

RECENT DEVELOPMENTS IN THE HISTORY AND THEORY OF VERY LONG RUN GROWTH

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Abstract: This paper examines recent developments in the analysis of very long run growth, drawing out common elements in the separate literatures focused on history and theory. Both literatures have made advances in three main areas: (1) linkages between wages, human capital and population (2) interactions between institutions, markets and technology and (3) the ways in which an initial increase in the growth rate can be sustained. The implications of these developments for the interpretation of the British Industrial Revolution are considered. Emphasis is placed on the need to break away from the traditional practice of using different methods to analyse the world before and after the Industrial Revolution.

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I. INTRODUCTION

There has been a strong revival of interest in very long run growth in the last decade or so, with important developments in both history and theory. This paper examines these developments, drawing out common elements in the two literatures, which have developed independently, with little reference to each other. An important common feature of both literatures is a refusal to recognise the traditional practice of using different methods to analyse the world before and after the Industrial Revolution. An examination of the two literatures is followed by a consideration of the implications for our understanding of the British Industrial Revolution.

The historical literature has recently established that: (1) Britain and Holland followed a different path from the rest of Europe, maintaining the real wage gains of the immediate post-Black Death period while limiting fertility. These countries also experienced growth of real GDP per capita during the late medieval and early modern period despite stagnation in the daily real wage, as a result of the “Industrious Revolution” and a precocious structural shift away from agriculture. (2) Interactions between institutions, markets and technology played an important role in the British overtaking of Holland, which marked the final stages of the transition to sustained modern economic growth. Innovation flourished in an environment where a patent system protected intellectual property, there was a large market, and factor prices provided an incentive to use machine-intensive methods. (3) The diminishing returns which had characterised earlier bursts of technological innovation were avoided as a result of the wide range of applications of steam power and the potential for improving the technology. The switch to fossil fuel was also important in sustaining economic growth by freeing the economy from an energy constraint.

These historical findings can be seen as running parallel to recent developments in the theoretical literature: (1) “unified growth theory” has emphasised the links between the returns to human capital and fertility in bringing about an industrial revolution and a demographic transition. (2) These models have recently begun to add features from an earlier generation of Schumpeterian endogenous growth models, which can incorporate links between institutions and technology. (3) Schumpeterian models have also made progress in understanding how technological progress can be sustained through the idea of a general purpose technology (GPT).

A concluding section considers the implications for the British Industrial Revolution, emphasising both the links to earlier phases of pre-industrial growth in Holland, Iberia and the northern Italian city states, and the differences which underpinned the transition to sustained modern economic growth. (1) The links to earlier phases of growth lay in the growing commercialisation of Britain during the late medieval and early modern periods, the growth of long distance trade during the seventeenth and eighteenth centuries and the development of an institutional framework that supported these phenomena. (2) Britain and Holland pulled ahead of the rest of Europe from around 1500, as the real wage gains following the Black Death were sustained only in northwest Europe. Commercialisation and specialisation went much further in Britain and Holland than in the Mediterranean states, indicated most clearly by the declining share of agriculture in employment. (3) Britain began to follow a radically different path from Holland with the growth of the British cotton textile industry in the eighteenth century. High wages in Britain compared with India, the main exporter of cotton textiles in the early modern period, caused the adoption of

a more machine-intensive technology in Britain. This stimulated an acceleration in the rate of technological progress, as the patent system provided protection of intellectual property rights for innovations embodied in machinery. (4) The resulting cluster of innovations did not run into diminishing returns as in previous cases of pre-industrial growth, as a result of the emergence of steam power as a general purpose technology. The switch to fossil fuel was also important in freeing the economy from an energy constraint.

Before moving to the recent developments in the literature, it is helpful to recognise the difficulties inherent in considering both the historical and theoretical approaches together. It is difficult to improve upon the perceptive comments of Schumpeter (1954: 815), who noted that “There are such things as historical and theoretical temperaments. That is to say, there are types of minds that take delight in all the colors of historical processes and of individual cultural patterns. There are other types that prefer a neat theorem to everything else. We have use for both. But they were not made to appreciate one another.”

II. RECENT DEVELOPMENTS IN HISTORY

1. Wages, human capital and population: northwest European exceptionalism

Recent research has suggested that northwest Europe, particularly Britain and Holland, developed very differently from the rest of Europe from the time of the Black Death in the mid-fourteenth century. This finding has followed from the recent development of comparing levels rather than simply growth rates of real wages in Europe. Although the necessary data have been available since the pioneering work of the International Scientific Committee on Price History during the 1930s, the early

work using the data on wages and prices tended to focus on the path of real wages in an individual country, or where comparisons were made, tended to focus on differences in the rate of change rather than differences in the level (Cole and Crandall, 1964; Braudel and Spooner, 1967; Phelps Brown and Hopkins, 1981). This really only changed with the work of van Zanden (1999) and Allen (2001), who made wage comparisons amongst many European countries for the period after 1500, focusing on levels. Broadberry and Gupta (2006) made wage level comparisons between Europe and Asia.

Real consumption wages of European unskilled building labourers are shown in Table 1, taking London in the period 1500-49 as the numeraire. By maintaining their real wages at a high level in this period, Britain and Holland followed a very different path from the rest of Europe, where real wages collapsed. Note from Table 2, furthermore, that during the period 1500-1800, Northwest Europe emerged as the region with the highest money wages, measured by the silver content of the local currency during a time when a silver standard was in operation. This has important consequences for international competition in labour intensive production processes, which have been explored by Broadberry and Gupta (2006; 2007).

It is tempting to draw very pessimistic conclusions from Table 1, seeing Europe as stuck in a “Malthusian Trap” until the “Great Escape” affected by Britain during the “Industrial Revolution” from around 1800. However, it is important to bear in mind that the wage data here are daily wages, rather than weekly or annual earnings. So although daily real wages stagnated in northwestern Europe, annual real earnings and per capita incomes were increasing as the number of days worked per

year increased substantially, in what de Vries (1994) labels the “Industrious Revolution”. The scale of this effect is quite large, with the loss of approximately fifty holidays per year following the reformation, and a further fifty days through the abolition of “St Monday”, the widely accepted pre-industrial practice of not working at the beginning of the week following the excesses of the weekend (Voth, 1998).

Hence the real wage evidence of Table 1 should not be taken as indicative of stagnating real per capita incomes in northwest Europe before the Industrial Revolution. A number of authors have pointed to a longer period of sustained growth in per capita income in Britain, reaching back into the early modern and medieval periods. An important paper by Campbell and Overton (1996) charted the long run path of output per worker in agriculture, the largest sector of the economy, deriving a growth rate of 0.16 per cent per annum over the period 1300-1800. Making assumptions about non-agricultural output growth and labour supply, van Zanden (2006) charts the path of per capita income in Britain over the period 1300-1800, shown here in Table 3. The growth rate of per capita income between 1300 and 1800, at 0.25 per cent per annum, was somewhat higher than the growth rate of agricultural labour productivity, partly as a result of faster productivity growth in industry and partly as a result of a larger share of the population entering the labour force. Recent estimates by Overton (2006) also point to sustained growth in the median level of personal wealth in England between the 1550s and the 1740s, at a rate of 0.35 per cent per annum, as we would expect with sustained growth of per capita income.

Studies of national income before the Industrial Revolution have also been made for other European countries, following the pioneering work collected together

in Maddison and van der Wee (1994). Table 3, taken from van Zanden (2006), provides estimates for seven countries. Although pre-industrial growth was quite substantial in Britain and the Netherlands, stagnation was the norm in the other countries for which we have data. The national income data thus reinforce the conclusion from the real wage data that Britain and Holland followed a different path from the rest of Europe. But again, it must be stressed that the national income data, based on annual observations, present a more optimistic view of the pre-industrial world than the real wage data, based on daily data.

British wages were not just the highest in Europe on the eve of the Industrial Revolution, they were also dramatically higher than in Asia throughout this period. Table 4, from Broadberry and Gupta (2006) shows silver and grain wages in Britain and India from the sixteenth to the nineteenth century. The grain wage, obtained by dividing the silver wage with the silver price of grain, the most important consumption item, is the closest that we can get to the real consumption wage for India at this time. However, the comparative Anglo-Chinese real consumption wage in the late eighteenth century calculated by Allen, Bassino, Ma, van Zanden and Moll-Murata (2005) is very close to the comparative Anglo-Chinese grain wage, and the Anglo-Indian grain wage here is around the same magnitude, i.e. about one-third of the English level. Table 4 suggests that although the silver wage was already much higher in Britain than in India by the sixteenth century, it translated into a higher real wage only from the late seventeenth century (Broadberry and Gupta, 2006).

The wage and price data suggest that Britain and the Netherlands developed rather differently from the rest of Europe between 1500 and 1850. Furthermore, for a

number of countries it is possible to extend the real wage evidence back to the period before the Black Death in the middle of the fourteenth century (Pamuk, 2005). Table 5 presents the pre-1500 real wage evidence for six European cities on the same basis as Table 1. Taken together with scattered evidence for other cities, the picture that emerges is of a rise in the real wage across the whole continent during the second half of the fourteenth century, following the sharp decline in population, which in many places fell by between 30 and 50 per cent. After this, the path of real wages proceeded very differently in northwestern Europe and the rest of the continent. In Britain and Holland, the increase in real daily wages was maintained, while in the rest of Europe, real daily wages fell back to their pre-Black Death level. This seems to be related to differences in demographic and labour market behaviour.

The argument has been made most forcefully by de Moor and van Zanden (2005). They argue that what Hajnal (1965) calls the European Marriage Pattern emerged in the North Sea region following the Black Death. The key component was the primacy of mutual agreement over parental authority in the choice of marriage partner. The fact that both partners had to consent to marriage increased the bargaining position of women, and this was underpinned by the system of inheritance and access to the labour market. Although women could inherit in southern Europe as well as in the northwest, the transfer occurred at the point of marriage in the south via the dowry, but upon the death of the woman's parents in the northwest. This made early marriage more attractive in the south, since it enabled a daughter to gain access to the dowry, but it also gave the parents power over the choice of partner because the value of the dowry was uncertain. Access to the labour market gave a woman the power to refuse to marry an unsuitable partner chosen by her parents.

English demographic history has been painstakingly reconstructed from the mid-sixteenth century. Wrigley, Davies, Oeppen and Schofield (1997) paint a detailed quantitative picture of England as an economy which was already controlling fertility through late marriage, and which cannot therefore be characterised as being in a high-pressure Malthusian equilibrium. Graph 1 shows clearly that during the seventeenth century, the mean age at first marriage for males varied between 27 and 28, falling below 27 for the first time during the decade 1730-39. By the 1830s, it had fallen below 25. For females, the mean age at first marriage rose as high as 26.3 in the 1710s before falling to 23.1 by the 1830s. It is worth noting that the increase in fertility which accompanied industrialisation in Britain was therefore not a general phenomenon, but rather depended on the earlier limitation of fertility through late marriage. This is also seen by Voigtländer and Voth (2006) as an important factor raising the probability of an industrial revolution in Britain.

2. Institutions, markets and technology

Economic historians have traditionally emphasised institutions as lying at the heart of the process of economic development, with the “rise of the west” explained in terms of better institutions than elsewhere. This approach has been criticised as Eurocentric, with writers such as Pomeranz (2000), Parthasarathi (1998) and Frank (1998) attempting to deny any general superiority of economic performance in Europe before the industrial revolution. As noted earlier, however, this approach has failed empirically, with the Great Divergence of living standards between Europe and Asia already well underway during the early modern period (Broadberry and Gupta, 2006). This has coincided with a revival of interest amongst medieval and early modern

economic historians in the idea that modern economic growth has long roots stretching back to the middle ages. The approach of the economic historians brought together in volumes such as Britnell and Campbell (1995), charting the rise of a commercialised institutional framework in England in medieval and early modern England, and demonstrating quantitatively its ability to sustain living standards well above subsistence, is important in this respect.

There has also been recent consideration of the links between the institutional framework and the acceleration of technological change during the Industrial Revolution via the patent system, on which I will focus. Although there have always been those who put technology at the heart of the Industrial Revolution, until very recently the patent system has received surprisingly little attention in mainstream economic history. The modern literature really began with the study of the English patent system during the Industrial Revolution by Dutton (1984) and Sullivan (1989), who highlighted the surge in patents from the middle of the eighteenth century, shown here in Graph 2, and saw it as a causal factor. MacLeod (1988) examined the evolution of the system from the mid-seventeenth to the end of the eighteenth century, but emphasised its shortcomings as much as its advantages.

More recently, the importance of the role of the patent system in the acceleration of British economic growth has been emphasised by Broadberry and Gupta (2007) in the context of cotton textiles, where there was a dramatic shift of competitive advantage between Britain and India. This study thus provides a link to the previous topic of wages and economic development, as well as a focus on the role of institutions. During the early modern period, India was the world's main producer

of cotton textiles, with a substantial export trade. Indian textiles were exported to Britain on a large scale from the seventeenth century (Baines, 1835: 55-83; Robson, 1957: 1). By the early nineteenth century, however, Britain had become the world's most important cotton textile producer, dominating world export markets, and even exporting to India (Ellison, 1886: 57-70; Robson, 1957: 1-3). This dramatic change in international competitive advantage is often told entirely in terms of developments within Britain, without any reference to India, and without any reference to factor prices and the patent system (Ellison, 1886: 14-70; Landes, 1969: 82-88; Rose, 2000: 22-37).

Consider, however, the implications of the huge difference in the earnings of cotton operatives in Britain and India shown in Table 6, taken from Broadberry and Gupta (2007). High money wages in Britain meant that cotton textiles produced domestically with labour-intensive production methods could not compete with Indian goods in third markets, and could only be sold domestically because of protective measures that remained in force between 1701 and 1774 (Inikori, 2002: 428-432; O'Brien, Griffiths and Hunt, 1991). This stimulated a two-stage process of technological change. First, high wages led to the adoption of a more capital intensive technology in Britain, characterised by the use of labour-saving machinery in factories. Second, this resulted in a faster rate of productivity growth in Britain, because of the patent system, which offered better protection of property rights in innovations that were embodied in machinery than it could afford to other innovations. Hence there was a stronger incentive to devote resources to innovation in the machine-intensive industry of Britain, compared with the labour intensive industry of India.

The argument is consistent with the positive relationship between capital intensity, resources devoted to research and development, and the rate of technological progress, highlighted in Schumpeterian models of economic growth, which will be examined in the next section (Aghion and Howitt, 1998). Sullivan (1989: 442) points out that machinery and motive power accounted for 42.9 per cent of all patents issued in Britain during the period 1661-1710, rising to 46.6 per cent by 1801-1850. The shift to a more machine-intensive technology in response to high wages thus carried with it a higher probability of resources being devoted to improving technology and hence a higher rate of technological progress. This description fits the British cotton textile industry very well, and textile innovations played an important role in the acceleration of patenting which occurred in Britain during the late eighteenth century (Sullivan, 1989: 430). Indeed, an examination of Woodcroft's (1857) subject matter index of English patents reveals that "spinning" was the largest category (Sullivan, 1989: 431). All this inventive activity in spinning led to a dramatic increase in productivity, as can be seen in Table 7. The improvements to Crompton's mule between 1780 and 1825 reduced operative hours to process 100 lb of cotton from 2,000 to 135.

Note, however, that the argument is also contingent on particular historical circumstances surrounding economic relations between Britain and India. The process of import substitution was started by the popularity of cotton cloth imported into Britain and the opportunity given to the early British cotton industry by the protective Calico Acts in force between 1701 and 1774 (Berg, 2002; Inikori, 2002: 428-432; O'Brien, Griffiths and Hunt, 1991). As productivity increased in the machine-

intensive British cotton textile industry and stagnated in India, a shift in competitive advantage occurred. However, the shift in competitive advantage was delayed in international markets during the late eighteenth and early nineteenth centuries by a temporary rise in raw cotton prices in Britain, as the increase in production put pressure on factor markets. The shift in competitiveness in the Indian market was delayed further by transport costs, which prevented the British from breaking into the Indian market on a large scale until after 1830 (Ellison, 1886: 63; Twomey, 1983).

Now consider the implications of this approach for the question of why the key technological breakthroughs in cotton textiles occurred first in Britain. When Crafts (1977) posed this question, the obvious comparator country was France, which was being portrayed in revisionist work as having similar development potential (O'Brien and Keyder, 1978). However, the revisionism now seems to have been overdone, and in the recent literature on comparative levels of development, France emerges as a relatively low-wage economy in the eighteenth century (Allen, 2001). The other high-wage European economy was the Dutch Republic, and it is therefore interesting now to restate the question posed by Crafts (1977) as “Why Britain, not Holland?” rather than “Why Britain, not France?” The answer offered here is that while Holland had high wages like Britain, it lacked the large market to provide sufficient rewards for innovation. And while France had a large population to provide a large market, it lacked the high wages to stimulate the adoption of machine intensive technology which underpinned the process of technological change that occurred in Britain.

3. Sustaining economic growth

What makes the British Industrial Revolution different from previous episodes of growth was that technological progress was not a one-off shift, but a sustained process. The recent economic history literature has focused on a number of ways in which the technological progress of the eighteenth century was sustained into the nineteenth century. One strand looks at the role of the steam engine, while a second strand focuses on the way that the use of fossil fuel overcame an energy constraint. A third strand focuses on the interactions between theoretical and practical knowledge.

Some writers have tended to play down the role of the steam engine, since it was not widely used during the early phase of the Industrial Revolution. Kanefsky (1979) shows that water wheels generated as much power as steam engines as late as 1830. Thus the finding of von Tunzelmann (1978) that the social saving of the stationary steam engine in 1801 was only 0.2 per cent of GDP in 1801 is not too surprising. However, this may understate the importance of the steam engine if what matters is the avoidance of the onset of diminishing returns, and if the steam engine helped to sustain productivity improvements across a wide range of activities. We now know that the early steam engine had great potential for improvement and could be applied across a growing range of activities. The Savery engine began operation pumping water out of mines, but later engines were used to power machinery in the cotton and iron industries and soon spread to most of the manufacturing sector. They were also used to power steam ships and steam locomotives in the service sector, and they were used to drive machinery in agriculture, and later to drive turbines to produce electricity, the next major source of energy. Calculations of the social savings of railways later in the nineteenth century suggest a much larger impact of just this one aspect of steam technology. For 1865, Hawke (1970) estimates the social savings

of the railways of England and Wales at 6.4 to 11.4 per cent of the GDP, depending on the treatment of passenger comfort. Leunig (2006), with a more sophisticated treatment of the saving of time, arrives at a similar figure.

Wrigley (2004) emphasises the importance for sustained growth of breaking free from the energy constraint of the “organic economy”. In an organic economy, the supply of energy is limited by the process of photosynthesis, by which plants use sunlight to produce vegetable growth. This organic material can be used to feed the population, provide heat energy (through burning) or mechanical energy (through feeding to draught animals). Since photosynthesis is not a very efficient process, this set limits to the size of the population and living standards that could be supported from a given land area. Land used for growing wheat to feed the population could not be available for forests to fuel blast furnaces or to provide animal fodder for draught animals. The escape from the energy constraint came with the use of coal, the product of photosynthesis accumulated over millions of years, as a source of energy. The coal-fired steam engine provided an abundant additional source of mechanical energy, while heat energy was increasingly obtained from burning coal rather than wood, culminating in the substitution of coke for charcoal in the smelting of iron during the course of the eighteenth century (Hyde, 1977).

Mokyr (2002) has recently argued that what made the British Industrial Revolution different from previous episodes of growth was the “industrial enlightenment”, which ensured that the original burst of innovations did not peter out. He draws a distinction between prescriptive knowledge (techniques or recipes that people can follow to produce a particular effect) and propositional knowledge

(explanations of why the techniques work). The two sets of knowledge together constitute the set of useful knowledge available to a society. If prescriptive knowledge advances but without any change in propositional knowledge, diminishing returns to invention set in. For Mokyr, the breakthrough to sustained economic growth based on continuous innovation was achieved during the Industrial Revolution because the advances in propositional knowledge were matched by developments in propositional knowledge. This occurred as a result of the growth of “open-science” in western Europe during the Enlightenment and the growing contact between theoretically minded scientists and more practical engineers and technologists.

III. RECENT DEVELOPMENTS IN THEORY

1. Human capital, demographic transition and industrial revolution

The most influential strand of the recent theoretical literature on very long run growth is unified growth theory, and within this approach, Galor and Weil (2000) provide the workhorse model (Galor, 2005). Galor and Weil (2000: 806) describe the motivation behind unified growth theory in the following terms:

“We view the unified modelling of this long transition process, from thousands of years of stagnation through the demographic transition to modern growth, as one of the most significant research challenges facing economists interested in growth and development”.

Instead of two separate regimes with the transition caused by a large shock, Galor and Weil see the escape from the Malthusian trap as a long dynamic process with long periods of gradual change leading eventually to phase transitions. In this respect, unified growth theory has something in common with historical researchers engaged in crossing the boundaries between medieval, early modern and modern economic history.

In the Galor and Weil model, the development of the economy can be summarised using two key relationships, the education curve and the growth curve. The education curve captures the idea that technological progress (rather than the higher income it creates) raises the rate of return on human capital, so that education (e) is an increasing function of the growth rate of technology (g):

$$e_{t+1} = e(g_{t+1}) \quad (1)$$

A modern sector is developing in the economy and raising the demand for skilled labour. The growth curve captures the idea that technological progress raises the value of education in producing human capital because parents cannot teach their children, but have to send them to school. Positive feedback occurs because investment in human capital increases the rate of technological progress:

$$g_{t+1} = g(e_t; L_t) \quad (2)$$

Note, however, that the growth curve is also affected by the size of the labour force and hence by the population size (L). This is the familiar scale effect of endogenous growth models.

The development of the economy can be characterised by three regimes, with different population sizes: small, moderate and large. The small population regime is illustrated by Figure 1A. With a small population, the only steady state equilibrium is with zero education and slow technical progress $(\bar{e}, \bar{g}) = (0, g^l)$. In Figure 1B, with a moderate size population (L^m), the growth curve has now shifted up to create the possibility of multiple equilibria. The steady state equilibrium of zero education and a low rate of technological progress $(\bar{e}, \bar{g}) = (0, g^l)$ is locally stable, as is the equilibrium with a high level of education and a high growth rate $(\bar{e}, \bar{g}) = (e^h, g^h)$.

There also exists an interior steady state $(\bar{e}, \bar{g}) = (e^u, g^u)$ which is unstable. In Figure 1C, with a large population, the growth curve shifts up further, so that there is now a unique globally stable steady state equilibrium $(\bar{e}, \bar{g}) = (e^h, g^h)$ with high levels of education and technological progress.

The intuition behind the model can be described as follows. The economy starts out in a Malthusian regime with a small population at the subsistence level of per capita income. There is no education and there is only very slow exogenous technological progress. In this world, population expands with technological progress in the standard Malthusian way. This follows from assumptions about preferences, with members of the current generation maximising the utility of their children as well as themselves. Over time, slow growth of the population under the Malthusian regime raises the rate of technological progress, shifting the growth curve upwards. This induces a shift into the moderate population regime, with multiple steady states. One equilibrium is the old Malthusian steady state with slow technological progress and zero education, but there is also a high education, high growth equilibrium. What happens to population in this Post-Malthusian regime depends on the balance of two effects. First, by inducing parents to give their children more education, faster technological progress reduces population growth, *ceteris paribus* (i.e. there is a trade-off between the “quantity and quality” of children, because education is costly). Second, by raising potential income, technological progress increases the fraction of time that parents can devote to child rearing. At first, we may expect faster population growth if potential income rises fast enough so that parents can afford to have more children. However, in the long run, technological progress means human capital has to be acquired outside the home, so the second effect gets cut off. Then the economy

passes through a demographic transition and population growth slows down. This is the Modern regime.

Note that at first sight, it may seem that the economy can only get to the higher equilibrium as the result of a large shock, since the economy must start in the Malthusian equilibrium, which is locally stable. However, it is important to remember that population is continuing to grow, further shifting up the growth curve. This makes the old Malthusian equilibrium no longer viable, as the economy moves into the large population regime, with modern economic growth. Here, the high equilibrium is globally stable.

Note the importance of the scale effect in the Galor and Weil model, with population growth shifting up the growth curve in Figure 1 and bringing about an industrial revolution via an acceleration of technological progress. However, this makes it hard to understand the technological stagnation of large economies such as Mughal India or Qing Dynasty China. Indeed, in the run up to the British industrial revolution, China's population expanded from 100 million in 1685 to 300 million in 1790 (Mokyr, 2005: 1148-1149). This issue is addressed by Jones (2001), who asks the question "was the industrial revolution inevitable?" Although he models the demographic transition in much the same way as Galor and Weil (2000), Jones (2001) dampens the feedback from population to technology. With a smaller scale effect, as in Jones (1995), institutional change is then required to bring about an acceleration in the rate of technological progress. The institutional change is modelled by Jones as an exogenous shift in the parameter π , defined as the share of consumption paid to compensate inventive effort. Without such a shock, the industrial revolution, by which

Jones (2001: 32-33) means “the onset of rapid population growth and per capita growth culminating in the large increase in standards of living during the 20th century”, does not occur. However, institutions remain a black box in the Jones model, which is unfortunate given the large amount of effort devoted to understanding institutions and institutional change in recent years.

2. Institutions, markets and technology

There has been much theoretical work on the institutional changes which underpinned the economic development of Europe from the middle ages, with important contributions from North (1990) and Greif (2006). Greif (2000) uses the game of trust or one-sided prisoner’s dilemma to analyse what he calls the fundamental problem of exchange (FPOE): how can you be sure that the other side to a bargain will fulfil their contractual obligations? The game is set out in Figure 2. Player I chooses either to initiate a trade (exchange) or not to initiate the trade (don’t exchange). If he plays “don’t exchange” then no trade occurs and both agents receive pay-off 0, denoted (0, 0). If player I does initiate trade by choosing “exchange”, then player II must decide whether to cooperate (player II plays “exchange-cooperate) or to renege, for example, by running off with the goods that player I has offered, giving nothing in return.

Assume that if there is cooperation then gains from trade are given by $\gamma > 0$, shared between the two players, so player I gets $\gamma - W$ and player II gets W . This is the most satisfactory outcome, where both players gain. However, player II can do better by renegeing and walking off with the goods; then player II gets $\alpha > W$ and player I faces a loss, with a pay-off $\delta < 0$. Note that if player I initiates trade, it is individually rational for player II to renege. But player I can anticipate this response, and so should not initiate trade. This means that the gains from trade (γ) will not be realized, as in Third

World countries today and Europe in the Dark Ages. How is it possible to get out of this situation? In theory, player II must be able to credibly commit to not renege. In practice, medieval Europe developed institutions such as merchant guilds for mitigating the FPOE. Guilds were able to regulate relations between merchants and also to defend merchants against expropriation by the state.

This work is very helpful in understanding the long build up to modern economic growth emphasised by economic historians such as Britnell and Campbell (1995), with the British Industrial Revolution having long roots in the commercialisation of the economy from the late middle ages. However, it is helpful also to apply the approach of institutional economics to the acceleration of technological progress during the Industrial Revolution. In the context of technological innovation, entrepreneurs can afford to devote resources to the search for new methods only if they can be sure that others will not “run off” with their innovations without paying. The institutional mechanism which solves this fundamental problem of innovation is the patent system. However, it is not simply a question of the introduction of a formal system. In terms of North’s (1990) definition of institutions, it is also important that the formal rules are underpinned by informal rules that make the system work. As MacLeod (1988: 1, 10) notes, the formal start of the system may be dated to the 1624 Statute of Monopolies, which was an attempt to end the Crown’s abuse of letters patent, or documents by which special privileges were given. The statute specifically exempted patents granted for new inventions from its general proscription. During the seventeenth century, however, only a small minority of inventors filed for patents, preferring other means such as secrecy, to protect their intellectual property. Despite the fact that there were no changes in the

formal institutional framework between 1624 and 1835, the system nevertheless developed in the light of the experience of administrators and patentees. By the mid-eighteenth century, MacLeod (1988: 1) suggests that the system had “developed its own momentum and promoted a first-strike mentality among its users: one neglected to patent at one’s peril”.

The patent system plays an important role in the Schumpeterian growth model of Aghion and Howitt (1992; 1998), who endogenise the rate of technological progress through spending on research and development (R&D). The model is summarised in Figure 2, taken from Carlin and Soskice (2006). The Solow relation shows a negative steady state relationship between the rate of innovation (x) and the degree of capital intensity measured in efficiency units (\hat{k}). However, the Schumpeter relation shows a positive relationship between innovation and capital intensity, which reflects in turn a positive relationship between capital intensity and R&D spending. The initial equilibrium is at A. As well as depending on capital intensity, R&D spending is also affected by the security of property rights in innovation. The introduction of an effective patent system, as in Britain on the eve of the industrial revolution, can thus be seen as shifting the Schumpeter relation upwards, resulting in a new equilibrium at B with a higher rate of innovation. An increase in the savings rate at the same time would shift the Solow relationship upwards, thus offsetting the fall in capital per unit of efficiency labour.

Broadberry and Gupta (2007) use the David (1975) model of technical choice to emphasise the role of the patent system in stimulating technological progress during the Industrial Revolution. In Figure 4A, there are two discrete Leontieff

techniques with efficient output at points A and B. Since both techniques could in principle be combined in different proportions, it is possible to construct an Available Process Frontier (APF) made up of the convex combination of the two. Initial choice of technique depends on factor prices, with a high-wage economy such as Britain adopting the capital-intensive technology at A, where the factor price line P_1 is tangent to the APF, and a low-wage economy such as India adopting the labour intensive technology at B, where the factor price line P_0 is tangent to the APF. In a world of patent protection, where innovations embodied in machinery enjoy better protection than other innovations, subsequent technological progress is then faster on the capital-intensive technology, as in the standard Schumpeterian model. An additional feature added by David is the idea of locally neutral technological progress, taken from Atkinson and Stiglitz (1969) and represented here by a stochastic process around the α -ray. The “elastic barriers” surrounding the α -ray passing through A in Figure 4B are seen as representing non-convexities in micro-engineering designs, constraining how far the technology can stray from its initial capital-labour ratio in a trial-and error process (David, 1975: 81).

3. Sustaining economic growth

Another important aspect of the Schumpeterian growth model which has been formalised recently is the clustering of innovations, which Schumpeter [1912] believed had occurred in Kondratieff waves since the Industrial Revolution. Although economists have long since abandoned the idea of a regular periodicity to such clusterings, the fundamental idea has been revived in the idea of a general purpose technology (GPT). Lipsey, Carlaw and Bekar (2005: 98) define a GPT as “a single generic technology recognisable as such over its whole lifetime, that initially has

much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects”.

One way of thinking about a GPT is as a major fundamental innovation which raises the productivity of applied research. This can be handled within a Schumpeterian growth framework such as Aghion and Howitt (1998), where production of the consumption good (y) depends on an intermediate good (x) and a productivity parameter (A) reflecting the quality of the intermediate good. Labour (L) can be used in the intermediate goods sector (m) or in research (n). The key relationships in the model are the labour market clearing condition (\hat{L}) and the research arbitrage condition (\hat{A}). The two relationships are shown in Figure 5, with the productivity adjusted wage ($\omega = w/A$) and the number of research workers (n) on the axes. The labour market clearing condition slopes upwards to the right because an increase in the productivity adjusted wage decreases the demand for labour in the intermediate goods sector, increasing the supply of labour to the research sector. The research arbitrage condition sloped downwards to the right because an increase in the productivity adjusted wage raises the rate of return required to attract workers into the research sector.

The discovery of a GPT raises the return to working in the research sector, hence shifting out the research arbitrage condition from (\hat{A}_1) to (\hat{A}_2). This increases the number of workers in the research sector and raises the growth rate. This is a very stripped-down version of the model, in which a general purpose technology, by altering the rate of return to research, can produce variations in the long run growth rate. Helpman and Trajtenberg (1998) provide a variant which produces a

Schumpeterian cycle. The discovery of a new generation of intermediate goods comes in two stages, with the arrival of a GPT followed by the invention of intermediate goods that implement the GPT. The intermediate goods associated with a particular GPT can only be used profitably in the consumption goods sector after some minimal number have become available. The arrival of a GPT is thus followed by a slump as labour is deployed in research, but the new intermediate goods cannot yet be used in the consumption goods sector. Only after the discovery of sufficient intermediate goods can they be deployed and the economy enter a boom period. The arrival of the next GPT then induces another slump. Within each cycle, research is conducted in the slump (a time to sow) and pays off only in the boom (a time to reap).

IV. CONCLUDING REMARKS: IMPLICATIONS FOR THE BRITISH INDUSTRIAL REVOLUTION

I shall now draw on the two literatures to offer a reappraisal of the British Industrial Revolution that locates it in the line of previous pre-industrial growth episodes reaching back to the early middle ages, but also highlights the features that made it different, ushering in the period of modern economic growth that has continued to the present.

1. The medieval roots of British industrialisation

The real wage evidence of writers such as Phelps Brown and Hopkins (1981) has traditionally been interpreted as supporting a pessimistic view of European development, with no sustained growth in living standards between the Middle Ages and the Industrial Revolution. However, it is important to bear in mind that this is based on the assumption of no change in the number of days worked per year.

Building up a picture of per capita income from the output side suggests a more optimistic interpretation, with an upward trend in per capita income. The two views are consistent so long as it is accepted that there was an “industrious revolution” in northwest Europe in the early modern period. Consumption levels could thus be maintained at the level established in the second half of the fourteenth century following the Black Death.

It is worth noting here the literature which sees medieval and early modern England as a “commercialising economy”, capable of sustaining living standards well above subsistence. Building on the historical evidence assembled in Britnell and Campbell (1995) and the theoretical framework of Greif (2000), England can be seen as having developed an institutional framework that solved the fundamental problem of exchange already by the late middle ages.

If the increase in per capita incomes in the fourteenth century was sustained during the fifteenth and sixteenth centuries by a low level of population, this was no longer the case by the seventeenth century, when population rose above its earlier peak. The growth of the seventeenth century shares many characteristics of the earlier episodes of growth examined by writers such as Kindleberger (1996) and Maddison (2001), who emphasise the role of long distance trade and the accompanying commercial development in changes of economic primacy within Europe. Economic leadership is seen as passing from the Italian city states before 1500 to Portugal and Spain in the sixteenth century, then to the Low Countries in the seventeenth century before the Industrial Revolution led to the economic primacy of Britain from the late eighteenth century (Kindleberger, 1996). In all cases before the British Industrial

Revolution, a period of dynamism was followed by stagnation and relative economic decline. Although Britain also entered a phase of relative economic decline from the late nineteenth century as world per capita income leadership passed to the United States, British GDP continued to grow at a respectable rate of 1.9 per cent per annum over the period 1870-2000, yielding a per capita income growth rate of 1.4 per cent per annum (Maddison, 2003).

2. Early modern Anglo-Dutch exceptionalism

The different path followed by Britain and the Netherlands during the early modern period has already been documented in the behaviour of wages and GDP in Tables 1 to 3. Although most of Europe shared in an increase in real wages following the Black Death, it was sustained through the sixteenth and seventeenth centuries only in the northwestern region, where it was underpinned by both growing commercialisation and demographic behaviour which limited fertility.

The importance of fertility limitation in England before the Industrial Revolution period is most clearly seen in the high mean age at first marriage, shown in Graph 1. The extent of commercialisation and the spread of specialisation which accompanied it can be captured in Table 8 in the declining share of the labour force engaged in agriculture. In 1500, the release of labour from agriculture had proceeded further in the Netherlands than in the rest of Europe, as the Dutch economy relied increasingly on imports of basic agricultural products such as grain and paid for them with exports of higher value added products (de Vries and van der Woude, 1997). Although Britain remained self-sufficient in grain until the Industrial Revolution, commercialisation ensured that by the early nineteenth century the value added per

worker in agriculture was no lower than in the rest of the economy (Deane and Cole, 1967: 65; Crafts, 1985: 61-63). After 1500, the sharpest decline in the share of the labour force in agriculture occurred in England, so that by 1800 the share of the labour force engaged in agriculture was lower in England than in the Netherlands. Furthermore, in both countries, agriculture's share of the labour force was substantially lower than in the rest of Europe.

3. Trade and the early phase of the Industrial Revolution

While the Dutch Golden Age of the sixteenth and seventeenth centuries was followed by economic stagnation during the eighteenth century, the British economy continued to expand. Although the British cotton textile industry experienced an unprecedented technological transformation that can be seen as ushering in a new era of modern economic growth, the roots of this transformation lay firmly in a commercial expansion that was more typical of earlier episodes of pre-industrial growth, centred on long-distance trade.

An important part of this overseas expansion was the establishment of an East India Company with a monopoly over trade between Britain and the East. Under prevailing mercantilist ideology, imports were seen as bad, so the popularity of Indian cotton textiles in the British market led to the introduction of protective measures. However, the early British cotton textile industry could not compete in third markets with Indian producers using the prevailing labour-intensive Indian production methods, on account of the much lower wages in India. This led to the adoption of more machine-intensive production technology in Britain. In the context of a patent system which offered better protection to innovations embodied in machinery than to

other innovations, this led to more resources being devoted to improving the machine-intensive technology, and hence an acceleration in technological progress. This technological transformation brought about a dramatic increase in labour productivity, which led to the shift of competitive advantage between Britain and India in cotton textiles.

4. Steam power, energy constraints and the later phase of the Industrial Revolution

The early phase of the Industrial Revolution was dominated by the spectacular growth of cotton textiles. Although cotton continued to be important during the later phase, the nineteenth century was characterised by a wider spread of new technology across the British economy. Prominent here was the role of steam power, which can be seen as the first truly pervasive general purpose technology, in a line which has subsequently included electricity and ICT. As Crafts (2004) notes, the contribution of steam technology to labour productivity growth can be calculated using the accounting framework of Oliner and Sichel (2000), which includes the effects of capital deepening as well as TFP growth. The results are shown in Table 9, with separate calculations for stationary steam engines, railways and steamships. Although the steam engine made very little contribution to economy-wide labour productivity growth in the early phase of the Industrial Revolution, its contribution increased after 1830, and accounted for around a third of economy-wide labour productivity growth after 1850. Furthermore, Crafts (2004: 348) accepts that this ignores important TFP spillovers from steam in the second half of the nineteenth century, following the introduction of the Corliss steam engine and steamships, which permitted increased

agglomeration and specialisation along lines of comparative advantage (Rosenberg and Trajtenberg, 2004).

The diffusion of the coal-fired steam engine can be seen as a crucial development in freeing the economy from a constraint on the availability of mechanical power. For the relaxation of the constraint on heat power, the key change was the switch from charcoal to coke smelting of iron, which occurred during the eighteenth century. The difficulty with using coal for smelting iron was the sulphur and other impurities given off in the process, which made the iron brittle. The solution was to produce coke by burning off the impurities. Although this was first achieved by Abraham Darby at Coalbrookdale as early as 1709, Table 10 shows that it was not widely adopted until the late eighteenth century as the price of wood increased and the coal-based technique was improved (Hyde, 1977).

TABLE 1: Daily real consumption wages of European unskilled building labourers (London 1500-49 = 100)

	1500- 49	1550- 99	1600- 49	1650- 99	1700- 49	1750- 99	1800- 49
<i>Northwestern Europe</i>							
London	100	85	80	96	110	99	98
Amsterdam	97	74	92	98	107	98	79
Antwerp	98	88	93	88	92	88	82
Paris	62	60	59	60	56	51	65
<i>Southern Europe</i>							
Valencia	79	63	62	53	51	41	--
Madrid	--	56	51	--	58	42	--
Florence/Milan	62	53	57	51	47	35	26
Naples	73	54	69	--	88	50	33
<i>Central & eastern Europe</i>							
Gdansk	78	50	69	72	73	61	40
Warsaw	--	75	66	72	45	64	82
Krakow	67	74	65	67	58	63	40
Vienna	88	60	61	63	61	50	27
Leipzig	--	34	35	57	53	44	53
Augsburg	62	50	39	63	55	50	--

Source: Broadberry and Gupta (2006: 7).

TABLE 2: Daily silver wages of unskilled building workers in Europe, 1500-1849 (grams of silver per day)

	1500- 49	1550- 99	1600- 49	1650- 99	1700- 49	1750- 99	1800- 49
<i>Northwestern Europe</i>							
London	3.2	4.6	7.1	9.7	10.5	11.5	17.7
Southern England	2.5	3.4	4.1	5.6	7.0	8.3	14.6
Amsterdam	3.1	4.7	7.2	8.5	8.9	9.2	9.2
Antwerp	3.0	5.9	7.6	7.1	6.9	6.9	7.7
Paris	2.8	5.5	6.6	6.9	5.1	5.2	9.9
<i>Southern Europe</i>							
Valencia	4.2	6.6	8.8	6.9	5.7	5.1	--
Madrid	--	6.3	8.0	--	5.1	5.3	8.0
Milan	--	--	5.9	4.1	3.2	2.9	3.1
Florence	2.9	3.8	4.7	--	--	--	--
Naples	3.3	3.5	5.3	4.8	4.8	3.8	3.8
<i>Central & eastern Europe</i>							
Gdansk	2.1	2.1	3.8	4.3	3.8	3.7	4.8
Warsaw	--	2.5	3.2	2.7	1.9	3.4	4.9
Krakow	1.9	2.9	3.4	2.9	2.2	2.9	2.4
Vienna	2.7	2.6	4.4	3.5	3.2	3.0	2.1
Leipzig	--	1.9	3.5	3.9	3.7	3.1	4.4
Augsburg	2.1	3.1	4.0	4.7	4.2	4.3	--

Source: Allen (2001: 416).

TABLE 3: Levels of annual GDP per capita in Western Europe (Great Britain in 1820=100)

	1300	1400	1500	1570	1650	1700	1750	1820
Great Britain	29	38	43	44	54	69	84	100
Netherlands			58	58	95	94	94	92
Belgium			46	55	53	55	61	62
Italy	71	71	67	65	60	57	61	53
Spain			46	46	44	42	41	48
Sweden				51				56
Poland			49	45	46	38	32	41
Weighted average			54	54	55	56	56	58

Source: Derived from van Zanden (2006).

TABLE 4: An Anglo-Indian comparison of the daily wages of unskilled labourers, 1550-1849***A. Silver wages (grams of silver per day)***

Date	Southern England	India	Indian wage as % of English wage
1550-99	3.4	0.7	21
1600-49	4.1	1.1	27
1650-99	5.6	1.4	25
1700-49	7.0	1.5	21
1750-99	8.3	1.2	14
1800-49	14.6	1.8	12

B. Grain wages (kilograms of grain per day)

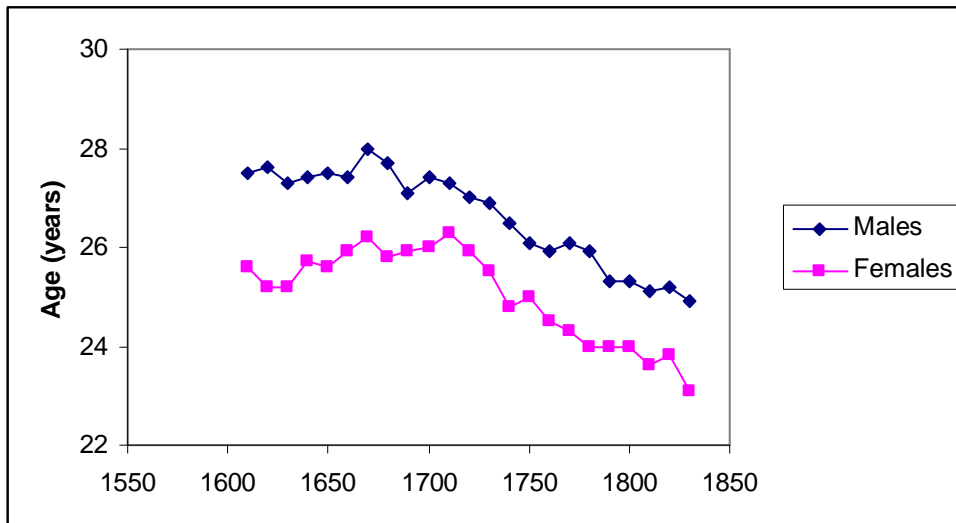
Date	England (wheat)	India (wheat)	India (rice, on wheat equivalent basis)	Indian wage as % of English wage
1550-99	6.3	5.2		83
1600-49	4.0	3.8		95
1650-99	5.4	4.3		80
1700-49	8.0		3.2	40
1750-99	7.0		2.3	33
1800-49	8.6	2.5		29

Source: Broadberry and Gupta (2006: 17).

TABLE 5: Daily real consumption wages of unskilled building labourers (London 1540-49 = 100)

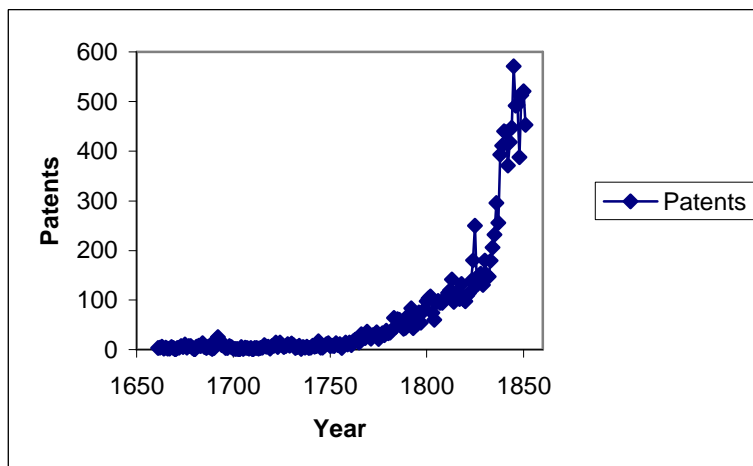
	1300-49	1350-99	1400-49	1450-99	1500-49
London	57	75	107	113	100
Antwerp			101	109	98
Valencia			108	103	79
Florence/Milan	44	87	107	77	62
Krakow			92	73	67
Vienna			115	101	88

Source: Derived from the database underlying Allen (2001: 429).

GRAPH 1: Mean age at first marriage, England (decennial data)

Source: Wrigley, Davies, Oeppen and Schofield (1997: 134).

Note: Each observation refers to the decade beginning in the year indicated. Thus, for example, the 1610 observation refers to 1610-19.

GRAPH 2: Patents issued in England, 1661-1851

Source: Derived from Sullivan (1989).

TABLE 6: Weekly earnings of cotton operatives in Britain and India, circa 1680-1820 (s/d)

	Lancashire	India	Lancashire as % of India
c.1680	6s/0d	1s/6d	400
c.1770	9s/0d	1s/6d	600
c.1790	13s/3d	2s/0d	663
c.1820	10s/4d	2s/0d	517

Source: Broadberry and Gupta (2007).

TABLE 7: Best-practice labour productivity in spinning 80s yarn in England, 1780-1825 (operative hours to process 100 lb of cotton)

	Technology	OHP
1780	Crompton's mule	2,000
1790	100 spindle mule	1,000
1795	Power-assisted mule	300
1825	Roberts' automatic mule	135

Source: Derived from Catling (1970: 54).

TABLE 8: Share of agriculture in the labour force (%)

	England	Netherlands	Italy	France	Poland
1300	76.4	--	63.4	--	--
1400	73.6	--	60.9	71.4	76.4
1500	72.8	56.8	62.3	73.0	75.3
1600	68.9	48.7	60.4	67.8	67.4
1700	55.0	41.6	58.8	63.2	63.2
1750	45.0	42.1	58.9	61.1	59.3
1800	35.5	40.7	57.8	59.2	56.2

Source: Derived from Allen (2000: 8-9).

TABLE 9: British labour productivity growth and the contribution of steam technology (% per annum)

	Economy-wide labour productivity growth	Contribution of steam technology:			Total
		Stationary steam engines	Railways	Steam ships	
1760-1800	0.2	0.01			0.01
1800-1830	0.5	0.02			0.02
1830-1850	1.1	0.04	0.16		0.20
1850-1870	1.2	0.12	0.26	0.03	0.41
1870-1910	0.9	0.14	0.07	0.10	0.31

Source: Derived from Crafts (2004).

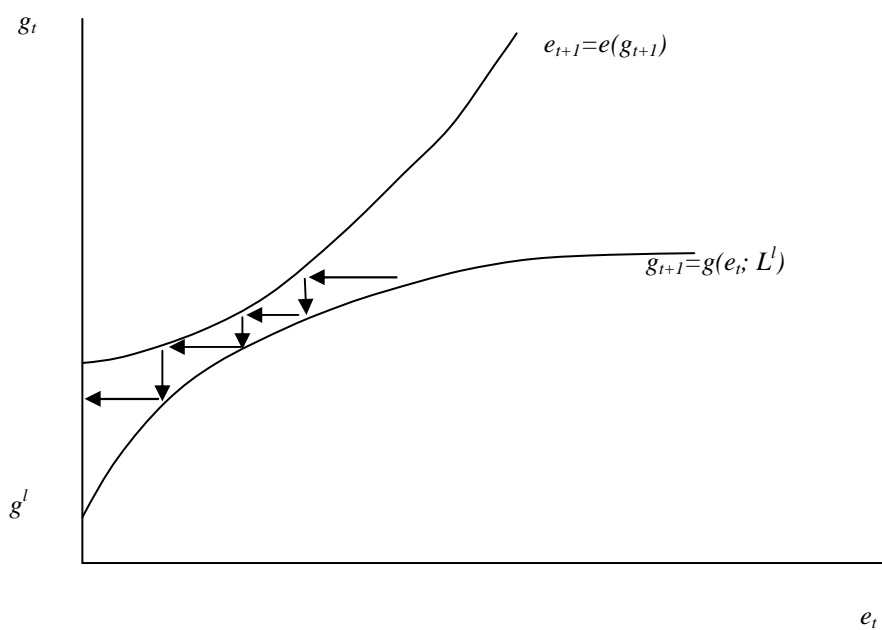
TABLE 10: Share of British pig iron smelted by coke

	%
1750	5
1760	28
1775	55
1780	68
1785	77
1788	79
1790	86
1791	90

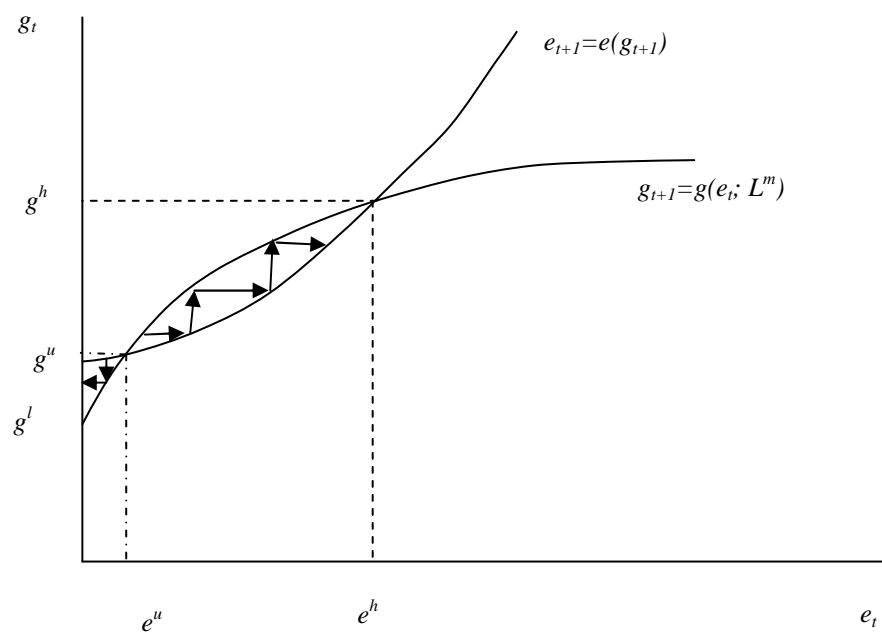
Source: Hyde (1977: 67).

FIGURE 1: Technological progress and education in the Galor-Weil model

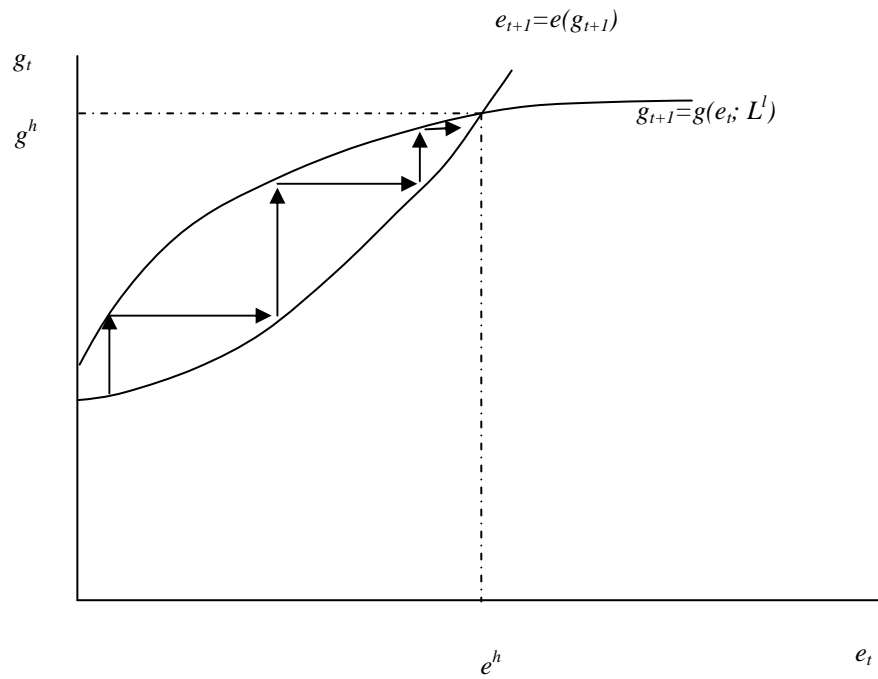
A. Small population



B: Moderate population

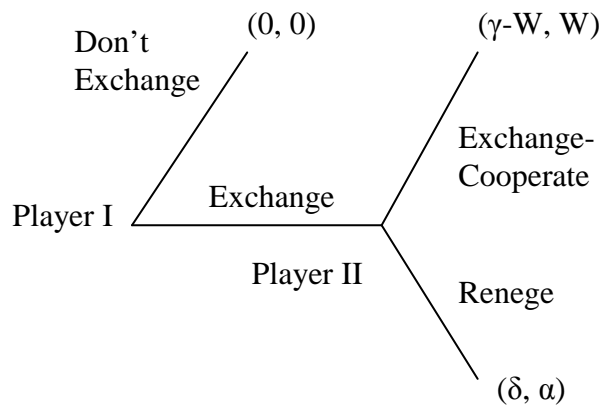


C: Large population

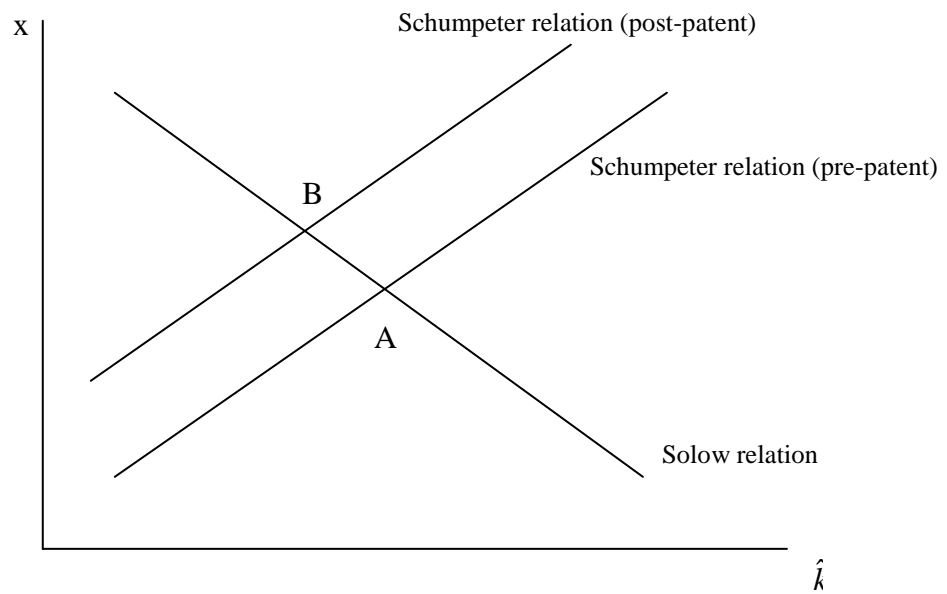


Source: Galor and Weil (2000: 818-820).

FIGURE 2: The one-sided prisoner's dilemma game



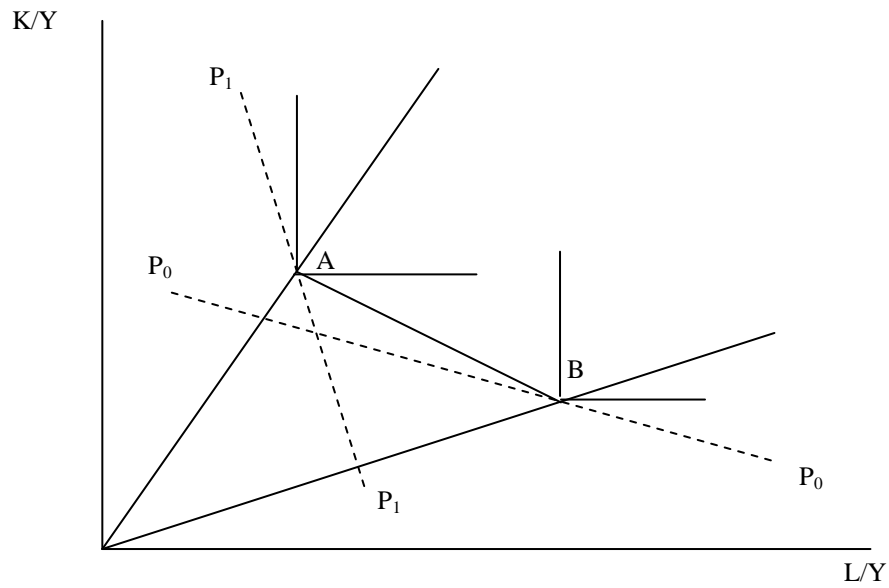
Source: Greif (2000)

FIGURE 3: An increase in returns to innovation

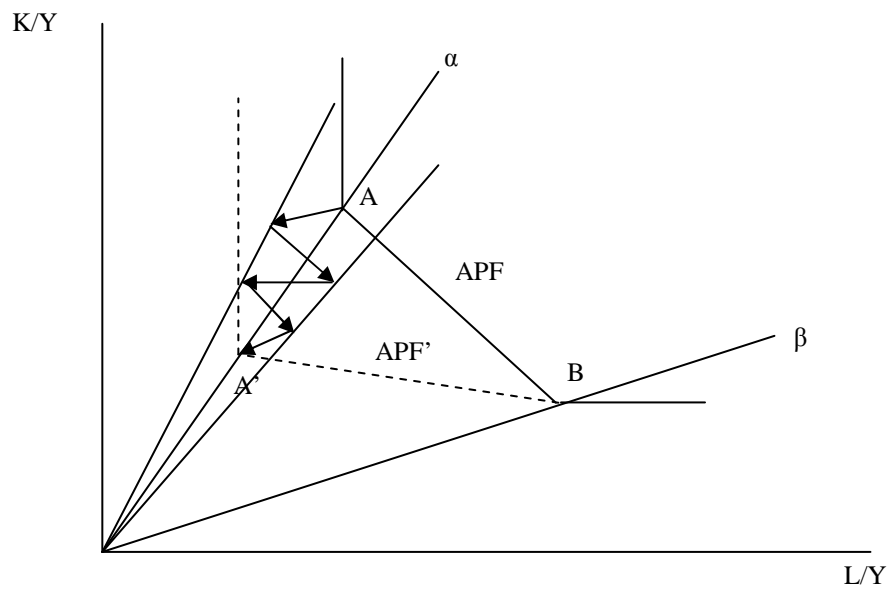
Source: Derived from Carlin and Soskice (2006: 544).

FIGURE 4: Factor substitution and technological progress

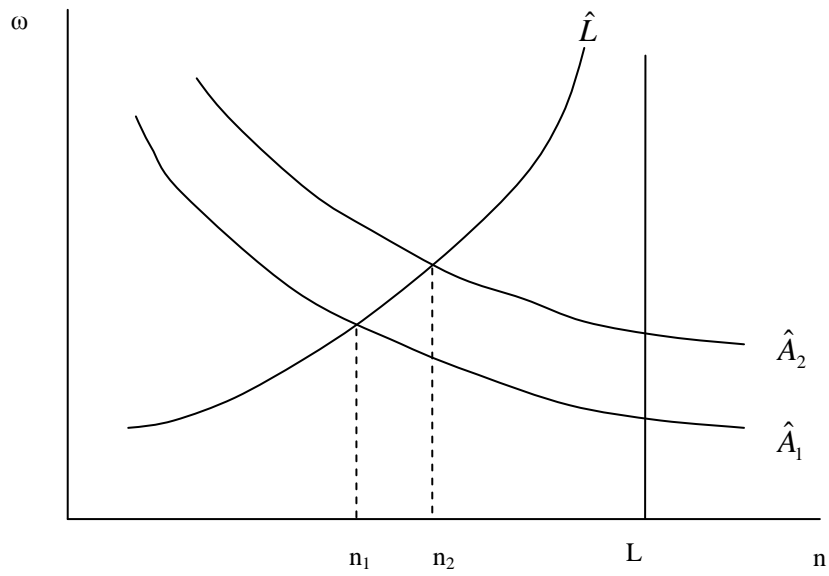
A. The role of factor prices



B. Localised technological progress



Source: Broadberry and Gupta (2007).

FIGURE 5: Effects of a General Purpose Technology in a Schumpeterian model

Source: Derived from Aghion and Howitt (1998: 58-59)

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