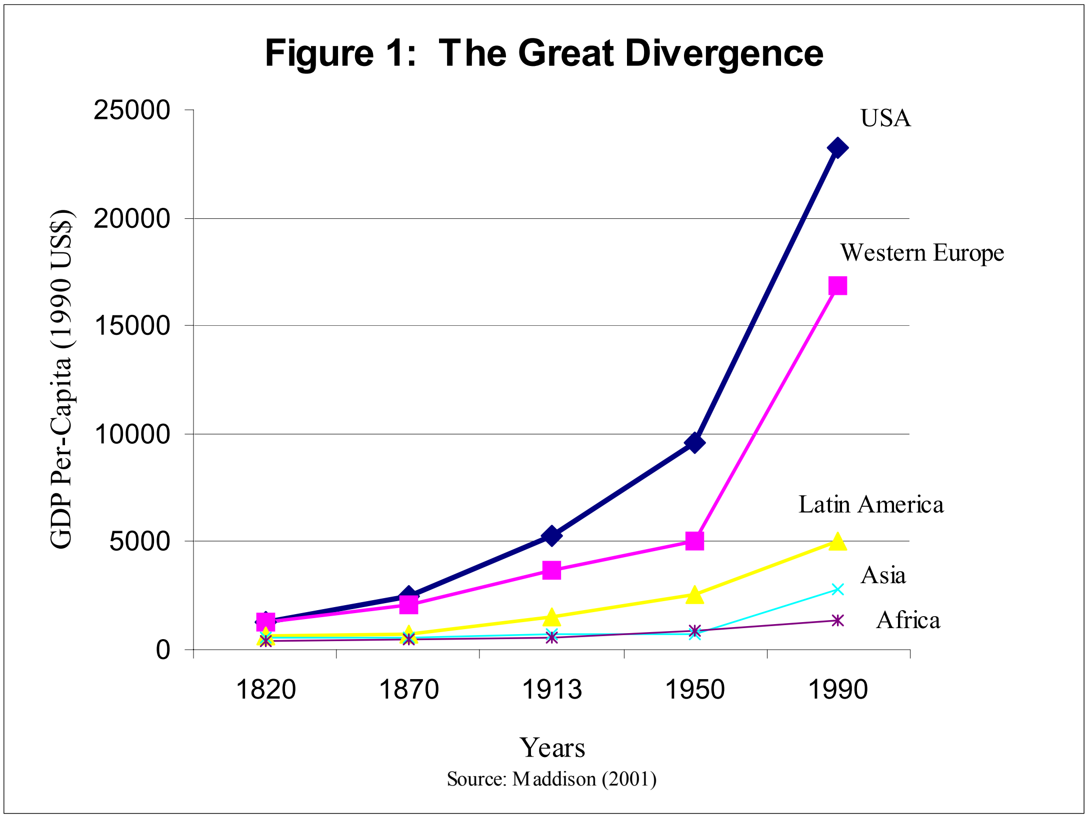
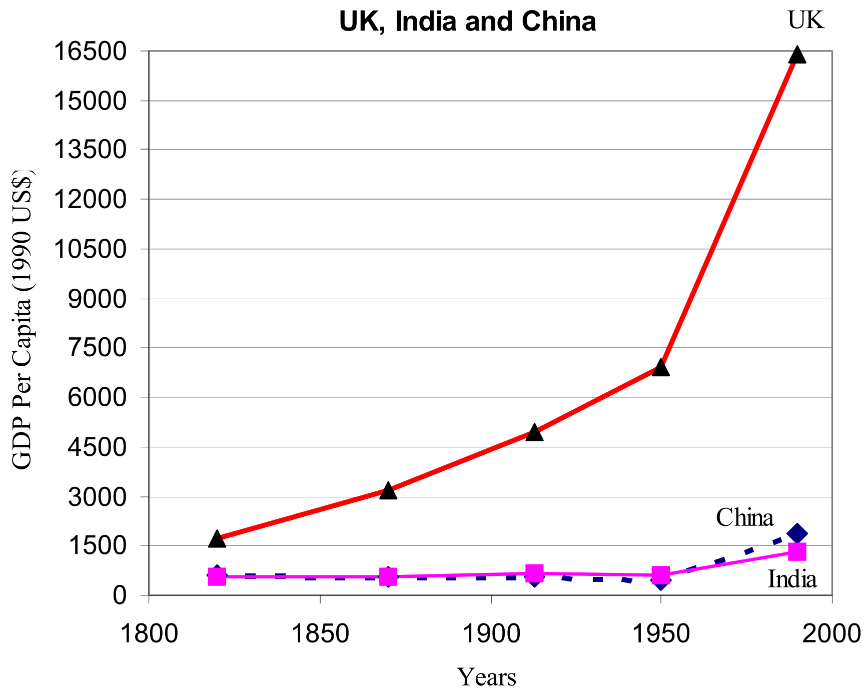


Figure 1: The Great Divergence
GDP Per-Capita (1990 US$)
25000
20000
15000
10000
5000
0
1820
1870
1913
1950
1990
Years
Source: Maddison (2001)
USA
Western Europe
Latin America
Asia
Africa

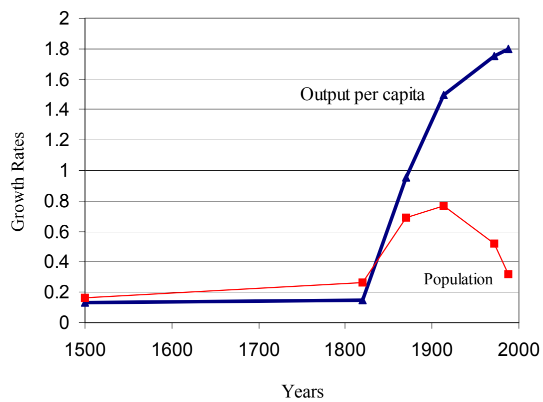
Figure 2: The Great Divergence:

UK, India and China



Source: Maddison (2001)

Figure 3: Growth of GDP Per Capita and Population: Western Europe



Data Source: Maddison 2001

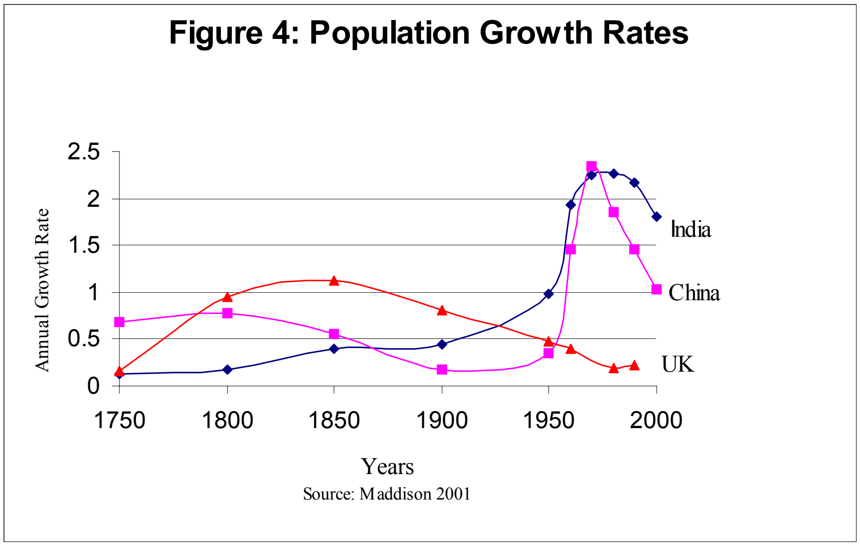


Figure 4: Population Growth Rates
2.5
2
1.5
1
0.5
0
Annual Growth Rate
1750
1800
1850
1900
1950
2000
Years
India
China
UK
Source: Maddison 2001