THE FIRST INDUSTRIAL REVOLUTION:RESOLVING THE SLOW GROWTH/RAPID INDUSTRIALIZATION PARADOX

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Abstract

The paper reviews recent attempts to quantify the British industrial revolution. It concludes that the episode was one of rapid industrialization but modest growth. To a considerable extent this is explained by the early adoption of capitalist farming and the weak impact of steam on productivity growth. However, this should not detract from a marked acceleration in the rate of technological change by the second quarter of the nineteenth century. This may be explicable in an endogenous innovation framework in terms of a reduced cost of accessing useful knowledge. Models of long-run growth should take this enhanced technological capability seriously. (JEL: N23)

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1. Introduction

Conventional wisdom about the rate of economic growth during the British industrial revolution changed dramatically as a result of research in the 1980s. A new view that describes the experience as one of gradual acceleration with rapid technological change and productivity growth confined to relatively few sectors was developed by Crafts (1985) and Harley (1982) and was completed by their revised estimates of the rate of growth set out in Crafts and Harley (1992).

The recent upsurge of interest among growth economists in modelling a long-run growth process that culminates in an industrial revolution has taken this gradualism to heart and calibrations of these models have aimed for consistency with the new view (Galor and Weil 2000, Hansen and Prescott 2002, Kremer 1993). Indeed, for some models a sharp increase in the growth rate would be a major problem (Clark, 2003).

There are, of course, serious imperfections in the data and a traditional ('old-hat') view emphasizing discontinuity and broadly-based productivity advance continues to be advanced (Temin, 1997). This school of thought is impressed by the notion of Britain as the 'workshop of the world' supplying a wide range of industrial exports rather than concentrating just on metals and textiles. Moreover, very rapid industrialization of the labour force has seemed to some to suggest fast industrial growth based on strong TFP growth in the manufacturing sector as a whole and weak TFP growth in agriculture (Williamson, 1987). These features of the First Industrial Revolution are held to be inconsistent with gradualism and technological change centred on a few modernized sectors.

This suggests that the new conventional wisdom of slow growth during the British industrial revolution needs to provide convincing explanations both as to why industrial productivity growth did not meet the expectations of those accustomed to think in terms of a 'wave of gadgets' (Ashton, 1948) and also as to what was the basis of precocious industrialization if it is to be fully persuasive. The aim of this paper is to review recent progress in achieving these objectives.

2. Making Slow Growth Credible

The Crafts-Harley view of output and productivity growth during the Industrial Revolution is summarized in Tables 1 and 2. The picture is one of steady acceleration in real GDP growth which was never particularly rapid by twentieth century standards. TFP growth remained weak throughout the eighteenth century but by the second and third quarters of the nineteenth century had reached a level consistent with sustained and significant technological change. Although these are 'crude' estimates of TFP in that no explicit allowance is made for human capital, it is generally agreed that increases in schooling and literacy were slight and that the contribution to growth from this source through 1830 was negligible rising perhaps to around 0.3 per cent per year in 1831-73 (Mitch 1999). Earlier estimates of growth showed a much more marked acceleration in output growth in the early nineteenth century with TFP growth rising from 0.2 per cent in 1761-1800 to 1.3 per cent per year in 1800-31 before subsiding to 0.8 percent in 1831-1860 (Feinstein, 1981).

Table 2 reports a breakdown of TFP growth by sector. This suggests that, outside of a select few sectors in manufacturing and transport, productivity growth in industry and services made a negligible contribution to overall TFP growth. Again this contrasts with the earlier view which, based on the belief that overall TFP growth was much faster, inferred that there must have been a pervasive acceleration in productivity growth in the early nineteenth century (McCloskey 1981).

Even so TFP growth accounted for the majority of labour productivity growth during 1780 to 1860. If traditional growth accounting is used, Table 2 shows that TFP growth was responsible for a little over 70 per cent of labour productivity growth (0.56/0.78). If new technology is regarded as embodied so that capital deepening in the modernized sectors is also taken into account, then technological change can be seen as responsible for almost seven eighths of labour productivity growth (0.68/0.78).[1]

It is apparent from Table 1 that the capital stock grew only a bit faster than the labour force which continued to grow rapidly until the last quarter of the nineteenth century. Only then did fertility begin to decline. In the face of this demographic pressure, real wages marked time from 1750 to 1820 before rising to 1 per cent per year in subsequent decades (Clark 2004) but this was a notable achievement since in earlier times population growth approaching 1.5 per cent per year would have seen wages fall appreciably (Lee and Anderson 2002). Over the years 1600 to 1750 population and real wages both grew at a little over 0.2 per cent per year (Clark 2004, Wrigley et al. 1997). If it is assumed that capital-deepening was negligible in this period and that land was a fixed factor of production, then this suggests that early modern British TFP growth was also a little over 0.2 per cent per year.[2]

Taken together these points mean that while TFP growth during the classic industrial revolution years was much lower than used to be believed and distinctly modest by the standards of industrializing countries in more recent times, nevertheless the key feature of British economic growth after the Napoleonic wars was much faster TFP growth than ever before over many decades. This was based on sustained technological progress in the era of the factory system and the steam engine and was heralded by a trend break in patenting in the 1760s (Sullivan 1989).

Given that the Industrial Revolution period is notable for a plethora of inventions, it might be supposed that there would have been a much more immediate and more dramatic increase in TFP growth than is found in the new estimates. Counter to this belief, the credibility of a

[1] As Feinstein put it, "many forms of technological advance...can only take place when embodied in new capital goods. the spinning jennies, steam engines, and blast furnaces were the 'embodiment' of the industrial revolution" (1981, p. 142).

relatively modest acceleration in TFP growth can be underpinned in three ways. Firstly, by recognising the implications of slow growth in real wages, secondly, by considering the incentive structures relevant to innovation and thirdly, by quantifying the contribution of steam power.

Research continues to show that real wage growth during the Industrial Revolution was very modest at best. Since TFP growth is equal to the weighted average of growth in factor rewards (Barro 1999) and labour's factor share was appreciable, of itself continuing slow wage growth makes a jump to rapid TFP growth highly unlikely.[3] This has been confirmed recently by a re-evaluation of TFP growth based on a price dual methodology which basically confirms the Crafts-Harley view (Antras and Voth 2003).

Britain certainly had relatively high quality institutions and policies by the standards of the time with property rights reasonably well-protected and an embryonic patent system in place, less scope for rent-seeking than in leading rival economies, and also comparing favourably with those countries in terms of financial markets and educational levels. By early twenty-first century standards, however, these aspects left much to be desired. Thus, science and technical education contributed little to technological progress, the extent of external finance was limited, the law, bureaucracy and the Church offered much better rewards than entrepreneurship, the legal protection offered by a patent was doubtful while the costs of taking out a patent were very high until the reform of 1852, and 'hold-up' by organized labour was a persistent problem to industrial pioneers (Crafts 1995).

Table 3 reports the results of a growth accounting exercise to quantify the contribution of steam power to British economic growth. This shows that the contribution made to labour productivity growth was trivial before 1830 and peaked in the second half of the nineteenth

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[2] Based on traditional growth accounting and assuming factor shares of 25 per cent for both capital and land.

century, almost a hundred years after James Watt, rather than during the classic Industrial Revolution period. Moreover, on a per annum basis, steam never remotely approached the contribution made by ICT to American productivity growth even before the late 1990s acceleration (Oliner and Sichel 2000). This is easily understood in that the cost of using steam declined a great deal more slowly than have the costs of computing and coal consumption remained high until the development of high pressure steam, as Table 4 reports. As late as 1830, when only 165,000 horsepower were installed in stationary steam engines and water power remained a good alternative in many activities (Kanefsky 1979).

If steam is compared with electricity and ICT as a General Purpose Technology, the historical record suggests that over time the impacts of these technologies on productivity have been realized more rapidly. While Britain waited almost a hundred years after James Watt for the contribution of steam to labour productivity growth to reach 0.4 per cent per year, the United States waited only 40 years after Thomas Edison for the contribution of electricity to reach 1.0 per cent per year and only 25 years after the microchip for the contribution of ICT to reach 1.6 per cent per year (Crafts, 2002). This presumably reflects, at least in part, improvements in our ability to understand how technologies work as well as better institutions to support research and development.

The British economy of the early nineteenth century struggled to make the best of steam and this reflected the weaknesses discussed above. Yet, eventually, further substantial progress was made and this can be seen as indicating improvements in scientific theory as well as learning from experience in the factory (Hills 1989). This epitomizes a key development which raised the growth potential of the nineteenth century compared with the

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[3] The relationship between TFP growth and wage growth is as follows. Factor income growth = $s_K (\Delta R/R + \Delta K/K) + s_L(\Delta W/W + \Delta L/L)$; outputs growth = $s_K\Delta K/K + s_L\Delta L/L + \Delta A/A$. So $\Delta A/A = \Delta Y/Y - s_K\Delta K/K - s_L\Delta L/L = s_K\Delta R/R + s_L\Delta W/W$.

early modern economy. Early Victorian society had much more knowledge with a wider epistemic base and the rise of the factory significantly reduced the access costs to this knowledge (Mokyr 2002). In terms of endogenous innovation models this could be expected to increase innovative activity and the rate of TFP growth.

3. Understanding Precocious Industrialization

It is well-known that Britain was an outlier in terms of its early and rapid industrialization. The share of employment in agriculture in Britain in 1840 was only 22 per cent, a level that was not seen in continental economies like France, Germany and Italy until well after World War II and about 25 percentage points below the 'European Norm" (Crafts, 1985). Table 5 illustrates this point. To understand this precocious British industrialization requires an open-economy, general-equilibrium perspective.

A standard small-country case with a conventional production possibility frontier yields the predictions listed in Table 6. Williamson (1985) developed a model of this kind and calibrated it much faster productivity growth in industry (exportable) than in agriculture (importable) which he saw as consistent with the strong drive towards urbanization and industrialization in the early nineteenth century. Yet the sectoral performance implied by the estimates in Table 2 above indicate that agricultural TFP growth outstripped that in industry (though not, of course, in the subset of modernized sectors). How can this paradox be explained ?

The starting point is to recognise two crucial differences between Britain and the standard textbook case. First, Britain was not a small country and, in particular, faced downward-sloping demand curves for its principal exports. Second, the supply of agricultural land in Britain was inelastic such that expansion of agricultural output incurred diminishing returns to capital and labour.

Harley and Crafts (2000) constructed a computable general equilibrium (CGE) model that embodies these features. They used it to address the claim made by Temin (1997), namely, that Britain could only have maintained its wide range of industrial exports if a rapid advance in productivity was achieved across the whole industrial sector. They showed that this was not the case. The combination of diminishing returns in agriculture and demand constraints on export revenues from cotton textiles ensured that a wide range of industrial exports were sustained to pay for food imports. Moreover, if pervasive TFP growth is assumed in the industrial sector, the CGE model cannot replicate key aspects of British development during the Industrial Revolution, notably the observed pattern of trade!

In a more recent paper (Crafts and Harley 2004) a slightly-modified version of this CGE model has been used explicitly to investigate the reasons for Britain's unusual experience of structural change in employment. Table 7 reports the results of simulations undertaken with this model in terms of their implications for employment shares compared with benchmarks for 1841 of 22 per cent for agriculture and 41 per cent for industry. If imports are constrained to their 1770 level (i.e., policy was much more protectionist), this changes both employment shares by about 4 percentage points.

The remaining simulations consider both a trade-adjusting solution and a trade-constrained solution. They indicate that if population had not increased after 1770 there would have been less industrialization, and that, had agricultural productivity not advanced after 1770, industrialization would have been boosted provided that open economy trade responses are allowed. Interestingly, however, taking away Britain's outstanding productivity performance in textiles and the iron industry has only a minor impact on the agricultural employment share. This sensitivity is so small that it is apparent that the pronounced industrialization of British employment should not be interpreted primarily as a symptom of outstanding TFP growth in British industry.

It seems unlikely that a route to explaining Britain's exceptional degree of industrialization can be found by seeking to account for it via an 'old-hat' belief in unbalanced productivity growth favouring industry. On the contrary, the key seems to be that capitalist farming was the norm in Britain but much less so in the rest of Europe.

The model of Cohen and Weitzman (1975) suggests a way of modelling the implications of this and points the way (in non-quantitative terms) to the results that are obtained with the CGE model. They assume that while capitalist farms employ labour to the point where its marginal product equals the wage in peasant farming workers receive wages equal to the average product of the household which also equals the market wage rate (cf. figure 1). The general equilibrium implications of a switch from peasant to capitalist farming makes agriculture less labour-intensive, provokes a net outflow of labour from agriculture to the rest of the economy, lowers wages and raises rents. Thus, if peasant farming persists, it entails a more agricultural labour force than in the neoclassical equilibrium.

Table 7 confirms these claims albeit in an open economy context. Had Britain operated with 2/3 of the land under peasant farming as in the seventeenth century, which was still the case in France in the 1840s, this would have had a major impact on the structure of employment. Thus simulations of the Harley-Crafts CGE model strongly suggest that the reasons why Britain was so much more industrialized than the 'European Norm' should be understood in terms of agrarian structure. Precocious industrialization does not undermine the view that the British industrial revolution was characterized by relatively modest and narrowly-based TFP growth.

The results in Tables 2, 3 and 7 can be compared with those obtained by Stokey (2001) using a general equilibrium model calibrated to replicate developments between 1780 and 1850 on the basis that the gradualist estimates of growth are basically correct. Stokey's two major findings are a) that the contribution of technological change in manufacturing was much more important than that of technological change in the energy sector and b) that the growth of food imports was very important in the shift from agriculture to manufacturing (2001, p. 98).

These conclusions are broadly similar to those outlined above. A comparison of Tables 2 and 3 suggests that between 1780 and 1860 both TFP growth and capital deepening in steam was dwarfed by that in the modernized sectors. Table 7 (row 1) suggests that if agricultural imports had not grown the economy would have been a good deal less industrial. Moreover, Stokey's simulation of the 1780 economy, which is achieved by eliminating the technological change and trade expansion of the Industrial Revolution period, does not push Britain anywhere near to the 'European Norm' for the agricultural employment share.[4]

4. Implications for Growth Economists

Several central messages can be taken from this review of the experience of growth and industrialization during the First Industrial Revolution. First, the downward revisions to output and productivity growth embodied in the Crafts-Harley view still appear plausible. Second, even though this entails a more gradual acceleration than would have been believed previously, already by the second quarter of the nineteenth century the sustained rate of TFP growth was well above anything achieved in earlier times. This permitted an unprecedented combination of population growth combined with real wage increases. Third, a key feature of the Industrial Revolution was a much enhanced capability for technological progress but this seems to owe little to improvements in institutions during these years.

On balance, neither the chronology and the quality of economic growth seem to be explained very well by the long-run growth models that have been proposed recently. In particular, attempts to model the Industrial Revolution without taking technological change

[4] Stokey's model does not address the issue of capitalist versus peasant farming.

seriously are surely misconceived. This does not mean an account of the Industrial Revolution based on the triumph of the steam engine as a General Purpose Technology but understanding the circumstances under which the systematic accumulation of knowledge and its application to production became the norm.

The specific difficulties which these models face include the following.[5] First, the acceleration in TFP growth appears to be rather large compared with that which might be predicted by a model of the type proposed by Kremer (1993) in which the growth rate of knowledge is (at best) proportional to population size. Between 1760-1801 and 1831-1873 the population approximately doubled whereas TFP growth quadrupled. Second, models which see the basis of the transition to modern economic growth as an acceleration in human capital formation based on fewere but better-educated children, for example, Galor and Weil (2000), capture one of the major differences between the eighteenth and the twentieth centuries but appear to have little purchase in the classic Industrial Revolution period where there was no increase in the premium for skill to encourage a change in parenting strategies (Clark, 2004), only a slight increase in literacy (Schofield, 1973) and the net reproduction rate was rising until 1820 (Wrigley et al., 1997). Third, there was a serious acceleration in productivity growth in the modernized sector and this is inconsistent with the Hansen and Prescott (2002) model which delivers an industrial revolution through composition effects but with constant productivity growth in each sector. The Industrial Revolution was not the result of composition effects.

If technological change was at the heart of the Industrial Revolution, this might suggest that new growth models of the endogenous-innovation type may have something to offer. An important strand of research has always claimed that the key to the acceleration in productivity growth is to be found in improved institutional quality and, especially, property

[5] The following comments have benefited from reading Clark (2003).

rights (North and Thomas, 1973). Similarly, more recently Acemoglu et al. (2002) have pressed the point that the seeds of the Industrial Revolution were laid by Atlantic trade and the impetus that it gave to the development of capitalist institutions. In the context of endogenous innovation models, these arguments can be seen as equivalent to an increases in appropriability which will lead to more innovation and faster growth.

However, as noted above, there was no obvious improvement in institutions at the time of the Industrial Revolution and the 'first modern economy', the Dutch Republic did not progress to be the first industrial nation. Whilst adequate institutions may have been necessary for the Industrial Revolution it is hard to believe that they were sufficient. If protection of property rights based on a state strong enough to enforce the rule of law but constrained from the abuse of its coercive powers is taken to be the central requirement for modern economic growth, then this situation was attained already when the supremacy of Parliament was confirmed at the end of the English Civil War in 1660 (Greif, 2004). If effective and affordable prtoection of intellectual property rights is regarded as vital for underpinning innovation, then patent law was unsatisfactory at least until 1852 or, even perhaps, 1883 (Macleod et al., 2003). Finally, it should be noted that the innovators of the Industrial Revolution period did not generally amass huge fortunes which remained much more likely to accrue to those engaged in commerce, finance and the professions (Rubinstein, 1981).

This suggests that, if the endogenous innovation approach is utilized to understand the enhanced contribution of technological change that characterized the move to modern economic growth, other aspects need to be brought into play. The most obvious possibility is that the productivity of inputs to innovative activity rose as a result of 'the knowledge revolution' of the eighteenth century (Mokyr, 2002). By the second quarter of the nineteenth century this had progressed to the point where effort was directed to understanding why things worked, knowledge was advancing on a scientific basis, and there were numerous organizations for the rapid dissemination of technical knowledge (Inkster, 1991).

5. Conclusions

The British Industrial Revolution was notable for a paradoxical combination of gradual acceleration of economic growth combined with pronounced industrialization of the labour force. The key underpinnings of these outcomes included an early move to capitalist farming, the long delay before steam power made any significant contribution to growth, and disincentives to innovative effort arising from rent-seeking opportunities, limitations of science and technology, and shortcomings in the legal system.

Gradualism in the transition to modern economic growth should not be confused with an absence of fundamental change. The hallmark of the Industrial Revolution was the emergence of a society that was capable of sustained technological progress and faster TFP growth, identified by Kuznets (1966) as the advent of 'modern economic growth'. Future attempts by growth economists to model this transition should take heed of Kuznets' insight and pay serious attention to the reasons for this improvement in the capability to generate innovations.

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Table 1. Growth Accounting Estimates (% per year)

	Capital Contribution	Labour Contribution	TFP Growth	Real GDP Growth
1700-60	0.4*0.7 = 0.3	0.6*0.3 = 0.2	0.2	0.7
1760-1801	0.4*1.0 = 0.4	0.6*0.8 = 0.5	0.1	1.0
1801-31	0.4*1.7 = 0.7	0.6*1.4 = 0.8	0.4	1.9
1831-73	0.4*2.3 = 0.9	0.6*1.3 = 0.8	0.8	2.4

Sources: Crafts (1994) (1995).

Table 2. Contributions to British Labour Productivity Growth (% per year)

Capital Deepening	0.22
Modernized Sectors	0.12
Agriculture	–0.03
Other	0.13
TFP	0.56
Modernized Sectors	0.34
Agriculture	0.19
Other	0.03
Labour Productivity Growth	0.78

Note. 'Modernized sectors' comprise cottons, woollens, iron, canals, railways and ships.
Sources: Capital deepening based on Crafts (2004a) and sources listed there; TFP growth from Harley (1999).

Table 3. Steam's Contribution to British Labour Productivity Growth 1760-1910 (% per year)

	1760-1800	1800-30	1830-50	1850-70	1870-1910
Capital Deepening	0.004	0.02	0.16	0.20	0.15
Steam Engines	0.004	0.02	0.02	0.06	0.09
Railways			0.14	0.12	0.01
Steamships				0.02	0.05
TFP	0.005	0.001	0.04	0.21	0.16
Steam Engines	0.005	0.001	0.02	0.06	0.05
Railways			0.02	0.14	0.06
Steamships				0.01	0.05
Total	0.01	0.02	0.20	0.41	0.31

Source: Crafts (2004b)

Table 4. Horsepower in Use, Costs of Steam Power and Maximum Performance of Steam Engines

a) Horsepower in Use (000)

	1760	1800	1830	1870	1907
Steam	5	35	165	2060	9639
Water	70	120	165	250	178
Wind	10	15	20	10	5
Total	85	170	350	2300	9842

Source: Kanefsky (1979)

b) Capital Cost and Annual Cost per Steam Horsepower per Year (£ current)

	Capital Cost	Running Cost
1760	42	33.5
1800	56	20.4
1830	60	20.4
1850	37	13.4
1870	25	8.0
1910	15	4.0

Sources: Kanefsky (1979), von Tunzelmann (1978) and Winterbottom (1907)

c) Coal Consumption (lb/hp/hour) and Pressure/Square Inch

	lb/hp/hour		p.s.i.
1760	30	1830	10
1790	12.5	1850	60
1850	5	1880	100
1907	2	1907	200

Sources: Hills (1989), Kanefsky (1979), Winterbottom (1907)

Table 5. Agricultural Share in Total Employment at British 1840 Real Income Level (%)

	Agricultural Employment	Year
Austria	64.1	1890
Belgium	44.4	1860
Britain	22.2	1840
Denmark	44.8	1890
Finland	64.6	1930
France	44.1	1890
Germany	39.9	1890
Greece	53.7	1930
Hungary	53.0	1930
Italy	55.4	1910
Netherlands	37.4	1860
Norway	39.5	1910
Portugal	48.4	1950
Spain	56.1	1920
Sweden	53.5	1900
Switzerland	42.4	1870

Sources: labour force data from Bairoch (1968) except for France from Dormois (1997); income levels from Maddison (2001)

Table 6. Specialization in a Small Open Economy

Specialize More in Exportable when	Specialize Less in Exportable when
Relative price of exportable rises	Relative price of importable rises
Production possibility of importable falls	Production possibility of importable rises
Production possibility of exportable rises	Production possibility of exportable falls
Exports and imports rise	Exports and imports fall

Table 7. CGE Simulation Results for 1841 Britain

	Agricultural Employment	Industrial Employment
Benchmark	22	41
1770 Imports	26	37
1770 Population		
Trade Adjusting	29	34
1770 Imports	34	30
1770 Agricultural TFP		
Trade Adjusting	19	45
1770 Imports	26	38
No Industrial TFP Gap[a]		
Trade Adjusting	24	40
1770 Imports	26	38
2/3 Land in Peasant Farming[b]		
Trade Adjusting	47	28
1770 Imports	57	21

Notes:
a. Primary inputs in cotton raised by 50 per cent, in other textiles by 5 per cent and in metals production by 20 per cent
b. TFP and the capital to land ratio in peasant agriculture are assumed to be 80 per cent of the actual 1841 levels.

Source: Crafts and Harley (2004); employment is measured as per cent of the labour force

Figure 1: Peasant and Capitalist Agriculture