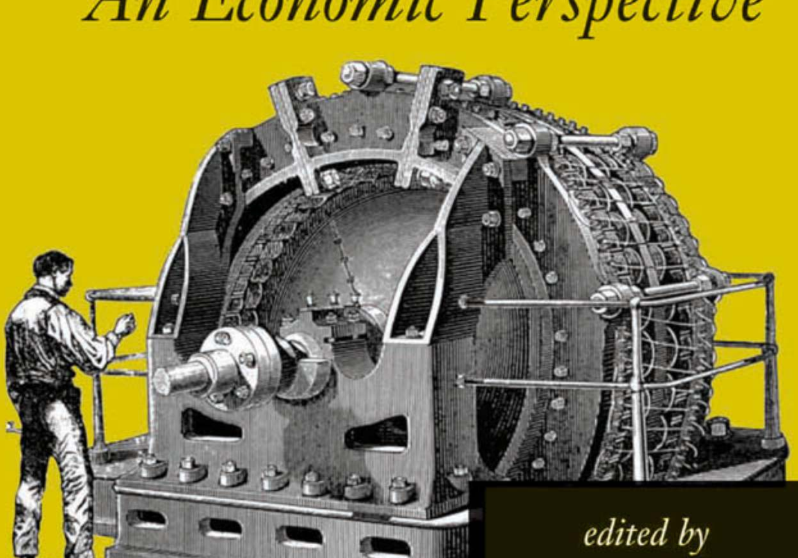
SECOND EDITION

The British Industrial Revolution

An Economic Perspective



edited by

Joel Mokyr

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Dedicated to
the memory of

JONATHAN R.T. HUGHES

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Editor's Introduction: The New Economic History and the Industrial Revolution

Joel Mokyr

The Industrial Revolution — a Useful Abstraction

In the past years, there have been more and more voices that claim, to rephrase Coleman (1983), that the Industrial Revolution is "a concept too many."[1] The feeling is that the term is either too vague to be of any use at all or that it produces false connotations of abrupt change comparable in its suddenness to the French Revolution. The main intellectual motive for this revision has been the growing (though not universally shared) consensus that economic growth in the early stages of the British Industrial Revolution was slower than had hitherto been supposed. The idea of the Industrial Revolution, however, predates its identification with economic growth by many decades. The revision of national income statistics should therefore not, in itself, be enough to abandon the concept. Yet revisionist social historians have found in those revisions the support to state categorically that "English society before 1832 did not experience an industrial revolution let alone an Industrial Revolution. . . . [Its] causes have been so difficult to agree on because there was no 'Industrial Revolution,' historians have been chasing a shadow" (Jonathan Clark, 1986, pp. 39, 66). Wallerstein (1989, p. 30) suggests amazingly that "technological revolutions occurred in the period 1550-1750, and after 1850, but precisely *not* in the period 1750-1850." Cameron (1990, p. 563) phrases it even more vituperatively: "Was there an industrial revolution? The absurdity of the

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This essay is a completely revised and largely rewritten version of my introduction to an earlier collection (Mokyr, 1985a). I am indebted to Gregory Clark, Stanley Engerman, C. Knick Harley, David Landes and Rick Szostak for comments on an earlier version. The second edition was much improved thanks to Tom Geraghty and Peter Meyer.

[1] Among those, see especially E.L. Jones (1988, pp. 13-27); Clive Lee (1986, pp. 21-22).

question is not that it is taken seriously but that the term is taken seriously . . . by scholars who should know better."

The important point to keep in mind is, of course, that from a purely ontological point of view, the British Industrial Revolution did not "happen." What took place was a series of events, in a certain span of time, in known localities, which subsequent historians found convenient to bless with a name. The argument whether the Industrial Revolution is a useful concept is therefore merely one about the efficiency of discourse: Does the term communicate? Do most people with whom we want to converse (colleagues, students, book purchasers) know by approximation what we mean when we use the term? And can we suggest a better term to replace it in our conversations? T. S. Ashton wrote in 1948 that the term was so widely used that it would be pedantic to offer a substitute (1948, p. 4; see also Crafts, 1985a, p. 68). Nothing has been learned since then to warrant changing that conclusion. Continuity or discontinuity, as McCloskey (1987) notes, are rhetorical devices. There is no "test" that we can apply: National income and aggregate consumption grew gradually; patents and cotton output grew much faster. Which one "measures" the Industrial Revolution?

Given this background, the sometimes strident voices calling for the banning of the word from our textbooks and journals seem off the mark and, to judge from the writings of scholars in the 1990s, have had little influence. Economic historians, like all scholars, need certain terms and concepts with which they can conduct their discourse, even if arguments about the *precise* definitions of these concepts continue. But scholars feel that the term communicates and insist on using it. In the years since the first edition of this book appeared, a number of important books and articles whose titles include the term *Industrial Revolution* have appeared, which demonstrates that their authors believe that the Industrial Revolution means something to their readers.[2]

To be sure, arguments about what exactly changed, when it started, when it ended, and where to place the emphasis keep raging. Such scholarly debate about the exact content of a central concept is common -- think of the arguments among biologists about the concept of species. Yet this is insufficient cause to abandon the term altogether: One might as well abandon such concepts as the Reformation or Imperialism.

How revolutionary was the Industrial Revolution? Compared to political revolutions, like the American and French revolutions that were contemporaneous with it, it was rather drawn-out, its dates usually set between 1760 and 1830 following Ashton (1948). To be sure, it was punctuated by some periods of feverish

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[2]For instance Allen (1994); Crafts (1994; 1995a, 1995b, 1995c); Crafts and Mills (1994); Easterlin (1995); Engerman (1994b); Hawke (1993); Horrell (1995a); Fisher (1992); Huck (1995); Jackson (1994); Solar (1995); Goldstone (1996); Meignen (1996); Neal (1994); Nicholas and Oxley (1993, 1994); Snooks (1994); Teich and Porter (1996); Temin (1997).

activity such as the year 1769, the *annus mirabilis* as Donald Cardwell (1972) called it, in which both James Watt's separate condenser and Richard Arkwright's water frame were patented. But, on the whole, economic changes, even economic revolutions, do not have their Bastille Days or their Lenins. Economic change is rarely dramatic, sudden, or heroic. Consequently, some scholars have found the revolutionary aspects difficult to stomach. John Clapham and Herbert Heaton, the doyens of economic history in the 1930s and 1940s, shunned the term *Industrial Revolution* altogether. In contrast, historians in the 1960s wrote of "Great Discontinuities" (Hartwell, 1971b) and "take-offs" (Rostow, 1960). Yet gradualism remained strong. Hughes (1970, p. 45) said it well when he wrote that anything that lasts so long is hard to think of as abrupt and added that "we cannot think of the events of the past seventy years as sudden. Seventy British years [in the period 1760-1830] passed no more rapidly."

There is merit to this argument, but not enough to abandon the terminology. Revolutions do suppose an acceleration of the rate of change, but how much does the rate have to change in order for it to qualify? Seventy years is a long period, but the changes that occurred in Britain between 1760 and 1830 dwarfed in virtually every respect the changes that had occurred in the previous seventy years.[3] The annual rate of change of practically any economic variable one chooses is far higher between 1760 and 1830 than in any period since the Black Death. The key concept is an increase in the rate of change, not the occurrence of change itself. The cartoon story of a preindustrial static society before 1750 with fixed technology, no capital accumulation, little or no labor mobility, and a population hemmed in by Malthusian boundaries is no longer taken seriously. Jones (1988) has stressed this point more than anyone else. At the same time Jones points out that before 1750 periods of growth were followed by retrenchment and stagnation. The Industrial Revolution was "revolutionary" because the technological progress it witnessed and the subsequent transformation of the economy were not ephemeral events and moved society to a *permanent* different economic trajectory. Moreover, it seems too much to demand that an event qualify as a revolution only if it follows a period of total stasis -- most political revolutions cannot meet this standard either. Furthermore, revolutions are measured by the profundity and longevity of their effects. In this regard, what happened in Britain after 1760 qualified beyond serious doubt for revolutionary status. The effects of the Industrial Revolution were so profound that, as Paul Mantoux (1928, p. 25) notes, few political revolutions had such far-reaching consequences.

One of the more perplexing phenomena is that contemporaries seemingly were unaware of the Industrial Revolution. A number of scholars have commented on the notable absence of references to anything as dramatic in the writing of political

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[3] As Ashton (1948, p. 41) writes, "In the period 1700-1760 Britain experienced no revolution, either in the techniques of production, the structure of industry, or the economic and social life of the people."

economists and novelists writing in the years before 1830 (Cameron, 1994; cf. North, 1981, p. 160, Adams, 1996, p. 106, and McCloskey, 1994, p. 243). From this it is inferred, somewhat rashly, that contemporaries were unaware that they were living during an Industrial Revolution and from this it is further inferred, even more rashly, that hence the term is useless. The latter inference is absurd: how many people in the Roman Empire referred to themselves as living during "classical antiquity?"[4] Yet the premise that contemporaries were unaware of the Industrial Revolution is simply and patently false. To be sure, they did not pay to it nearly the attention that subsequent historians have, but why should they have, not knowing where all this was leading? By confining oneself to reading Adam Smith (who published his *Wealth of Nations* in the very early stages of the Industrial Revolution), T.R. Malthus (who was above all interested in population and agriculture), or Jane Austen (who lived mostly in the South of England), one can easily misrepresent the perceptions of contemporaries. The Scottish merchant and statistician Patrick Colquhoun (1814, pp. 68-69) in a famous quote declared that "It is impossible to contemplate the progress of manufactures in Great Britain within the last thirty years without wonder and astonishment. Its rapidity ... exceeds all credibility. The improvement of the steam engines, but above all the facilities afforded to the great branches of the woolen and cotton manufactories by ingenious machinery, invigorated by capital and skill, are beyond all calculation..." At about the same time, Robert Owen (1815, pp. 120, 121) added that "The general diffusion of manufactures throughout a country generates a new character in its inhabitants... This change has been owing chiefly to the mechanical inventions which introduced the cotton trade into this country... the immediate effects of this manufacturing phenomenon were a rapid increase in the wealth, industry, population, and political influence of the British Empire." David Ricardo, despite being mainly interested in theoretical questions inserted a chapter on Machinery into the third edition of his *Principles of Political Economy* in which he is concerned with its impact on employment, an issue known as "the Machinery Question" and which only makes sense in the context of the Industrial Revolution (Berg, 1980).[5] Other writers and

[4]Clearly awareness by contemporaries of the nature of the period in which they lived is not an absolute rule in Professor Cameron's book. He uses the term "Middle Ages" without qualm (chapter 3 of his textbook is called "Economic Development in Medieval Europe"). He may find it interesting to learn that the term was first used by one Christopher Keller or Cellarius in a book that appeared first in 1688. Although there, too, have been "countless reflections on the appropriateness of its label" the term has survived in conventional usage. See Fuhrmann, (1986), p. 16. I am indebted to my colleague Robert E. Lerner for bringing this reference to my attention.

[5]E.A. Wrigley (1994, pp. 30-31) makes essentially the same point when he notes that classical economists and their contemporaries were perfectly aware of the technological developments of their age and that it is impossible to doubt that Smith, Ricardo, and Malthus were as knowledgeable as anyone on these matters. Most political economists, however,

essayists, each from his or her own perspective, made similar comments. Similarly, literary references to the Industrial Revolution are not altogether absent, and Wordsworth, Blake, Charlotte Brontë, and Elizabeth Gaskell contain unambiguous references to the Industrial Revolution (see Mokyr, 1994, pp. 194-95 for details). Such references are relatively rare, but given the locational concentration of the Industrial Revolution in its earlier stages, this is not surprising.[6]

Nevertheless, there is a kernel of truth to the notion that the Industrial Revolution looms larger to us than it did to contemporaries. History is inevitably written with a certain amount of "presentism." Hindsight provides us with a tool to assess which details matter and which do not. In some instances, of course, this tendency should not be exaggerated. Some dead-ends and failures "mattered" as much as success stories and can be instructive for many reasons. The knowledge, however, that the Industrial Revolution set into motion a historical process of momentous global consequences is available to us and was not to contemporaries. It is a matter of taste and judgment to what extent that kind of knowledge should influence our work. Yet the thousands of scholars concerned with some aspect of economic growth, technological change, industrialization, and the emergence of the modern economies after 1750 are all employing this kind of judgment and for good reason. In 1815 it was impossible to discern whether the "wonderful progress of manufactures" was a temporary affair or the beginning of a sustained cumulative process of social and technological change, and some political economists believed, largely on a priori grounds, that progress would be temporary. Yet it is ludicrous for an economic historian at the end of the twentieth century to pretend to be equally ignorant.

In sum, in considering whether there "was an Industrial Revolution" I cannot do better than cite Max Hartwell, summarizing a career of study and reflection on the topic "Was there an Industrial Revolution?" succinctly: "There was an Industrial Revolution and it was British" (Hartwell, 1990, p. 575). Despite the announcements of opponents of the concept that modern research has demonstrated its vacuity, much recent work that looks beyond the aggregate statistics into the regional and microeconomic aspects of the Industrial Revolution emphasizes the acceleration

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rejected sustained economic growth as an equilibrium condition, largely on a priori grounds.

[6]As the area and the number of people affected by the Industrial Revolution increased, fiction, too, started to take note. In 1832 Elizabeth Gaskell moved to Manchester where she studied the same conditions that Friedrich Engels witnessed a decade later, resulting in her *Mary Barton* (1848). Both saw the same thing. Gaskell did not call it an Industrial Revolution (Engels did) but what they saw clearly disturbed them. Factory conditions are described in novels of the 1840s, obscure ones such as Frances Trollope's *Michael Armstrong, the Factory Boy* (1840) and Charlotte Elizabeth (Tonna)'s *Helen Fleetwood* (1840) and well-known ones such as Dickens's *The Old Curiosity Shop* (1841) and Disraeli's *Sybil* (1846). It is inconceivable that these authors were observing conditions that were brand-new.

and irreversibility of economic change in the regions associated with the Revolution.[7]

The origin of the term *Industrial Revolution* was long attributed to two French-speaking observers writing in the 1830s, the Frenchman Jerome-Adolphe Blanqui and the Belgian Natalis de Briavoinne.[8] As David Landes shows elsewhere in this book, its origins can be traced back even further. All the same, there is little dispute that the term became popular following the publication of Arnold Toynbee's famous *Lectures on the Industrial Revolution* in 1884. The term is taken to mean a set of changes that occurred in Britain between about 1760 and 1830 that irreversibly altered Britain's economy and society. Of the many attempts to sum up what the Industrial Revolution really meant, the most eloquent remains Harold Perkin's: "A revolution in men's access to the means of life, in control of their ecological environment, in their capacity to escape from the tyranny and niggardliness of nature . . . it opened the road for men to complete mastery of their physical environment, without the inescapable need to exploit each other" (Perkin, 1969, pp. 3-5).

Although economic historians tend naturally to emphasize its economic aspects, the Industrial Revolution illustrates the limitations of the compartmentalization of historical sciences. More changed in Britain in those years than just the way goods and services were produced. The role of the family and the household, the nature of work, the status of women and children, the social role of the church, the ways in which people chose their rulers and supported their poor, what people wanted to know and what they knew about the world—all these were altered more radically and faster than ever before. It is an ongoing project to disentangle how economic, technological, and social elements affected each other. The event itself transcended any definable part of British society or economic life; it was, in Perkin's phrase, a "more than Industrial Revolution."

What, then, was it that changed in the years that we refer to as the Industrial Revolution? We shall have to leave out of the discussion many of the aspects that made it a "more than Industrial Revolution"—attitudes, class consciousness, family

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[7]For example, Marie Rowlands (1989, p. 124), who tries hard to find continuity in the economic changes in the West Midlands, is still describing it in dramatic terms: "There can be no question of the revolutionary impact of the introduction of the coal-fired blast furnace into the area from 1766. Within a single generation the furnaces . . . revolutionised not only the south Staffordshire economy but also its settlement pattern and landscape. . . . Agriculture became progressively more difficult, the night sky was illumined with flames and the day darkened with smoke, and the district began to be called the Black Country." Similarly, John Walton, writing of Lancashire, has no doubt that "there is something cumulatively impressive to explain. Nothing like it had been seen before. . . . The chain of events began in the 1770s and gathered . . . overwhelming momentum in the nineteenth century" (Walton, 1989, p. 64).

[8]Blanqui (1837, p. 389); Briavoinne (1839, vol. 1, pp. 185ff.).

life, demographic behavior, political power, though all of these were transformed during the same period—and concentrate on economic variables. Four different schools of thought about "what really mattered" during the Industrial Revolution can be distinguished.[9] The four schools differ in matters of emphasis and weight, yet they overlap to such an extent that many writers cannot be readily classified.

1. **The Social Change School**. The Industrial Revolution is regarded by the Social Change School to have been first and foremost a change in the way economic transactions between people took place. The emergence of formal, competitive, and impersonal markets in goods and factors of production is the basis of this view. Toynbee ([1884] 1969, p. 58) writes that "the essence of the Industrial Revolution is the substitution of competition for the medieval regulations which had previously controlled the production and distribution of wealth." Karl Polanyi ([1944] 1985, p. 40) judges the emergence of the market economy as the truly fundamental event, to which everything else was incidental. A more recent contribution in this spirit, which emphasizes the emergence of competitive markets in manufacturing is Wijnberg (1992). Most modern social historians probably would view the central social changes as having to do with labor and the relation of workers with their work environment, other laborers, employers, and capitalists. An enormously influential work in this regard is E. P. Thompson (1963). Some recent contributions influenced by this work are Berg and Hudson (1992) and Randall (1991).

2. **The Industrial Organization School**. Here the emphasis is on the structure and scale of the firm -- in other words, on the rise of capitalist employment and eventually the factory system. The focal point is the emergence of large firms, such as industrial mills, mines, railroads, and even large retail stores, in which production was managed and supervised and where workers were usually concentrated under one roof, subject to discipline and quality control. The work of Mantoux (1928) is a classic example of this school, but Karl Marx's interpretation of the rise of "Machinofactures" also belongs here as do some modern writers in the radical tradition (Marglin, 1974-1975). A classic work discussing the Industrial Revolution from this point of view is Pollard (1965). In the same tradition is Berg (1994). More recently, Szostak (1991) has argued that changes in the organization of the firm were the causal factor in technological change and thus primary to it. Goldstone (1996) explicitly equates the Industrial Revolution to the emergence of the factory system and argues that because China was unable for social reasons to adopt factories, the Industrial Revolution came late to it.

A somewhat different microeconomic approach to the Industrial Revolution emphasizes the distinction between circulating capital and fixed capital, a distinction that goes back to the classical political economy of David Ricardo and Marx. Some modern economists have defined the Industrial Revolution as a shift

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[9] What follows is inspired by Hartwell (1971b, pp. 143-154), although the classification here differs to some extent.

from an economy in which capital was primarily of the circulating kind (e.g., seed in agriculture and raw materials in domestic industry) to one in which the main form which capital took was fixed capital (e.g. machines, mines, and structures) (Hicks, 1969, pp. 142-43; Ranis and Fei, 1969).

3. **The Macroeconomic School**. The Macroeconomic School is heavily influenced by the writings of Walther Hoffmann and Simon Kuznets. Here the emphasis is on aggregate variables, such as the growth of national income, the rate of capital formation or the aggregate investment ratio, or the growth and composition of the labor force. Rostow (1960) and Deane and Cole (1969) are important proponents of this school, and their influence has extended to noneconomists (e.g., Perkin, 1969, pp. 1-2). Recent statements by E. A. Wrigley and Gary Hawke that baldly define the Industrial Revolution in terms of economic growth (Wrigley, 1987, p. 3; Hawke, 1993, p. 58) show that this approach still enjoys some support despite growing evidence that economic growth *during* the Industrial Revolution was unremarkable. Some writers, such as Gerschenkron (1962), prefer to aggregate on a sectoral level, dealing with the rate of growth of the manufacturing sector rather than the growth of the entire economy. Early practitioners of the New Economic History have tended to belong to this school, because by its very nature it tends to ask questions about large collections of individuals rather than about single persons (Fogel, 1983, p. 29) and because of its natural interest in quantitative analysis.

4. **The Technological School**. The Technological School considers changes in technology to be primary to all other changes and thus focuses on invention and the diffusion of new technical knowledge. Technology is more than just "gadgets," of course: It encompasses techniques used for the organization of labor, consumer manipulation, marketing and distribution techniques, and so forth. The most influential book in this school is Landes (1969).

The attitudes of many writers regarding the revolutionary nature of the period is to some extent determined by the school to which they adhere. The most confirmed advocates of discontinuity have typically been *technological* historians. Quantitative analysis of patent statistics reveals a sharp kink upward in the late 1750s (Sullivan, 1989). Insofar as the level of technical innovation can be approximated by patenting, this finding lends support to the discontinuity hypothesis. Nonquantitative economic historians with a strong interest in technology have had little difficulty with the discontinuity implied by the use of the concept of the Industrial Revolution. David Landes's chapter in this book represents a summary of this view, which goes back at least to the writings of A. P. Usher and before.[10] Another

[10] Usher (1920, p. 247), in a chapter entitled "The Industrial Revolution," cites with approval J. A. Blanqui for stressing the profound changes occurring in his own lifetime (the 1830s) and adds that the two revolutions, the industrial in England and the political in France, each in their own way contributed to a break with the past "so complete that it is difficult for us to reconstruct the social life of the old régime."

leading technological historian, D.S.L. Cardwell (1972, p. 139), uses the term *revolutionary epoch* (which he reserves for the years 1790-1825), whereas Arnold Pacey (1975, p. 216) prefers to apply the term *revolutionary* to the last third of the eighteenth century. In a more recent work, however, he has no qualms about using the term *Industrial Revolution* (Pacey, 1990, chap. 7). H. I. Dutton (1984), Richard Hills (1979, p. 126), and Bertrand Gille (1978, p. 677) stress the technological discontinuities of this period. Maurice Daumas, despite reservations, accepts the concept for the case of Great Britain between 1775 and 1825 (1979, p. 8). Akos Paulinyi expresses the sentiments of many when he writes that "the perception [that denies the revolutionary character of the innovations during the Industrial Revolution] bewildered me because in no book on the history or philosophy of technology is it doubted that the technological changes which took place between 1760 and 1860 introduced a new era" (1986, p. 261). In his recent book on science and technology, Ian Inkster supports this view and adds that "removing the Industrial Revolution may simply lead to boredom" (1991, p. 61). Without necessarily accepting this view, it seems fair to object to a de-dramatization of the events purely because of some preconception that "nature does not make leaps."

On the other hand, historians interested in macroeconomics and emphasizing economic growth have in recent years found little support for discontinuities. In this they differ from earlier aggregative approaches such as Rostow (1960) and Deane and Cole (1969), which seemed to find sudden leaps in the macroeconomy. As Harley's essay in this book makes clear in more detail, modern research has established that economic growth before 1830 was slower than was previously thought. This could lead to the conclusion that the acceleration, if there was one at all, does not merit the adjective *revolutionary*. Table 1.1 presents average annual compound rates of growth of the economy before and during the Industrial Revolution, contrasting earlier and more recent efforts.

Compared to Deane and Cole's national income statistics, Crafts' figures reveal an aggregate growth that was much slower during the Industrial Revolution. Industrial production is more ambiguous: Hoffmann's data, computed in the 1930s, clearly show a rapid acceleration during the period of the Industrial Revolution, but Deane and Cole's series is much more erratic and, like the revisionist data of Harley and Crafts, show that most of the quantitative expansion occurred *after* 1800. All the same, Crafts and Harley explicitly deny adhering to a school that would negate the profound changes that occurred in Britain during the Industrial Revolution (1992) and restate that "industrial innovations . . . did create a genuine Industrial Revolution reflected in changes in Britain's economic and social structure," even if their impact on economic growth was more modest than previously believed (p. 3). The point stressed by Crafts and Harley, as well as by students of other episodes of rapid technological change, is worth repeating: There is typically a long lag between the occurrence of changes in technology, even those of fundamental importance, and the time they start affecting aggregate statistics such as industrial production and national income per capita.

The revisionist view of the Industrial Revolution proposed by Harley and Crafts has led to lively exchanges with scholars critical of their methodology and views. Landes (below) still feels that during the Industrial Revolution growth of per capita income accelerated to the extent that we are justified in considering the Industrial Revolution a breaking point. In a different mode, a number of scholars have attacked the quantitative methodology underlying the revisionism and pointed out that rather than based on new research, the new series proposed were a reshuffling of the same raw materials used by Deane and Cole and questioned one detail or another in the technical procedures (Hoppitt, 1990; Jackson, 1992, 1994; Cuenca, 1995). In particular, as table 1.1 indicates, Javier Cuenca has questioned the estimates of industrial output growth produced by Crafts and Harley. Given the significant role of the lower industrial output growth estimates in GDP (Jackson, 1994, p. 91) these scholars can be seen to have taken issue with the fundamental revisionism which contends that *during* the Industrial Revolution aggregate growth rates were far lower than Deane and Cole had originally postulated.[11] All the same it remains a matter of consensus that we do not observe, and indeed *should* not observe a sharp break in aggregate long-term growth rates.

On a different front, the Crafts-Harley has been criticized by Berg (1994) and Temin (1997). Part of the economic logic of the Crafts-Harley view of slow growth was that productivity growth and technological progress were confined to a few relatively small sectors such as cotton, wool, iron, and machinery whereas much of the rest of manufacturing remained more or less stagnant till after 1830. Temin maintains that this argument is inconsistent with the patterns of British foreign

[11]The most effective criticism was made by Cuenca (1994) who has questioned the procedures used by Crafts and Harley (1992) to estimate the growth of the cotton industry during the Industrial Revolution. Cotton output was the fastest growing component of industrial production, and its relative share in industrial output is thus a crucial variable in the estimation of industrial output. Cuenca argues that cotton prices fell rapidly after 1770 and hence output was growing faster than is generally believed. His revisions in the prices of cotton raise the rate of output growth of industrial production from the 1.27 percent per year estimated by Crafts and Harley to a much higher level of 2.61 percent, higher even than Deane and Cole's estimate. In their "reply", Crafts and Harley (1995) dispute the price series used by Cuenca and point out that his figures imply that in 1770 the relative share of cotton in the industrial sector was far larger than was hitherto assumed which explains the large increase in aggregate industrial output claimed by Cuenca. In any case, even the radical revisions in *industrial* growth proposed by Cuenca do not change GDP growth rates by all that much, from the 1 percent per year (1760-1801) estimated by Crafts to about 1.4 percent (ibid., p. 142). Still, such seemingly small differences in growth rates compounded over 40 years would mean that GDP would be 75 percent higher in 1801 than in 1760, as opposed to 49 percent by the lower growth rates. Since population grew at around 0.8 percent per annum over the same period, meaning that population in 1801 was about 40 percent higher than in 1760, these differences imply rather dramatic differences in income per capita growth.

TABLE 1.1 Estimated Annual Rates of Growth, 1700-1871 (in percentages)

Period	*National Income per cap. (Deane & Cole)*	*National Income per cap. (Crafts)*	*Indust. Product (Hoff-mann)*	*Indust. Product (Deane & Cole)*	*Indust. Product (Harley)*	*Indust. Product (Crafts)*	*Indust. Product (Cuenca)*
1700-1760	0.44	0.3	0.67	0.74	n.a.	0.62	—
1760-1800	0.52	0.17	2.45	1.24	1.6[a]	1.96	2.61[c]
1800-1830	1.61	0.52	2.70	4.4	3.2[b]	3.0	3.18
1830-1870	1.98	1.98	3.1	2.9	n.a.	n.a.	

a - 1770-1815
b - 1815-1841
c - 1770-1801

Source: Computed from Harley (below); Hoffmann (1965); Cuenca (1994).

trade, which clearly shows that Britain maintained a comparative advantage not just in the rapidly expanding "new industries" but in a host of small, older industries such as linen, glass, brewing, pottery, buttons, soap, candles, paper, and so on. Temin relies on export figures to make a point about comparative advantage and to infer from it indirectly that technological progress occurred on a variety of fronts. Anecdotal evidence and examples of progress in industries other than the paradigmatic high-flying industries can be culled together from specialized sources.[12]

Nonquantitative analysts also disagree on the issue. The Social Change School tends to be divided: Toynbee and his contemporary H. Gibbins (1895) thought that the changes that mattered most were rapid. Modern social historians such as Jonathan Clark would clearly disagree. More recent work (e.g., Berg and Hudson, 1992) asserts that the pendulum has swung too far in the direction of gradualism and points to a number of radical and discontinuous social changes. The same holds for the Industrial Organization School; whereas Mantoux clearly believed in sudden

[12]On the hardware industry, see Berg (1994), ch. 12. On many of the other industries classic industry studies carried out decades ago have not yet been supplanted such as Coleman (1958) on the paper industry, Mathias [1953,(1979)] on brewing, Haber (1958) on the chemical industries, Church (1970) on the shoe and boot industry, McKendrick (1961, and 1982b) on potteries, and Barker (1960) on glass.

and rapid change, modern scholars in this tradition are more gradualist in their views and stress the dynamic elements in the pre-1760 economy. Maxine Berg (1994) has resisted the new quantitative orthodoxy of Harley and Crafts while insisting at the same time (p. 281) that "industrial growth took place over the whole eighteenth century and not just in the last quarter of it." In any event, there is no justification for extreme statements such as that of Musson (1978, p. 149), who flatly declares that by 1850 Britain was not a very different economy than it had been in 1750. After all, the population of Britain had tripled by that period, and at least in some regions everything, from the landscape to the occupational structure, had been turned upside down. The statement is, perhaps, closer to the truth for southern and eastern England and the Scottish Highlands, but even there it is debatable.

Debates on gradualism vs. sudden change are not specific to the literature on the Industrial Revolution or even economic history. There has always been an intellectual current that believed with Charles Darwin and Alfred Marshall that Nature makes no leaps. Within evolutionary biology, a debate between gradualists and saltationists has been conducted with equal intensity and perhaps similarly inconclusive results (Mokyr, 1990b, 1991a). After many years of undisputed reign by gradualists, a new compromise is emerging that allows for sudden outbursts of accelerated change although not insisting that *all* historical change is necessarily of that kind. It seems that economic historians and evolutionary biologists have been walking on parallel paths.

A moment of reflection and a few simple computations indicate that for a country that undergoes structural change while it grows, very sudden accelerations in the growth rate of the kind that Rostow envisaged are simply impossible. Thus the finding that the aggregate effects of the Industrial Revolution are not overwhelming before 1820 is not surprising. It is useful for this purpose to regard Britain during the period of the Industrial Revolution as a dual economy in which two economies coexisted although the argument would be no different if we considered a continuum of many sectors. One was the traditional economy, which, although not stagnant, developed gradually along conventional lines, with slow productivity and slowly rising capital-labor ratios. This sector contained agriculture, construction, domestic industry, and many traditional "trades" that we would now classify as industrial but which in the eighteenth century and before were partially commercial: bakers, millers, tailors, shoemakers, hatters, blacksmiths, tanners, and other craftsmen. The modern sector consisted of cotton, iron smelting and refining, engineering, heavy chemicals, mining, some parts of transportation, and some consumer goods such as pottery and paper. At first, however, only segments of these industries underwent modernization, so that dualism existed *within* as well as *between* various products, which makes calculations about the performance of the modern sector rather tricky.[13] According to McCloskey's (1985) computations, the traditional economy was large, if relatively shrinking. The average size of agriculture and "all others" between 1780 and 1860 was 79 percent of the British economy, meaning that in 1760 it was likely to have composed close to 90 percent of the British economy. Productivity growth in this sector is estimated by McCloskey at about 0.6 percent per annum. During the same period productivity in the modern economy grew at a rate of 1.8 percent per annum.

Two-sector growth models imply that abrupt changes in the economy *as a whole* are a mathematical impossibility because the aggregate rate of growth of any composite is a weighted average of the growth rates of its components, the weights being the respective shares in output. Even if changes in the modern sector itself were discontinuous and its growth rate very high, its small initial size would limit its impact on the economy-wide growth rate, and its share in the economy would increase gradually. In the long run the force of compound growth rates was such that the modern sector swallowed the entire economy. How long was the long run? A numerical example is illuminating here. Assume two sectors in a hypothetical economy, one of which (the modern sector) is growing at the rate of 4 percent per annum while the other (the traditional sector) is growing at the rate of 1 percent per annum.[14] Suppose that initially the modern sector produces 10 percent of total output. Then the aggregate growth rate is at first 1.3 (=.9x1 + .1x4) percent. After ten years the aggregate rate of growth will have increased to 1.39 percent per year.

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[13] Some approximate idea of the differences between the two sectors can be obtained from comparing pre-1760 rates of output growth to those between 1760 and 1800. Real output in cotton, for example, grew at 1.37 percent per annum in 1700-1760 and 7.57 percent in 1760-1800. In iron output, the growth rates were, respectively, 0.60 percent and 4.10 percent. In two traditional industries the acceleration is less marked: In linen the growth rates were 1.25 percent and 1.44 percent, and in leather 0.25 percent and 0.57 percent, respectively (all data from Crafts, 1985a, p. 23).

[14] Note that these rates differ from the ones McCloskey presents, since what is relevant here is *total* output growth, not productivity growth. The average rate of growth of "manufactures, mining, and building" in 1801/11-1851/61 was 3.57 percent, whereas that of "agriculture, forestry, and fishing" was 1.5 percent per annum (Deane and Cole, 1969, p. 170). For the closing decades of the eighteenth century, industrial output grew according to Crafts's calculations at a rate of 2.11 percent per annum and agricultural output at 0.75 percent. Crafts has also revised Deane and Cole's figures for the nineteenth century, but the differences are not large enough to affect the point made here. As was noted above, the rate of growth of the "modern sector" must have been faster than that of "industry." For instance, the consumption of cotton—the raw material of the modern industry par excellence—increased at the annual rate of 10.8 percent between 1780 and 1800 and at the rate of 5.4 percent between 1800 and 1840. In his essay below, Clark radically revises the growth of agriculture and claims that there was practically no growth of agricultural output in the eighteenth century. Yet the traditional sector was more than agriculture, and some of its parts clearly were benefitting from improvements elsewhere in the economy.

After thirty years of "dual growth" the share of the modern sector will have increased to 21 percent of the economy and after fifty years to one-third. Only after seventy-four years will the two sectors be of equal size (at which point aggregate growth equals 2.5 percent per year), and a full century after the starting point the traditional sector will have shrunk to about 31 percent of the economy. The British economy as a whole was changing much more slowly than its most dynamic parts, because growth was diluted by slow-growing sectors (Pollard, 1981, p. 39). These hypothetical numbers fit the actual record rather well, and they indicate that it is hardly surprising that it took until 1830 or 1840 for the economy-wide effects of the Industrial Revolution to be felt.

In reality the "modernity" of industries and enterprises was a continuum rather than a dichotomy, and the example is thus highly simplified. The distinction between the modern and traditional sectors leaves an inevitable gray area, and it has been criticized effectively in recent work as a simplification (Berg and Hudson, 1992). Not all industries that mechanized were growing quickly (e.g., paper), and not all industries in which output was growing rapidly were subject to rapid technological change.[15] In some industries, such as instrument and clock making, important technological changes were occurring in a traditionally organized industry. The distinction also abstracts from what actually happened in that it does not take into account that the modern and the traditional sectors affected each other. Although technological change in the traditional sector was slow by comparison, its productivity was affected by what happened in the modern sector. For instance, construction technology may have changed slowly, but improvement in transportation technology allowed the shipment of bricks throughout Britain, which made cheaper and better buildings possible. Agriculture benefited in some ways from technological developments in manufacturing, including the production of clay and, later, metal drainage pipes and various agricultural machines and implements. The development of coke ovens allowed the extraction of tar from coal. Gaslighting, one of the most neglected of the "great inventions," allowed many artisans and craftsmen in the traditional sector to work longer hours and reduced the cost of night work (Falkus, 1982). These intersectoral spillover effects imply that the distinction between the traditional and modern sectors is to some extent arbitrary. The coexistence of the old and the new is important, and the interaction of the two sectors greatly affected the growth of the aggregate. These

[15] There is no a priori economic reason that suggests that industries in which technological change was rapid would also necessarily experience rapid output growth. If technological progress was especially important in industries for which demand was inelastic, these industries could grow slower than industries for which demand was highly price and income elastic. All the same, the real origin of growth would be in the progressive but slow-growing sector, as lower prices for its product would funnel purchasing power to other industries.

interactions do not, however, change the principle of gradual change of the aggregate economy.

Despite the abstraction involved in distinguishing between a modern and a traditional sector, many economic historians still think that two-sector models are useful (Crafts, 1985a; McCloskey, 1985). The modern sector was more than industry but not all of industry. Its production was carried out in workshops or factories where workers were concentrated in workplaces away from their homes, many of which were located in urban or suburban areas. The traditional sector, roughly speaking, covered industries and services that remained little affected by the new technology. Much of the production was still carried out in the household or small workshop (though some larger establishments employed nonmechanized techniques), where the worker had few personal interactions with other workers or supervisory personnel. The interaction of the two sectors was, of course, reciprocal. From the point of view of the modern sector, the traditional sector was important because it determined the sociopolitical environment in which the new industries operated. And, although the modern sector was largely self-sufficient in capital and partially so in raw materials, it depended on the traditional sector for its labor supply and skills.

Utilizing the distinction between a modern and a traditional sector allows us to summarize what happened to the British economy during the Industrial Revolution as a three-pronged economic change. First, a small sector of the economy underwent quite rapid and dramatic technological change. Second, as a consequence, this sector grew at a rate much faster than the traditional sector so that its share in the overall economy continued to increase. Third, the technological changes in the modern sector gradually penetrated the membrane of the traditional sector so that parts of the *traditional* sector eventually became modernized. The economy grew, but because its sectoral composition changed, it did more than just increase in size, it was "growing-up" (Mokyr, 1976b).

The idea that the Industrial Revolution was primarily a story of rapid economic growth has thus been discredited. One obvious reason is the composition effects just described. But there are other arguments raised by scholars in recent years that have cast some doubt on this view. One is that the assumption that the pre-1750 economy (despite some obvious fluctuations in population and income) was essentially stationary is difficult to sustain. Although answers to the questions about what happened to long-term income before 1800 are even more limited by data problems, the circumstantial evidence seems to indicate that on the eve of the Industrial Revolution Britain was already a wealthy and sophisticated market economy. This means it must have been growing during *some* stages of its medieval and early modern past.

Moreover, in addition to the stormy developments in production technology, the British economy in the eighteenth century was subject to other, more gradual forces that affected the long-term growth of income. The most prominent of these forces were the growth of trade and the division of labor it brought with it. For Adam

Smith, not surprisingly, the gains from trade and specialization were the main sources of economic growth. As Table 1.1 indicates, economic growth preceded the Industrial Revolution and thus can hardly have depended on it. Jones (1988) emphasizes that the technological changes of the last four decades were superimposed on an economy that was already growing. Had there been no Industrial Revolution, growth would have continued in the long run, though at a much slower (and decelerating rate). The Smithian and the technological elements of economic change, though interrelated at many nodes, could have operated independently of each other. The Industrial Revolution was neither a necessary nor a sufficient condition of economic growth. In the very long run, however, without continuous technological change, growth would slowly grind to a halt. The gains from trade and specialization, which in Smith's vision were the key to wealth, would have run into diminishing returns, as further declines in transportation or transactions costs would have yielded smaller and smaller marginal gains. Similarly, gains from improvements in the allocation of resources due to more effective economic institutions and the development of markets in factors and resources, eventually start yielding less and less as most of the easy gains are made early on. Changes in technology, that is, changes in human knowledge and ability to understand and utilize the laws of nature, is the the only dynamic element that seems thus far to be exempt from diminishing returns.

Despite the disagreements in interpreting the Industrial Revolution, it is appropriate to note that there are many areas of broad agreement. The consensus is that within the relatively narrow confines of production technology in a number of industries, more numerous and more radical inventions occurred during the Industrial Revolution than ever before in so short a period. It is equally uncontroversial that these changes had a far-reaching effect on the lives of only a minority of Britons throughout our period. The Industrial Revolution was, above all, a regional affair, affecting Lancashire and parts of the adjoining counties and the Scottish Lowlands but leaving most of the rest of the country without visible marks. As late as 1851, only about 27 percent of the British labor force worked in the industries that were *directly* affected by the Industrial Revolution, although almost everyone had been touched by it indirectly as consumer, user, or spectator.

One of the problems with assessing the macroeconomic and social impact of the Industrial Revolution in its early stages is that it occurred simultaneously with other events whose effects are impossible to disentangle from those of the Industrial Revolution proper. Unlike a chemical experiment, history does not provide us with the circumstances to test the effects of one element by holding the others unchanged. First, for most of the period under discussion here, Britain was at war. Wars disrupted commerce and finance, increased taxation, and siphoned off labor to unproductive uses. Second, the Industrial Revolution coincided with the resumption of population growth in Britain, which had slackened off in the first half of the eighteenth century. There were ever more people who needed to be fed and clothed, threatening to materialize the dire predictions of the Reverend Malthus.

The economic impact of population change was further complicated by the fact that it was in large part due to an increase in the birth rate. Like many underdeveloped countries today, this left Britain with an ever-younger population in which the proportion of small children who did not yet work was increasing.[16] Third, the Industrial Revolution happened to occur during a period of worsening weather conditions, leading to a string of poor harvests, high food prices, and scarcity. Some of the worst harvests, as fate would have it, coincided with the war years, as they did in 1800/01 and 1812/13, compounding the misery.

These three extraneous factors—wars, population growth, and poor harvests — were not caused by the Industrial Revolution nor did they affect it directly. From the point of view of the economic historian looking for causes and effects, they are contaminations in an economic experiment that could be carried out only once. Economic history does not lend itself to neat and clean analysis: Even if we had far more data than we do, contaminating events and feedback loops make it exceedingly difficult to reach definite conclusions about causality. Yet the importance of the Industrial Revolution in British and indeed world history is such that we cannot afford not to try.

What Was the Industrial Revolution?

Technological determinism does not enjoy a great reputation among scholars, and in many accounts it is usually preceded by the telling adjective "crude."[17] In the metaphor coined by a famous if anonymous schoolboy cited by T. S. Ashton, the Industrial Revolution is defined as "a wave of gadgets that swept Britain." In this view, invention becomes an exogenous variable that then affects the endogenous variables: factories, urbanization, social change, and, with a long lag, economic growth. This is an unsatisfactory cartoon of history. Inventions do not rain down upon an economy like manna from heaven. They are stimulated by economic and social pre-existing conditions. They emerge in the minds of some people for some

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[16] The dependency ratio (defined as those aged 0-14 and those aged 60 and over divided by those aged 15-59) thus increased from 815 in 1751 to 942 in 1801 (1826 = 1000) (Wrigley and Schofield, 1981, p. 447).

[17] For a recent summary of this literature, see Smith and Marx, eds. (1994). This collection highlights two kinds of technological determinism: one that views technology as an autonomous force which acts on other variables but is not explained itself, and another that regards technology as one of the central forces determining economic performance. Economic historians have rarely felt particularly guilty at assigning a major role to technology in history because of their preoccupation with *material* conditions. Moreover, technological historians such as David Landes and Lynn White have done much to improve our understanding of the cultural and economic sources of technological progress. In so doing, they have identified technological innovation as one channel through which existing social conditions and changes in human knowledge lead to economic change, and they can hardly be accused of "crude" determinism.

reason which may or may not be identified, are communicated, adapted, refined, implemented, and imitated. An innovation may succeed or it may be resisted so fiercely that it never has a chance to compete. Some societies exhibit a quality that, lacking a better term, we will call "technological creativity." Technological creativity is not the same as inventiveness; it also includes the willingness and ability to recognize and then adopt inventions made elsewhere. We have barely begun to understand why some societies are technologically creative and others are not, and why some societies that are technologically creative at some time cease to be so later on. I will argue below that Britain, indeed, was a technologically creative society, and that we can make some reasonable hypotheses as to why and how she became so. Regardless of its source, the Industrial Revolution was above all an age of rapidly changing production technology propelled by technological creativity.[18] This view attributes to technology an important historical role, and the challenge is to somehow disentangle those cases in which technological change "may indeed have had some independently initiating role from others in which it is better understood as secondary, dependent, or derivative" (Adams, 1996, p. 107).

The story of the most important innovations of the Industrial Revolution has been told elsewhere many times.[19] Without repeating all the details here, it may be useful to make a few distinctions that help to make sense of the story. Technological change consists of the creation of new knowledge and its diffusion and implementation, sometimes referred to as innovation. As always there is a gray area between the two, and here it is rather large. On many occasions when a known technology is introduced in a new place, it has to be modified and adapted to suit a different environment and sometimes a different product, and thus it acquires some of the characteristics of invention. Inventions and innovations are very much complementary processes, and asking whether technological change proceeds more by one or the other is like asking whether a pianist makes music with the left or the right hand. An invention that is not adopted remains a dead letter and at best ends up in a footnote in a text on the history of technology. On the other hand, without new inventions the process of innovation will lose steam and eventually reach a dead end.

We can envisage the relation by using the economist's terms of average- and best-practice technique. At any given point of time an industry uses a variety of techniques. Some producers use the most recent and most up-to-date (best-practice) technique, but because of a variety of diffusion lags not all firms use state-of-the-art

[18]To some students, the definition of the Industrial Revolution in technological terms may seem commonplace, even banal. Yet in some corners there are serious reservations about this view. Braudel (1984, p. 566) states categorically that "if there is one factor which has lost ground as a key explanation of the Industrial Revolution, it is technology."

[19]See, for instance, Ashton (1948); Cardwell (1972); Cardwell (1994); Landes (1969); Mantoux (1928); Mokyr (1990a, chap. 5); Mokyr (1992a).

technology all the time. As best-practice techniques are diffused, the average-practice technique pursues and eventually catches up with the state-of-the-art technique. If, however, the technical frontier advances continually through invention, average-practice never catches up with best-practice. Invention keeps throwing new fuel on the fires of innovation and progress. The rate of progress of an industry is thus a function of both the rate of advance of the best-practice techniques and the mean diffusion lag.

Many of the inventions that made the British Industrial Revolution were, in fact, adaptations of inventions made overseas. Thus the Fourdrinier paper machine, introduced by Bryan Donkin in London in 1807, was originally invented by the Frenchman N. L. Robert in 1798. Gaslighting, the Leblanc soda process, chlorine bleaching, and the wet-spinning process for flax were Continental inventions imported into and perfected in Britain. By being receptive to these foreign technologies, as much as through their own inventions, Britain's industries displayed an unprecedented technological creativity that lay at the foundation of the British Industrial Revolution.

Inventions, too, come in different sizes and packages. If we counted successful inventions mechanically as if they represented one unit each, we would find that the vast bulk of inventions made during the Industrial Revolution—or in our own time—were small, incremental improvements to known technologies. Such "gap-filling" inventions are often the result of on-the-job learning-by-doing or of a development by a firm's engineers realizing ad hoc opportunities to produce a good cheaper or better. Over time, a long sequence of such *micro*inventions may lead to major gains in productivity, impressive advances in quality, fuel and material saving, durability, and so on. At times the accumulated effect of incremental inventions changed the nature of the product. Consider one example: the sailing ship. Since the emergence of the fully rigged, three-masted ship in the fifteenth century, the art of shipbuilding had not been stagnant: Ships were cheaper to build and to maintain, more seaworthy, and more durable in 1800 than in 1450. Yet there had been no radical changes in either planking or rigging, no discontinuous leaps in ship design (Gilfillan, 1935) since 1500. The same is true for technologies as diverse as the cultivation of grains, the smelting of iron ore, the printing of books, and the making of guns.

Rarer, but equally important, were dramatic new departures that opened entirely new technological avenues by hitting on something that was entirely novel and represented a discontinuous leap with the past. Such *macro*inventions created what Dosi (1988) has called technological paradigms, entirely new ways of thinking about and carrying out production. Within the new paradigm, once it is created, incremental *micro*inventive activity takes over: radically novel techniques need to be adjusted, extended, refined, and debugged.[20] It is rare that a totally new invention is fully ready to go into production from the start. But without occasional leaps of this kind, the process of continual incremental improvement within an existing technological paradigm would run into diminishing returns and eventually give out.

An exact criterion to distinguish macro- from microinventions is not easy to define. On the whole, a successful macroinvention meets three criteria: novelty, workability, and potential for further improvement. It involves a new technique to carry out production or consumption in a way that was radically different from anything before. Yet a radical idea, even a blueprint, that could not actually be materialized in practice was useless. Without the workmanship, the materials, and the supporting maintenance technology, the new idea would not survive. Macroinventions typically open new avenues to further improvements in production, reducing cost and enhancing product quality, finding new applications and new permutations, so that eventually it also acquired economic significance. However, it need not be a single event. Many macroinventions consisted of a number of steps that together were necessary for the new paradigm to emerge. The number of steps has to be small enough, however, to preserve some sense of discontinuous change.

The steam engine is a case in point.[21] It was conceptually one of the most radical inventions ever made. Energy, as used by people, comes in two forms: kinetic energy (work or motion) and thermal energy (heat). The equivalence of the two forms was not suspected by people in the eighteenth century; the notion that a horse pulling a treadmill and a coal fire heating a lime kiln were in some sense doing the same thing would have appeared absurd to them. Yet converting heat into work must be regarded as one of the most crucial advances ever made; energy had been exploited for many centuries through controlled fire, the domestication of animals, and the use of watermills and windmills. However, heat and work were not yet convertible into each other, so that wood and fossil fuels could not be used to produce motion and watermills could not produce heat.[22]

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[20] As one of the great engineers of the Industrial Revolution, John Farey, told a Parliamentary committee in 1828, "The inventions which ultimately come to be of great public value were scarcely worth anything in the crude state, but by the subsequent application of skill, capital and the well-directed exertions of the labour of a number of inferior artizans . . . brought to bear to the benefit of the community . . . such improvements are made progressively, and are brought into use one after another, almost imperceptibly" (cited by Inkster, 1991, pp. 84-86).

[21] For a similar argument, see Cipolla (1965).

[22] There was one exception to the rule. Gunpowder as used in the West was a method to convert heat into kinetic energy. But it was an uncontrolled conversion, and the uses of gunpowder for civilian purposes prior to the invention of dynamite were limited. It is telling that Christiaan Huygens, a Dutch scientist, proposed in 1673 to build a combustion

By breaking through this separation, then, the steam engine was truly radical. Its invention stemmed from the realization that the earth was surrounded by an atmosphere and that differences in atmospheric pressure could be utilized to harness energy. Suggestions of this kind had been made throughout the second half of the seventeenth century, but the half-baked sketches and flights of the imagination did not add up to much until 1690 when Denis Papin produced a prototype of a piston that moved up and down in a cylinder due to alternative heating and cooling. Thomas Savery's vacuum pump notwithstanding, the first truly successful steam engine was not produced until 1712 when an English engineer named Thomas Newcomen produced the first working steam engine. Large, cumbersome, noisy, and voracious in its appetite for fuel, the Newcomen engine must have appeared fierce and somewhat awesome to contemporaries. It was a prime example of what some have called "a hopeful monstrosity."[23] Newcomen engines were, however, viable and were used widely as pumps in mines where fuel was plentiful and flooding a threat. It was not until 1765, however, that the steam engine could be turned into an economic revolution, when James Watt introduced the separate condenser, as well as number of other important microinventions.

A second macroinvention of enormous economic importance was the invention of mechanical spinning. Since time immemorial, spinning had been carried out by a distaff-and-spindle method in which the spindle was dropped while the worker twisted the rovings of raw material and turned it into yarn. The index finger and thumb of the spinner, or (usually) spinster, were essential to this process, because it was their motion that drew out the fibers and carried out the true "spinning." The addition of the spinning wheel in the Middle Ages did not change that principle; the wheel just helped wind the finished yarn on a rapidly turning spindle. Replacing the human finger by a machine turned out to be a difficult problem, and it took until the last third of the eighteenth century to finally find a solution. When it happened, not one but two inventions emerged, which together changed spinning forever. One was the throstle, or water frame, invented by Richard Arkwright in 1769, which used two pairs of rapidly turning rollers to mimic the human fingers. The other was the Hargreaves spinning jenny (1765), based on the insight that it was possible to impart the twist by the correct turning of the wheel itself, with metal bars guiding the spun yarn onto the spindle. These two were then combined in 1779 by a third inventor, Samuel Crompton, into a hybrid of the two, appropriately called the mule. For more than a century, the mule remained the backbone of the British cotton industry.

The inventions in spinning led to a technology that was radically different from what came before. Economically, its importance was that it delivered a yarn that

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engine prototype using gunpowder.

[23]The term was actually coined by biologist Richard Goldschmidt to denote mutations that create new species.

cost a small fraction compared to the previous technique and yet was of far higher quality than anything that could have been produced in Britain before. The new spinning technology practically created an industry *de novo* (prior to 1770 cotton had been a small industry, in the shadow of its cousins, the woolen and linen industries). Above all, the spinning machines were truly a novel concept, one that could subsequently be further improved. The novelty was in the substitution of a machine for the fine movements of the human fingers, one of the most delicate and flexible mechanisms designed by nature. Although cotton spinning was concentrated in a small part of Britain (Lancashire), its ramifications were truly global. It led to the destruction of the Indian cotton-spinning industry, which previously had supplied the high-quality yarns needed to make calicoes. Across the Atlantic, the growth of the British cotton industry led to the emergence of the cotton economy and the survival of slavery in the United States.

The *economically* most important inventions were not necessarily the most spectacular macroinventions, though that was the case with the steam engine and cotton-spinning machinery.[24] Consider, for instance, the invention of the puddling-and-rolling technique by Henry Cort in 1784, which solved the problem of efficiently converting the output of blast furnaces, pig iron, into what industry needed, wrought iron. Arguably, it was the most indispensable invention of the era because unlike steam power and cotton there was no substitute for iron. Yet Cort's invention was hardly a radical departure; rolling had been practiced for centuries, and the conceptual novelty of the process was modest. On the other hand, consider the Jacquard loom, invented in France in 1804. This loom wove complicated patterns into fabric using instructions that were embedded in an endless chain of cards, which had holes that were prodded by special rods. What these cards contained was a revolutionary new insight: the binary coding of information, a system that was conceptually novel and a harbinger of things to come. The importance of the insight was fully recognized by Charles Babbage, the inventor of the "analytical engine," the precursor of the modern computer. Yet the Jacquard loom produced largely an up-market, expensive product (silk and high quality worsteds) and did not produce a very different product than the old draw loom. Its economic significance, compared with Cort's invention, was relatively small.

The most radical of macroinventions of the time had even less of an economic impact: hot air ballooning (invented in France in 1783). It never had much commercial use, and even its military use, though attempted, was less than decisive.

[24]The "social savings" of an invention is defined as the addition to total consumer surplus generated by it. It thus depends on the difference in costs between using the technique in question and the next best alternative.

Yet it was one of the most radical technological events of all time: the first manned flight, defeating the tyranny of gravity. It was typical of the period, the last third of the eighteenth century, in which traditions, conventions, and old boundaries were recklessly cast aside and new ideas tried everywhere. In 1796, Edward Jenner discovered the smallpox vaccination process, in which for the first time non-human substances were introduced into the human body to confer immunity — an unprecedented step in the history of medical technology. Other examples abound: the use of gas for lighting, the bleaching of fabrics with chlorine, new designs in waterwheels, the preservation of food through canning, and the idea of interchangeable parts in clocks and firearms all date from this period.

A technological definition of the Industrial Revolution would point to a clustering of macroinventions leading to an acceleration in microinventions. The macroinventions not only increased productivity at the time but opened enough new technological vistas to assure that further change was forthcoming. Such a definition does not pretend to exhaust what happened in Britain in those years. The macroinventions were significant in large part because they created the germs of what came later: a gradual diffusion, adaptation, improvement, and extension of the techniques developed during the Industrial Revolution. The high-pressure steam engine led to the railroad and steamship. Improvements in cotton-spinning and weaving were reinforced by innovations in the preparatory stages in yarn-making, such as carding and slubbing and the finishing processes such as bleaching and printing. The inventions in cotton manufacturing spread to wool and linen. The cheap wrought iron found many new uses for iron, including construction, water mills, ships, machines, and specialty tools. The Leblanc soda-making process (1787) and bleaching powder (1798) laid the foundation for a chemical industry. In the absence of subsequent microinventions, some macroinventions remained little more than curiosa. Thus Faraday's invention of the electrical motor in 1821 remained of largely academic interest until the principle of self-excitation was developed in the late 1860s. Ballooning, too, could not be exploited commercially until small, lightweight engines could be mounted on the balloons for steering.

Despite the obvious importance of changes in technology in the British economy, their analysis and measurement have been slippery, and economists have found it exceedingly difficult to quantify them. Innovations and inventions are difficult to count and they do not follow the laws of arithmetic. An invention may supersede a previous invention, it may be independent of it, or it may in fact supplement it and improve it. The combined effects of two inventions could thus be equivalent to one, two, or a larger number of improvements. Yet economic historians have felt intuitively that if technological change is to be analyzed, it has to be quantified in some way. Two alternative ways of measuring the level of technological change are the counting of patents or related statistics, which is a microeconomic approach and estimating total factor productivity, which is mostly a macroeconomic approach.

Patent statistics have always tempted economists. Jacob Schmookler (1966), whose work is often cited in this respect, was preceded in his interest in patents by economic historians such as Ashton (1948, p. 63) who pointed to the sharp rise in patents as a symptom of the Industrial Revolution. Recently, the patent statistics have been subjected to quantitative analysis (Sullivan, 1989; for the United States, see Sokoloff, 1988, and also Griliches, 1990). Yet the counting of patents has always been subject to sharp criticism. First, it is a measure of *invention*, not of *innovation*. The statistics reveal nothing about the subsequent usefulness of the invention: Arkwright's and Watt's patents would be counted together with that of the inventor who took out a patent on nightcaps specially designed for sufferers from gout and rheumatism. Weighting the patents by their "importance" is of course far from easy. Second, not all important inventions were patented. The reasons for this range from the inability of the inventor to pay the required fee (£100 for England, £350 for Great Britain as a whole) to the inventor's preference for secrecy. This objection would perhaps not be so damaging if the inventions that were patented were in some sense a representative sample of the larger population of inventive activity. But recent research strongly suggests that that was not the case (Griffiths, Hunt, and O'Brien, 1992; MacLeod, 1988). Patenting statistics thus measure the propensity of inventors to patent as well as the distribution of inventive activity over high- and low-patent industries. As such, its usefulness as an index for the level of inventive activity is limited.

Total factor productivity measurements take a completely different road: they are, if anything, measures of innovation, not of invention. The economic logic behind total factor productivity estimates is that output grows due to either increases in inputs or shifts *of* the production function (such as technological change). If the weighted contributions of the inputs are subtracted from the growth rates, the "residual" measures the rate of productivity growth, which is associated with innovation.[25] The two best-known attempts to compute total factor productivity for Britain during the Industrial Revolution were made by McCloskey and Crafts, and they are discussed in detail in the chapter by Harley below. Between 1760 and 1800, Crafts and Harley estimate, total factor productivity "explained" about 10 percent of total output growth; in the period 1801-1831 this went up to about 18 percent. This seems rather unimpressive, but it should be kept in mind that growth is concerned with output per worker (or per capita). If we look at output per worker, we observe that for the period 1760-1830 practically the entire growth of per capita

[25] The actual estimation (e.g., McCloskey, 1985) often uses the "dual" approach, which consists of looking at input and output prices. This approach is formally equivalent to the production function approach but utilizes different information.

income is explained by technological change.[26] Economic growth was slow, as Harley and Crafts have shown, but what little there was is explained by the residual. Differences in the exact procedure are still not entirely resolved.[27] Precisely because growth per capita was so slow and there is little to explain, small differences in procedures and estimation will produce different residuals. For instance, Voth (1998) radically revises labor inputs and claims that because labor input per capita increased in the fifty years before 1800, the residual is extremely small and possibly negative. Coming from a different direction, Clark (below) has revised the growth of per capita income between 1760 and 1800 and finds it to be essentially zero. The apparent dominance of invention over abstention suggested by total factor productivity analysis, one of the most striking findings of the New Economic History, seems less secure now than it did a decade ago. Clearly it is unwarranted to expect that major technological breakthroughs will lead to more or less simultaneous increases in productivity. Most of the payoff to such breakthroughs occurs in the more remote future and is spread over a long period.

Identifying the residual with technological change, in any event, is far from warranted. The residual is a measure of our ignorance rather than of our knowledge. Any errors, omissions, mismeasurements, and aggregation biases that occur on the output and the input sides would, by construction, be contained in the residual. For instance, we simply do not know much about the flow of capital services. If horses or machines worked longer hours or factory buildings were occupied for more than one shift, it is unlikely to be registered in our estimates as an increase in capital inputs. Moreover, changes in the *quality* of inputs would also be captured in the residual. If labor becomes more productive because workers are healthier or better disciplined, total factor productivity will increase though technology has remained unchanged. Furthermore, the residual is affected by market imperfections and

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[26]The contribution of total productivity toward per capita output can be computed from data provided by Crafts (1985a, p. 81) and Crafts and Harley (1992, table 5).

	Per Capita Growth	*Contrib. of Capital/ Labor Ratio*	*Contrib. of Resources per Capita Ratio*	*Total Contrib. of Nonlabor Inputs*	*Total Factor Productivity Growth*	*Productivity as a % of Total per Capita Growth*
1760-1800	0.2	0.2*0.35 = 0.07	-0.065*0.15 = -0.01	0.06	0.14	70
1800-1830	0.5	0.3*0.35 = 0.105	-0.1*0.15 = -0.015	0.09	0.41	82

[27]Crafts and Harley themselves find somewhat larger contributions of capital and correspondingly lower contributions of productivity, which results from their procedures lumping capital together with land and thus overstating total input growth somewhat.

external economies, economies or diseconomies of scale, changes in factor mobility, and so on. The residual is more than productivity change, and productivity change is more than technological change. At the same time, not all technological progress necessarily shows up in the residual.

A related literature has emerged in recent years concerning the question of "exogenous" vs. "endogenous" growth. Modern new growth theory, pioneered by economists such as Paul Romer, has tended to attribute a much larger portion of economic growth to endogenous factors, that is, factors that are part of the economist's models. The sense of economists is that they prefer models that do not rely on unexplained and exogenous events, replacing them, as one recent paper has it, "with explanations of historical experience" (Greasley and Oxley, 1997, p. 935). Endogenous growth theory assumes that technological progress is really produced by the system, either by people getting better skills and education or by some capital good that brings it about. This view implies that the time series properties of industrial output will be quite different than the old exogenous growth models in which economic growth triggered by exogenous technological shocks eventually reverted back to a steady-state rate. In exogenous growth models the output series does not exhibit persistence to shocks that is, it does not possess a unit root. An interesting debate has developed in the pages of the periodical literature on whether the time series of industrial output in Britain between 1780 and 1914 exhibits a unit root, the argument being that trend vs. difference stationarity presents a strong test of the kind of process that generates economic growth (Crafts, 1995a; Greasley and Oxley, 1997; Crafts and Mills, 1997). The idea is that if the series can be shown to be difference stationary, economic growth will be "endogenous" because a production function of the Romer type exhibits persistence and does not revert back to its trend. Trend stationarity, on the other hand, means that the growth process did not exhibit persistence: each productivity shock would, if not followed by others, peter out and the system required a constant infusion of new productivity-increasing technological advances if a technology-driven process of economic growth is to be sustained.

The econometric evidence, thus far, is inconclusive. Nicholas Crafts has argued that at least some part of the growth was exogenous and that trend stationarity cannot be rejected. Others have re-examined their data and concluded the reverse. One problem is that too much ink is spilled on devising the right test for persistence and too little, some would say none at all, attention to the underlying data. For a wide range of goods the quantity indices used by all participants in the debate consistently understate the rate of growth and so tend to be biased. It is not clear whether such a bias would increase or decrease the likelihood of rejecting the unit root hypothesis, but it does mean that many of the tests have been run on flawed data. While a few products such as cotton and coal are thought to be of more or less uniform quality, improvement in the *quality* and nature of capital goods, from steam engines to cattle to streetlights, makes the series employed by Crafts and others a source of concern. Performing a conclusive unit root test on consistently measured output data is difficult enough, as Christiano and Eichenbaum (1990) pointed out years ago — doing so with output data which are not and could not be measured in a consistent way strikes me as demanding too much credulity-suspension. To be sure, one can do such analyses on disaggregated series, and here too there is some evidence of persistence.

Moreover, the exact economic meaning of such persistence is still rather unclear. It means that a sudden technological "shock" due to an invention of sorts will disturb the rate of growth of output for ever, which is what one would expect if the aggregate production function exhibited increasing returns. But what if technology is itself a Markov process in which present values depend on the past? In that case what looks like output responding forever to a sudden technology shock is nothing but output responding to new knowledge building on itself. Beneath the changes in technology there are changes in human knowledge not readily observed in production time series. That knowledge does not have to be scientific by our modern definition. But there was an accumulation of experience, of tricks, of practical engineering knowledge "what works" "what material is suitable" and "what tool is appropriate here." Unless the econometrician observes the underlying knowledge directly, she will mistakenly infer that it is the output that follows the "persistent" trajectory. We know something about how this knowledge was transmitted, diffused, improved upon, and eventually discarded. Little of it had much to do with formal education and other readily observable accumulation of human capital, least of all in Britain. The role of physical capital, as we shall see below, was also ambiguous. Thus far, it remains very much an open question if the insights of the "new growth theory" can be applied to the Industrial Revolution (Crafts, 1996).

Technological change was only one phenomenon in a series of events that transformed Britain in this period. To what extent it caused the other changes or were caused by them remains a matter of interpretation. Whatever its exact role, it is impossible to provide any definition of the Industrial Revolution without it. Thus, if one insists on economic growth, capital accumulation, or changes in the organization of production as integral parts of the Industrial Revolution, it is difficult to separate them from the changes in technology. Even the most convinced detractors of the concept of the Industrial Revolution will concede two things. One is that although income per capita did not rise much between 1760 and 1830, it is hard to see how Britain could have sustained a more than doubling of its population while fighting a number of major wars had not its economic potential increased.[28] Moreover, the undeniable sustained growth that occurred in the British economy

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[28]The population of England in 1760 was 6.1 million; in 1830, 13.1 million (Wrigley and Schofield, 1981, p. 534). The populations of Wales and Scotland grew at comparable rates.

after 1830 would not and could not have occurred without the changes in technology in the previous seventy years.[29]

Secondly, most scholars agree that simple causal mechanisms will not explain something like the Industrial Revolution and that positive feedback and interactive path-dependent models will be needed if the phenomenon is to make sense. One example will suffice to convey this point: Many scholars emphasize commercial changes in this period and regard the rise of a national market and improvement in transport as causes of the changes in technology (Szostak, 1991). Adam Smith, writing before the Industrial Revolution or in its very early stages, had a view of economic development in which specialization and "the gains from trade" were at center stage. Yet improvements in technology subsequently fed back into improved transport, allowing even greater specialization and internal trade. Due to the inventions of John Loudon McAdam and Thomas Telford, improved roads and canals were constructed. Ships were built with planks cut by steam- or water-driven mills. Eventually the high-pressure steam engine and the precision-tool industry, developed during the Industrial Revolution, were applied to land and sea transport leading to changes in commerce that would have been unimaginable even to that inveterate optimist, Adam Smith. Thus gains from trade and specialization interacted with gains from technological progress, and such interactions led to a long and sustained path of economic development. Monocausal, linear models based on concepts of equilibrium or steady states will have difficulty doing justice to the historical reality.

To understand the phenomenon of the British Industrial Revolution, we will ask two related questions: What were the causes of technological progress in Britain? What other elements permitted its society to adapt and transform itself to absorb the innovations and become the "workshop of the world"?

The Causes of the Industrial Revolution

Why was there an Industrial Revolution? In this crude form the question is unanswerable. In more focused versions of the question some answers have been provided, and although full agreement is still remote, the discussion is one of the more lively in the historical literature. Examples of more focused formulations are: Why did the Industrial Revolution occur in Britain and not in France (or in the Netherlands, Germany, Spain)? Why did it start in the last third of the eighteenth century rather than, say, a century earlier? Can we find factors that should be regarded as "necessary preconditions" for the Industrial Revolution to have taken place? Historical causality in the analysis of an event as momentous as the

[29] Gross domestic product per person-hour, which grew at 0.5 percent in the United Kingdom in the period 1785-1820, accelerated to 1.4 percent in the period 1820-1890. Real income per capita between 1820 and 1870 is estimated to have grown at 1.5 percent per annum (Maddison, 1982, pp. 31, 44).

Industrial Revolution is not likely to generate much consensus, since a multitude of different models can be devised to explain it.

To start with the last question, the notion that certain changes were a sine qua non for the Industrial Revolution has become increasingly difficult to maintain (Gerschenkron, 1962, pp. 31-51). Some factors present in Britain facilitated the Industrial Revolution and in this sense can be said to be causal. Others impeded its progress, and the Industrial Revolution proceeded in spite of them.[30] The term *facilitated* does not mean, however, that there were any elements that were indispensable. After all, factors that were neither necessary nor sufficient for the outcome can still be thought of as causal. For instance, heart attacks cause deaths, though not all deaths are caused by them and not all heart attacks are fatal. Moreover, insofar as heart attacks are themselves caused by other factors, it is debatable to what extent they are ultimate causes or just "transmission mechanisms." The causal explanation of the Industrial Revolution runs into similar quandaries. Economic historians have increasingly come to concede that the positive effect that factor X had on the Industrial Revolution does not entitle factor X to the status of "necessary factor." Counterfactual analysis has to be resorted to, at least implicitly, to assess the indispensability of the various elements.[31]

It is not even certain that the question Why did the Industrial Revolution occur in Britain rather than in some other country? is necessarily the best way to approach the material. For one thing, as we have already indicated, the Industrial Revolution was not so much a national as a regional affair. This has been stressed again in a collection devoted to this issue (Hudson, 1989). The regional argument was presented most cogently by Sidney Pollard (1981, 1985). Instead of dividing the European continent into "economies," Pollard prefers to look at regions that transcended national boundaries and shared a common economic fate. Thus one

[30]A useful way of organizing our thinking about such causal factors is proposed by David Landes in his recent book (1998, pp. 217-19): write down the kind of characteristics that an ideal society and polity should exhibit (Landes lists twelve) and see how well different countries approximated such features. Our knowledge does not allow us to place weights on these factors, and hence, since no country is really close to the "ideal growth society," a ranking based on the proximity to the ideal economy is not feasible.

[31]Counterfactual analysis involves constructing a hypothetical world that never was. It is helpful in testing the hypothesis that factor X was a necessary condition in bringing about outcome Y; i.e., that in the absence of X, Y would not have taken place. Although the New Economic History is often credited with, or blamed for, introducing this mode of analysis, it has always been a staple tool of traditional historians. Thus Craig (1980, p. 1) begins his magisterial survey of German modern history: "It is certainly unnecessary to apologize for introducing Bismarck's name at the outset. If he had never risen to the top of Prussian politics, the unification of Germany would probably have taken place anyway but . . . surely not in quite the same way." For a more recent analysis of counterfactual history and a collection of case studies, see Tetlock and Belkin, 1996.

ought to prefer a comparison of, say, a region consisting of Lancashire and the West Riding of Yorkshire with a region consisting of southern Belgium and the northern *départements* of France.

Pollard's criticism of the national economy as the unit of analysis is not likely to remain unchallenged itself. The best arguments for the choice of nation-state as the appropriate unit of analysis are still in Kuznets (1966, pp. 16-19), who pointed out that nations share common heritages and histories, and thus people tend to be more interested in their national history than in regional histories. Moreover, a nation-state has a common government that is the major legislative and policy-making body, and insofar as it affects economic development, the unit under its jurisdiction should be the unit of analysis. The state was also, in most instance, the agency that collected economic statistics. Consequently, for better or worse, most of our data (e.g., foreign trade statistics, fiscal returns, price and wage figures) come on the national level.

It is debatable whether Britain was a unified economy or not on the eve of the Industrial Revolution (compare Crafts, 1985a, p. 3, and Szostak, 1991, p. 79, with Berg and Hudson, 1992). Yet it was certainly becoming more of one after 1760, and with the possible exception of the United Provinces, it was the most unified economy in Europe. Above all, it is hazardous to disavow comparisons of national units on account of *intra*national variances because the regional differences were themselves a *consequence* of the process of national development. As Rick Szostak (1991) has recently emphasized, no nation can devote itself entirely to one industry. With the improvements in transportation, interregional specialization became an inevitable part of the phenomenon that we are trying to analyze, namely the concentration of some industries in the Northwest of the country. The rise of the Yorkshire woolen industry was the mirror image and the "cause" of the demise of its counterpart in the West Country. The south of England remained largely unaffected by the Industrial Revolution because it specialized in agriculture.

A second criticism of the question Why was England first? has been raised in a pioneering paper by N.F.R. Crafts (1985b; see also Rostow, 1985). Quite simply put, Crafts's argument is that much of the Industrial Revolution was self-sustaining. In the extreme view, there is no point in asking why some nations underwent economic development and became rich while others remained poor and backward; it was all a matter of pure luck, a roll of the dice and in the limiting case causal analysis is useless. Much of the persuasiveness of this view depends on the accuracy of its premises. If we think of the Industrial Revolution as a sequence of strongly interrelated phenomena, it becomes indeed something close to a single event whose explanation may be beyond us. In reality, however, the set of facts we are trying to explain are to some extent independent events; by 1830 Britain had become a leader in a variety of industries, from papermaking to engineering to chemicals. If a coin is tossed once and heads comes up, there may be nothing to explain. However, if the coin is tossed dozens of times and heads comes up in every one of them, a closer look at the fairness of the coin would be called for. Much depends on how independent the events were; if they were strongly correlated, the "chance" explanation may hold true. If the correlation is weak, the plausibility of the "random-event" explanation is weakened. An analogy from genetics is instructive here: We know that mutations are chance events, copying-errors in the DNA. Yet the number of mutations can be affected by radiation or mutagenic chemicals, and a sharp rise in the number of mutations would itself not be a chance event because mutations are unlikely to lead to further mutations. Can we, in economic history, define something equivalent to mutagens, environmental agents stimulating invention and innovation?

Landes, in his Tawney lecture (1994, p. 653), insists that big processes call for big causes and that models in which small initial differences are reinforced over time to produce an ever-widening gulf are unrealistic. Yet models of positive feedback have actually those characteristics, and it is easy to think of some historical processes in which increasing returns, induced technological change, frequency dependent processes, and the co-evolution of institutions and technology led to a spiral in which similar societies landed on quite different locations. Positive feedback can occur, for instance, when there are learning effects or under increasing returns (Arthur, 1994). In those cases technological change leads to lower prices, which could lead to the realization of scale economies, complementarities with other industries, demonstration effects, self-fulfilling expectations, bringing about even lower prices. Once the process had started, it fed on itself. Just as we have vicious circles in which backwardness breeds poverty and poverty breeds more backwardness, we have virtuous circles in which the reverse is true. More recent work in the theory of economic development has formalized much of this thinking (e.g., Matsuyama, 1991; Arthur, 1994). If so, the role of contingency and accident in economic history may be far larger than people have supposed. In this approach, economic theory has to be complemented by insights from chaos theory: Comparatively minor differences in initial conditions can lead to major differences in historical outcomes. The Industrial Revolution in this interpretation was a "bifurcation point." Thus, as historians are learning from evolutionary biology and chaos theory, accidents and contingency are increasingly seen under the right circumstances to matter a great deal, and fairly small historical events can set an economy off into one direction or another.[32] The key qualification is "under the right circumstances" — did the structure of the economy switch from one of predominantly negative feedbacks to one in which positive feedback loops dominated? If so, can the Industrial Revolution be represented by such a model? Some thinking in modern systems-analysis seems to be moving into that direction. For instance, Stuart Kauffman has suggested that technological change can occur when the dynamic system's parameters are such that it is either in a subcritical

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[32] Paul Mantoux realized this long ago when he pointed out that "only a negligible quantity of ferment is needed to effect a radical change in a considerable volume of matter" (1928, p. 103).

region in which innovation is isolated and peripheral or in a supercritical one in which "new goods and services create niches that call forth the innovation of further new goods and services . . . such avalanches create enormous arenas of increasing returns because of the massive early improvements climbing learning curves along the novel technological trajectories" (1995, p. 296). If, as he suggests, the boundaries between the "regions" can be quite thin, it might be fruitful to think of the Industrial Revolution as a grand traverse from an economic system dominated by negative feedback and diminishing returns to one of positive feedback and sustained, indeed, explosive growth and innovation. Such interpretations must remain speculative, but they tend to underscore the central finding of the historians of technology, namely that the Industrial Revolution was not the beginning of economic growth or of technological progress, but it was the beginning of sustained, divergent, self-reinforcing and accelerating economic change. Up to a point, Pollard's (1996, p. 373) recent summary captures these dynamics: "the discovery of discovery itself became a commonplace and a driving force...as soon as inventions became widespread rather than isolated they provided mutual support for each other... Technology had 'taken off'". Yet positive feedback stories of this kind have to contend with the problem that offsetting negative feedback can equally be discerned and eventually in the long run "nothing failed like success." For that reason, we need to examine the details of Britain's economy and society to understand why she came to play the role she did.

Geography

Britain's geographical advantages over other economies have often seemed to be good explanations for its economic success after 1750. In one book, a social historian states it as self-evident that "England is built [*sic*] upon an underground mountain of coal. Its exploitation was the motor-force in the revolution in production that created modern industrial society" (Levine, 1987, p. 97).[33] The belief that "geography is destiny" is an old and venerable one. Some major objections can be raised against the view that places too heavy an emphasis on accidents of nature as causal factors. In part, the impact of such accidents is ambiguous. Resource availability plays a somewhat bizarre role in the historiography of technological progress. On the one hand, resource abundance is considered a blessing because it cheapens production and encourages the development of complementary techniques. On the other hand, many authors maintain that the challenge imposed by resource *scarcities* stimulates invention.

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[33] See also, for example, Parker (1979, p. 61). Coleman (1983, p. 443) even goes so far as to conclude that coal and iron were of greater consequence in determining the pattern of British industrialization than the existence of domestic industry. In making this statement he fails to apply to his own hypotheses the strict empirical standards he demands from others. E. A. Wrigley (1987; 1988, essay 4) has emphasized the importance of coal in the British Industrial Revolution, although his treatment is far more judicious.

Thus the deforestation of Britain is alleged to have led to a rise in timber prices, thus triggering Britain into adopting a novel and ultimately far more efficient set of techniques using fossil fuels. The evidence for this oft-repeated tale is far from convincing.[34] As a general statement, however, it suffers from the logical difficulty that the scarcity of natural resources and their abundance cannot *both* be regarded as stimulating factors for technological progress. At most, one can say that nature worked as a "focusing device," to use Nathan Rosenberg's felicitous term. Given a certain level of technological creativity, nature would direct this creativity in a certain direction, what Kuznets (1965, p. 91) has called a national bias in technological progress. Thus coal-rich Britain would focus on Newcomen engines, while coal-poor Switzerland would find economic success in precision-intensive low-energy industries such as watchmaking and engineering. Many other economies, rich or poor in resources, lacked the technological creativity and achieved little progress in this period. For a focusing device to work, there has to be a source of light.

Geography and physical endowment, like most other factors, are rarely either sufficient or necessary. Britain's geographic good luck was that it was an island and thus had not been successfully invaded since 1066. Being an island also provided it with access to a cheap form of transportation (coastal shipping). Yet being an island does not seem to have done much for Ireland, and good internal transportation was not very helpful to the Dutch economy in generating a phenomenon similar to the Industrial Revolution. Moreover, geography had to be aided by capital and technology. Patrick Verley (1997, p. 219) has recently recycled Babbage's (1835) calculations showing that in terms of naturally navigable rivers, England and France had similar proportional endowments, but once canals are taken into account, England (including Wales) had more than twice the internal waterways per square mile in 1820 and more than three times per capita. Britain's advantage in mineral wealth is equally problematic. Britain had coal and iron, but

[34]For an effective refutation of this argument, see Flinn (1959, 1978) and Hammersley (1973). If it is true, as Hammersley (p. 609) notes, that wood as a crop could only use what to the landowner was marginal land and yielded returns far below those on pasture and other crops, it must have been the case that the "scarcity" of timber even in Britain was not too acutely felt. In his excellent survey of the issue, John Harris (1988) points out that the switch from charcoal to coal-based fuels in the iron industry in the second half of the eighteenth century is often believed to be the first such transition whereas in fact it was "virtually the last." Industries such as soapboiling, brewing, and glassmaking had switched to coal centuries earlier, and home-heating (the largest use for fuel) had become dependent on coal much earlier as well. While the iron industry itself may therefore not have been seriously constrained by the putative scarcity of charcoal, the benefits of abundant coal for Britain were larger than the advantages of Darby's famous new technique of iron smelting. Yet this timing pattern also suggests that the nexus between Britain's fortunate endowment of coal and the Industrial Revolution is more complex than simple-minded models of geographical determinism suggest.

coal and iron were traded commodities; in 1794-1796 it imported £852,000 worth of iron and iron ore, mostly from Sweden. In the second half of the nineteenth century, it imported high-quality haematite ores from Spain. Coal, too, was traded, though its volume expanded only after 1830. Above all, much of the Industrial Revolution depended on cotton and that raw cotton was entirely imported. Trade, it should always be remembered, liberates nations from the arbitrary tyranny of resource location. On the Continent, too, the evidence is mixed: Belgium, the first nation to adopt Britain's techniques, shared with her a wealth of iron and coal; Switzerland, a close second, had neither. Buying coal and iron from other economies added to industrial costs, but such additions were, on the whole, sufficiently small to be dwarfed by other cost differences. In other words, it is possible to accept Wrigley's (1987) view that substituting coal for wood was an important part of the economic transformation of Britain, without attributing undue significance to the geographical accident of the presence of coal in Britain. Coal had substitutes; coal-poor nations like the Netherlands and Ireland relied on peat for fuel, while the mountainous areas of Europe relied on water power for energy and flat windy areas in the Low Countries relied on wind power. Such substitutions involved costs, of course, but the examples of Switzerland and New England prove that water power could provide an adequate energy base for a mechanized industry.

It could be maintained, however, that there were more subtle links between location and technological change. Small differences in resource endowment could set into motion chain reactions and steer a nation along a technological trajectory quite different from one that would have been followed in the absence of those resources. Britain's use of coal did not only help by providing cheap fuel; it focused Britain's attention on the solution to certain technological problems: pumping, hoisting, and mineral-exploration, which then spilled over to other industries (Cardwell, 1972, p. 73). Shipping, too, generated externalities in sawmills, carpentry, instrumentmaking, sailweaving, and so on. Yet in a deeper sense such mechanical descriptions are unsatisfactory since they describe opportunities; but clearly these opportunities were neither necessary nor sufficient conditions for success. Maritime Holland was not able to use its shipbuilding sector as a gateway into the Industrial Revolution.

History

In recent years, a growing number of scholars have followed the lead of Eric Jones (1988) in arguing that the Industrial Revolution was the culmination of a long process of modernization that started in Britain many centuries before (though opinions vary to when, exactly, this process started). The most influential economic historian of British medieval agriculture (Campbell, 1997), maintains that by the thirteenth and fourteenth centuries Britain was a market economy in which production decisions were sensitive to factor and commodity prices. Gregory Clark (1998, see also the essay below) has argued that medieval agriculture was as productive and sophisticated as British agriculture was on the eve of the Industrial

Revolution and that markets for grain were well-functioning. Foreign travelers visiting Britain commented in living colors about the luxury and extravagance of British living standards in the last third of the eighteenth century (McKendrick, 1982a, pp. 9-10; Landes, 1998, pp. 221-222). Graeme Snooks (1994) has argued forcefully that economic growth was not unique to the period of the Industrial Revolution and that by the late seventeenth century Britain was an advanced and sophisticated economy.[35] In pointing this out, these scholars are joining the venerable company of MacFarlane (1978) who was one of the first scholars to pinpoint the beginning of Britain's modernity to the late middle ages. It is clear by now that far from being a "traditional" and "static" society, Britain on the eve of the Industrial Revolution was a country of sophisticated markets, in which profit-hungry homines economici did what they are supposed to do to help a country develop. Yet while this does explain Britain's wealth on the evolution of the Industrial Revolution, it raises as many difficulties as it solves. Is it so obvious that an urbanized, literate, market-oriented society leads inevitably to an Industrial Revolution? The Dutch economy, as De Vries (1973) and more recently De Vries and Van Der Woude (1995, pp. 798-806; 1997, pp. 693-710) have argued, had many elements of modernity and yet turned out to be one of the last economies to jump the bandwagon of modern manufacturing in Western Europe, whereas Switzerland, a relatively remote and simple highland economy had by 1850 a progressive modern sector.

Nor is it so obvious that income and wealth are positive feedback processes in which the rich get richer so that the Industrial Revolution can be seen as an example of economic divergence. Certainly, within the relatively small group of Atlantic economies, the past two centuries have shown a process of *con*vergence in which the backward economies managed to catch up with the leaders, so that within this group a process of income compression is clearly visible. Even less can we speak of a connection between income and technological creativity. Rich capitalist

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[35]Snooks's (1994) belief in pre-modern growth is based essentially on his comparison between the income per capita he has calculated from the Domesday book (1086) and the numbers provided by Gregory King for 1688. While such computations are of course always somewhat worrisome (what, exactly, does it mean to estimate the nominal income of 1086 in the prices of 1688 given the many changes in consumption items?), the order of magnitude provided by Snooks (an increase of real income by 580 percent) may survive such concerns. Medievalists tend to agree with the occurrence of economic growth in Britain, though their figures indicate a much slower rate of growth, about a 111 percent growth rate between 1086 and 1470 (Britnell, 1996, p. 229), which would require more economic growth in the sixteenth and seventeenth centuries than can be justified to square with Snooks's numbers. Engerman (1994b, p. 116) assesses that most observers will agree with Snooks's view that by 1700 England had a high level of per capita income and was in a good position to "seek the next stage of economic growth." Yet clearly he is correct in judging that "modern" economic growth (prolonged, continuous, rapid) did not begin until the early nineteenth century.

countries may be technological leaders for a long period, as Britain undoubtedly was. Yet more often than not, such leadership was eventually lost as it was in Britain's case and later in Germany's. Where historical accident did play an important role was in the coincidence of the British Industrial Revolution with the French Revolution and the Napoleonic Wars. Whereas the wars probably slowed growth and technological progress down everywhere, they did so far more seriously on the Continent than in Britain. Western technology emerged in a Western European club of economies, and while Britain was the undoubted leader, in its absence some other European economy would have played this role. The quarter of a century of turmoil and destruction that plagued the Continent after 1790 deepened and accentuated Britain's leadership and were especially hard on the Dutch economy, Britain's closest economic rival (Mokyr and Buyst, 1990). Yet it remains true that its technological leadership was already well-established by 1790, and while the diffusion of technological change and Continental industrialization may well have been faster in the absence of the French Revolution and its aftermath, there still would have been a British Industrial Revolution.

Technological Creativity

If it is agreed that at the base of the Industrial Revolution lay something we call technological creativity, some speculation about the factors responsible for it is in place here. To start with, Britain seems to have no particular advantage in generating macroinventions; a large number of them were generated overseas, especially in France. Steampower and cotton technology were British inventions, but many of the other examples cited previously were imported: Jacquard looms, chlorine bleaching, the Leblanc soda-making process, food canning, the Robert continuous paper-making process, gaslighting, mechanical flaxspinning.

Any period of successful technological creativity requires both fundamental breakthroughs and small, incremental, often anonymous improvements that take place *within* known techniques. The key to British technological success was that it had a *comparative* advantage in *micro*inventions. This may seem unorthodox to those who think of the milestones set by Richard Trevithick, Richard Arkwright, and Henry Cort, but it should be recalled that it is possible to have an absolute advantage in both areas yet a comparative advantage in one, although it is not altogether clear whether Britain had an *absolute* advantage in macroinventions.

Evidence for the statement that the British comparative advantage was in improvement and not in originality comes in part from contemporary sources. In a widely cited comment, a Swiss calico printer remarked in 1766 that for a thing to be perfect it has to be invented in France and worked out in England (Wadsworth and Mann, 1931, p. 413). In 1829 the engineer John Farey stated that the prevailing talent of English and Scotch people is to apply new ideas to use and to bring such

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The following paragraphs draw heavily on Mokyr (1990a, 1992a).

applications to perfection, but they do not "imagine" as much as foreigners (Musson, 1975, p. 81). Continental Europeans felt frustrated, reflecting Leibniz's prophetic words, written in 1670: "It is not laudable that we Germans were the first in the invention of mechanical, natural, and other arts and sciences, but are the last in their expansion and betterment" (cited in William Clark, 1991). A test of the hypothesis that Britain had a comparative advantage in microinventions is in the establishment of net trade directions. Economies tend to specialize in the areas in which they have a comparative advantage. The British economy, roughly speaking, was a net importer of macroinventions and exporter of microinventions and minor improvements. We should of course look at this specialization as a broad central tendency, but in rough lines the distinction stands up. Britain took its major inventions where it could find them, but whatever it borrowed it improved and refined.[36]

On the eve of the Industrial Revolution, Britain was neither a scientific leader nor could it boast of a particularly effective education system. As David Mitch explains in more detail in a later chapter, British education was at its best outside the schools, and Britain trained most of its mechanics and engineers by its age-old apprenticeship system without introducing much formal schooling. In a sample of 498 applied scientists and engineers born between 1700 and 1850, 91 were educated in Scotland, 50 at Oxbridge, and 329 (about two-thirds) had no university education at all (Birse, 1983, p. 16). Yet these people thirsted for technical, applied, pragmatic knowledge, the knowledge of how to make things and how to make them cheap and durable. A few of them were educated at Scottish universities or dissenting academies, but many were self-taught or had acquired their knowledge through personal relations with masters, libraries, itinerant lecturers, and mechanics institutes. By the middle of the nineteenth century, there were 1,020 associations for technical and scientific knowledge in Britain with a membership that Inkster estimated conservatively at 200,000 (Inkster, 1991, pp. 73, 78-79).

For Britain in this period, this system clearly delivered. It produced some of the finest applied engineers in history. As long as technological advances did not require a fundamental understanding of the laws of physics or chemistry on which they were based and as long as advances could be achieved by brilliant but intuitive tinkerers and persistent experimenters, Britain's ability to create or adapt new production technologies was supreme. Most inventors and engineers were dexterous

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[36]The case of chlorine bleaching is revealing here. The Swede Karl Wilhelm Scheele and the Frenchman Claude Berthollet clearly produced the original breakthrough, but the commercial value of the idea was recognized by James Watt (whose father-in-law, James McGrigor, was a Glasgow bleacher), and a series of British chemists and entrepreneurs set out to improve on the original invention (Musson and Robinson, 1969, pp. 251-337). The definitive improvement came when a Scottish bleacher Charles Tennant replaced potash with slaked lime as the solution in which chlorine was absorbed. Chemical bleaching, a Continental macroinvention, was made into bleaching powder, a British improvement.

merchants or enterprising craftsmen whose technical ideas were often the result of luck, serendipity, or inspiration even if the successful completion of the innovative process required patience, determination, and confidence.

Moreover, some of the industries in which Britain had specialized before 1760 required skilled mechanics. Clock and instrument making, shipbuilding, iron making, printing, wool finishing, and mining required a level of technical skill that came in handy when new ideas had to be translated from blueprints to models and from models to real commodities. John Wilkinson, it is often remarked, was indispensable for the success of James Watt, because his Bradley works had the skilled workers and equipment to bore the cylinders exactly according to specification. Mechanics and instrument makers such as Jesse Ramsden, Edward Nairn, Joseph Bramah, and Henry Maudslay; clock makers such as Henry Hindley, Benjamin Huntsman, and John Kay of Warrington (not to be confused with his namesake, the inventor of the flying shuttle, who was trained as a reed and comb maker), engineers such as John Smeaton, Richard Roberts, and Marc I. Brunel; ironmasters such as the Darbys, the Crowleys, and the Crawshays; chemists such as John Roebuck, Alexander Chisholm, and James Keir were as much part of the story as the "superstars" Arkwright, Cort, Crompton, Hargreaves, Cartwright, Trevithick, and Watt. Below the great engineers came a much larger contingent of skilled artisans and mechanics, upon whose dexterity and adroitness the top inventors and thus Britain's technological success relied. These unknown but capable workers produced a cumulative stream of anonymous and small but indispensable microinventions without which Britain would not have become the "workshop of the world." It is perhaps premature to speak of an "invention industry" by this period, but clearly mechanical knowledge at a level beyond the reach of the run-of-the-mill artisan became increasingly essential to create the inventions associated with the Industrial Revolution. Dozens of scientific journals and the published transactions of scientific societies had appeared by 1800, most of them after 1760 (Kronick, 1962, p. 73). A widespread thirst for knowledge about "natural philosophy and its relation to the useful arts" penetrated Britain down to the small towns of the kingdom where itinerant lecturers were in much demand. The people who worked in applying the principles of physics, chemistry, and biology in their daily work were thirsty for innovations. In this milieu *micro*inventions, the gradual improvement of pathbreaking ideas, will prosper. In the early stages of the Industrial Revolution this ability was the key to Britain's technological success.

It is of course a truism that advantages in skilled labor were a matter of degree, not an absolute. France, Germany, and the Low Countries had their share of able and innovative engineers. But degree is everything, and in the early nineteenth century Britain tried, in vain, to keep the secret of its success by prohibiting the exportation of machines and the emigration of skilled mechanics. Yet as it had imported macroinventions, it exported microinventions and the people who implemented them. The engineers who spread the new technologies to the Continent after 1800 had names like Cockerill, Hodson, Ainsworth, Douglas, and

Holden. Insofar as trade patterns reveal comparative advantage, these patterns reveal Britain's technological superiority. Explaining this superiority is a different matter: Landes (1969, pp. 61-64), who was one of the first to call attention to Britain's advantage in mechanics and technicians, spoke of the question of British mechanical skills as "mysterious." Clearly, any explanation will have to take us beyond the narrow boundaries prescribed by economic science.

Social and Institutional Factors

It is easier said than demonstrated that Britain had the "right kind of society" to have an Industrial Revolution. After all, what exactly do we mean by social preconditions to industrialization and how do we demonstrate the proposition that they were important? One way to approach the subject is through the concept of a "hierarchy of values." Each society defines in some way the criteria of success. Success means access to certain nonmarket goods such as political offices, membership of social clubs, being plugged into information networks, and in general earning respect from people whose opinions matter. Social status and prestige are always and everywhere *correlated with* economic success but are almost never *identical* with it. In many societies the causation ran from non-economic success to enrichment; victorious Roman generals were rewarded by remunerative governorships. One key to the economic success of a society is the degree to which social respect not only correlates with economic success but is caused by it.[37]

The most complete and persuasive attempt to provide a social explanation of the Industrial Revolution based on this idea has been provided by Perkin (1969). Perkin dates the creation of the type of society that was most amenable to an Industrial Revolution to the Restoration of 1660 and the social and political changes accompanying it.[38] He points out that the principle upon which society was established following the Civil War was the link between wealth and status. Status means here not only political influence and indirect control over the lives of one's neighbors but also the houses to which one was invited, the partners that were eligible for one's children to marry, the rank one could attain (that is, purchase) in

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[37]Economic theorists have belatedly rediscovered this rather obvious fact and have tried to formalize it. See Cole, Mailath, and Postlewaite (1992, 1995). Their model of "social norms" distinguishes between a "wealth is status" norm and an aristocratic ("birth is status") norm. They show, among others, that the former norm encourages savings to facilitate social climbing. When wealth is not directly observable, individuals may engage in conspicuous consumption, signaling their wealth, but such consumption by itself destroys part of the wealth.

[38]Some social historians argue that the changes started much earlier. Alan MacFarlane (1978, pp. 199-201) explicitly dates the beginning of English "modern society" to some point before the Black Death.

the army, where one lived, and how one's children were educated. In Perkin's view, the quality of life was determined not just by "consumption," as usually defined by economists, but by the relative standing of the individual in the social hierarchy. Whether this social relativity hypothesis is still a good description of society is an open question, but a case can be made, as Perkin does, that it is an apt description of Britain in the eighteenth century. Perkin cites a paragraph from Adam Smith's *Theory of Moral Sentiments*, which economists— always a bit selective in what they learned from the Master—have been ignoring at their risk:

> To what purpose is all the toil and bustle of the world . . . the pursuit of wealth, of power, and preeminence? Is it to supply the necessities of nature? The wages of the meanest labourer can supply them. . . . What then is the cause of our aversion to his situation? . . . Do the rich imagine that their stomach is better, or their sleep sounder in a palace than in a cottage? The contrary has so often been observed. . . . What are the advantages [then] by that great purpose of human life which we call bettering our condition? . . . It is the vanity, not the ease of the pleasure, which interests us. But vanity is always founded upon our belief of our being the object of attention and approbation. The rich man glories in his riches, because he feels that they naturally draw upon him the attention of the world. . . . Everybody is eager to look at him. . . . His actions are the objects of the public care. Scarce a word, scarce a gesture can fall from him that is altogether neglected. In a great assembly he is the person upon whom all direct their eyes. . . . It is this, which . . . renders greatness the object of envy and compensates . . . all that toil, all that anxiety, all those mortifications which must be undergone in the pursuit of it (Smith, 1759, pp. 50-51).

In Perkin's own words, "To the perennial desire for wealth, the old society, [i.e., Britain after 1600] added more motivation which gave point and purpose to the pursuit of riches. Compared with neighbouring and more traditional societies it offered both a greater challenge and a greater reward to successful enterprise. . . . the pursuit of wealth *was* the pursuit of social status, not merely for oneself but for one's family" (Perkin, 1969, p.85).[39] Examples are not hard to find: The riches accumulated by Richard Arkwright in cotton spinning bought him not only all the comforts that money could buy but also a knighthood and the office of sheriff of the

[39] Perkin anticipated here the interesting work of Fred Hirsch (1976), who, although not concerned with history, sets up a framework that complements Perkin's. Hirsch distinguishes between material goods—i.e., ordinary commodities—and positional goods of which there are by definition a constant amount. Examples of the latter are social prestige, political power, and symbols indicating one's relative position. Markets for material goods tend to be well developed, so material wealth provides easy access to them. Markets for positional goods are less well developed. The more efficient the markets for positional goods, the easier it is to acquire them by the means of acquiring wealth or to lose them by the lack thereof. Therefore, relatively efficient markets for positional goods should strengthen the incentive to get rich (increase the marginal utility of income) and make the toil and risks of entrepreneurship more worthwhile.

County of Derby. Other cotton manufacturers who rose to high office included Robert Peel, Sr., who became an MP and whose son became prime minister. Brewers, paper makers, potters, and iron masters became barons, earls, MP's, and castle dwellers. Men of business could, through money, "advance in rank and contend with the landlords in the enjoyments of leisure, as well as luxuries," as Malthus (1820, p. 470) put it.[40]

Perkin's insight is important because it underlines a basic point often overlooked by economists trying to understand entrepreneurial behavior. It is almost always true that an easy opportunity to earn money will not be passed over by a rational individual. Moreover, if there is a divergence of opinion about the expected profitability of an opportunity, one should expect the optimists to replace the pessimists. Unexploited opportunities to quick gains will rapidly disappear. There were opportunities to make money during the Industrial Revolution, but few were quick and easy. Almost all major entrepreneurial figures took enormous risks, worked long and hard hours, and rarely enjoyed the fruits of their efforts until late in life or enjoyed them vicariously through their descendants. Entrepreneurship will be more forthcoming if the rewards of money exceed the costs of risk bearing, hard work, and postponed gratification. Perkin's thesis stresses the benefit side in this equation; in Britain money bought more than just comfort. Money acquired in commerce or industry was less tainted by the stigma of being "nouveau riche" than elsewhere. The example set by the elite (the landowning gentry and aristocracy) profoundly influenced the values and attitudes of those who aspired to be like them. In Britain, far more than on the Continent, a materialist element had come to dominate these values. As Landes (1969, p. 70) put it, "The British nobility and gentry chose to meet the newcomers on middle ground: they affirmed their distinction of blood and breeding; but they buttressed it with an active and productive cultivation of gain."

Still, some empirical questions have to be answered before the connection between wealth and status can be accepted as one explanation of England's success.[41] Was the correlation between wealth and social status stronger in Britain than elsewhere? Holland was an urban, capitalist, bourgeois society, indicating that having the "right kind of society" is not a sufficient condition for a successful

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[40] Local studies confirm the importance of wealth as a determinant of status. Urdank, in his study of Gloucestershire, found that "between 1780 and 1850 wealth had become a more obvious criterion for defining status than in the past, so much so that men with the humblest occupations might call themselves 'gentlemen' if the size of their personal estates seemed to warrant the title" (Urdank, 1990, p. 52).

[41] Perkin's further attempts to explain the timing of the Industrial Revolution in terms of population growth and demand are far less successful. Some of these issues will be dealt with later in this chapter.

Industrial Revolution.[42] But what about France? In the eighteenth century aristocratic titles could be bought, and much of the nobility was a *noblesse de robe*, i.e., of bourgeois origins. Was the aversion to parvenus among the upper class stronger in France than in England? Although the latter question cannot readily be answered, there were two important differences between the two countries in this respect. First, in France, too, money could enhance social status, but the respectable local country gentleman who ran the affairs of the parish was a wholly British institution. Second, in France social status was often literally bought. The price of a noble title reflected a tax exemption, so that the sale of titles was not a one-way street by which the crown soaked up wealth. But nobility implied high standards of consumption in the noblesse oblige tradition. In England, by contrast, wealth was correlated with influence and respect, but one did not necessarily have to part with the former to attain the latter.

Furthermore, Perkin's logic implies an almost dialectical dynamism of the supply of entrepreneurship. If merchants and manufacturers made money in order to buy themselves or their descendants the good life of the country squire, the ranks of the entrepreneurial class would be constantly depleted. Upward mobility by means of wealth thus also led to the eventual destruction of the entrepreneurial class. Having attained their new status, the new elite tended to slam the door shut to further entrants. This "gentrification" of the commercial and industrial class, which has been blamed for the decline of Britain's leadership in the Victorian age (Wiener, 1981), seems a logical extension of Perkin's thesis. Because the debate on the "failure" of Victorian Britain lies outside the scope of this volume, this implication cannot be pursued here.

Society is, of course, more than attitudes and mind-sets. Its importance lies above all in the institutions within which economic activity takes place. Some institutional setups are more suitable for technological change than others, and although institutions eventually may respond to economic and political needs and pressures, these responses are sufficiently sluggish to allow us to point to institutions as a "causal" factor in economic development. Institutions defined property rights and thus the rate of return on inventive and entrepreneurial activity. This has been stressed by North (1981, 1990). In North's interpretation, property rights and incentives are the crucial elements in the story. He stresses (North, 1990, p. 75) that patent laws and other institutions raised the rate of return on innovation and thus stimulated the process of technological progress. Britain's patent law dates back to 1624, whereas France and most of the rest of the Continent did not have such laws on the books until after 1791.

The exact role of the patent system in Britain's Industrial Revolution is hard to determine. A patent is only one way of encouraging a potential inventor to spend time and money on the uncertain road to success. The French government, for

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[42]For economic explanations of the Netherlands's failure to industrialize, see Mokyr (1976a) and Griffiths (1979).

instance, awarded pensions through the Royal Academy and through so-called *privilèges* (administered by the king), which were also intended to encourage invention (MacLeod, 1991). North overrates the effective protection that the British patent system provided to inventors; court decisions in infringement cases tended to be unsympathetic to inventors, and patents were overthrown on minor technical points such as scribes omitting one line. In some cases, financial success came without patent protection, as in the case of Richard Arkwright. The court's invalidation of his patent did not stop him from becoming extremely rich. In other cases, when inventions failed to be patented or when patents were lost because of technicalities, inventors were rewarded by Parliament in recognition of their social value. The mule's inventor, Samuel Crompton, and the power loom's inventor, Edmund Cartwright, were both the beneficiaries of Parliament's gratefulness. Moreover, patents and infringements of them led to endless court battles that sapped the energy and resources of technologically creative people. Arkwright and his sometime partner, Jedediah Strutt, spent much time in courts defending their patents. Some innovators, such as John Kay, the inventor of the flying shuttle, and the Fourdrinier brothers, who pioneered the paper-making machine, were ruined by litigation. In many cases, inventors decided to protect their monopoly rents by keeping their inventions secret. If "reverse engineering" was not likely or if the inventor could make his money by employing his machines to produce a final output rather than by selling capital goods, this was often tried. Yet secrecy had its risks: Industrial espionage was an ever-present danger.[43]

The effects of patents on the rate of innovative activity is further clouded by the fact that the patentability of innovations differed a great deal from industry to industry. Christine MacLeod has estimated that nine out of ten patents arose in industries that saw little innovation and concludes that patents were related to technological change in an erratic and tangential manner and were more closely associated with "emergent capitalism" than with inventiveness (1988, pp. 145, 156-157). Moreover, patent protection, as is well known, is a double-edged sword. If a patentee is a monopolist, the invention's diffusion will be retarded and the industry will grow at a slower pace, unless the inventor's firm can expand as fast as the industry as a whole. One dilemma in the economics of technological change is that there is a trade-off between generating inventions and their diffusion.[44] The more

[43]Richard Roberts, one of the leading engineers of his time, felt that "no trade secret can be kept very long; a quart of ale will do wonders in that way" (cited by Dutton, 1984, pp. 108-111).

[44]The efficient solution maximizing the social savings could be attained if the patentee could license his patent out and earn royalties equivalent to the monopoly rent. Yet setting the correct prices and monitoring the arrangements were a major difficulty. MacLeod (1991) concludes that only after 1800 did British patentees learn to exploit licenses more profitably, and even then only a tiny minority mastered the art at the cost of extensive

monopoly protection is used to encourage invention, the slower its adoption and thus its social benefits. Patents imply the choice of a particular point on this trade-off; so do alternative arrangements. Moreover, patents may have had a mixed effect on invention itself; in some cases owners of wide-ranging and vague patents used their power to close avenues they deemed undesirable or potentially competitive. The best-known example of that in the period of the Industrial Revolution is Watt's use of his patent to resist the development of high-pressure steam engines.

All the same, the importance of the patent system for Britain's technological success cannot be wholly dismissed by these objections. As Adam Smith was the first to point out in his *Lectures on Jurisprudence*, patents alone preserved some automatic correlation between the value of an invention and the return received by the inventor. The French system of rewards administered by a governmental committee made the return on invention dependent on political clout more than on the test of the market (Gillispie, 1980, pp. 459-478). Moreover, incentives refer to potential inventors' *ex ante* expectations of being financially rewarded if they were successful. Disappointments and lawsuits were relevant to further technological progress only to the extent that they discouraged others. By definition, each patent is inherently different from every other one, and so the failure of an inventor to secure a return on his efforts may not have necessarily indicated to others that their fate would be the same. The desire to patent new inventions did not weaken during the Industrial Revolution. Goethe may have been somewhat naive when he wrote that the British patent system's great merit was that it turned invention into a "real possession, and thereby avoids all annoying disputes concerning the honor due" (cited in Klemm, 1964, p. 173). Yet in 1845 the Swiss industrialist Johann C. Fischer concluded that "the system of patents so early introduced there may well have . . . been responsible for manufactured goods possessing so high a degree of perfection." Britain's greatest post-1830 inventor, Henry Bessemer, believed that "the security offered by patent law to persons who expend large amounts of money in pursuing novel inventions, results in many new and important improvements in our manufactures" (Bessemer, [1905] 1989, p. 82). Not all inventors concurred with this view, but if enough of them saw it this way, the British patent system deserves some credit. H. I. Dutton (1984, p. 203) has argued that for many inventors patents were the only means by which they could appropriate a sufficient return for their effort and that patents thus provided security in an exceptionally risky activity. The patent law was often poorly defined and the courts unfriendly to inventors, but it remained in most cases the best incentive for inventive activity. Dutton argues that the patent laws were a "slightly imperfect" system that created an ideal system in which there was enough protection for inventors to maintain an incentive for inventions, yet was not so watertight as to make it overly expensive for users. If inventors systematically overestimated the rate of return on inventions by not fully

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litigation.

recognizing the weaknesses of the patent system, they would have produced more innovations than in a world of perfect information.

Government and Politics

British political institutions differed greatly from those of most European countries, and recent thinking by economists has tended to place considerable emphasis on political elements. Some of the differences are obvious: Despite the fact that the Industrial Revolution coincided with two major wars, there was no fighting on British soil, and except for a few serious but localized riots and an abortive uprising in Ireland, Britain was spared the turmoil and turbulence of the Continent after 1789. The need to allocate resources to the war effort involved a substantial effort on the part of Britain, and the disruptions of trade and the disequilibria caused by the wars and blockades clearly slowed down the development of the British economy (Crouzet, 1987; Mokyr and Savin, 1976). Yet as already noted, these disruptions were far more deeply felt on the Continent, and the wars widened the gap between Britain and its main competitors in Europe.

Douglass C. North (1981, pp. 147, 158-170) has argued that the British Industrial Revolution was facilitated by better-specified property rights, which led to more efficient economic organization in Britain. The link between property rights and economic growth consists of the greater efficiency in the allocation of resources resulting from the equalization of private and social rates of return and costs. Property rights in innovation (patents and trademarks), better courts and police protection, and the absence of confiscatory taxation are examples of how the same phenomenon could raise the rate of innovative activity and capital accumulation.[45] North points out that well-specified property rights are not the same as laissez-faire. The former were by far more important because they reduced transaction costs and thereby allowed more integrated markets, higher levels of specialization, and the realization of economies of scale. Britain on the eve of the Industrial Revolution was far from a laissez-faire economy, but the net effects of the policies and regulations on the Industrial Revolution remain a matter of dispute. What is clear is that by the time of the Industrial Revolution Britain's government was one of, by, and for private property. Such property rights should be contrasted, not with chaos

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[45]Confiscatory taxation during the French Revolution took three main forms in Europe at this time. First, there was outright confiscation of property, such as the Church lands and the assets of *emigrés* expropriated during the French Revolution. Second, raising armies by conscription, as practiced by France, constitutes a de facto confiscation of labor. Third, the French government (and subsequently the Dutch) defaulted on their debts by reducing interest payments on debts by two-thirds. Moreover, many innovators who had been voted pensions by the *ancien régime* were denied their payments, and some of them, like Nicholas Cugnot, the inventor of a steam-powered wagon, died in poverty. Nicholas Leblanc, the inventor of the soda-making process, tried in vain to make the revolutionary regime recognize his rights on his invention and in the end committed suicide.

and anarchy, but with traditional and customary rights, often disputed, undocumented, and hard to establish. O'Brien (1991, p. 6) insists that in the eighteenth century the British government came down hard and persistently "in favour of property and against customary rights." Yet as the case of the Dutch Republic demonstrates, a well-defined system of property rights too, was not sufficient cause for an Industrial Revolution.

North and Weingast (1989) survey the institutional changes that occurred in Britain in the wake of the Revolution of 1688, in which wealth holders increased their grip on power, and the government was put on a sound fiscal footing and committed itself to respect the existing distribution of property rights. They pose their question starkly: Had there been no Glorious Revolution in 1688, or had the Stuarts won, would there have been an Industrial Revolution? (p. 831). Although they wisely confess ignorance as to how to set up the counterfactual, they point to secure contracting and property rights as a precondition for specialization and impersonal exchange. Without denying the importance of secure contracts as a precondition for allocative efficiency, one could object that the Industrial Revolution was not first and foremost an example thereof. It was an example of Schumpeterian disequilibrium, in which the main dynamic elements came from innovation and rebellion against the status quo. Invention and change may well have come at the expense of an efficient allocation of resources and more static equilibrium conditions. Moreover, the impact of financial markets, the development of which is emphasized by North and Weingast, on the Industrial Revolution is still very much the subject of debate. Finally, it seems unwarranted to imply that before the Glorious Revolution contracts and property rights in Britain were insecure. By taxing according to prespecified and well-understood rules, and by gradually abandoning the Tudors' and Stuarts' reliance on monopoly rights as a source of crown revenues, the post-1689 regime continued a trend that had begun long before and was certainly well established by the Restoration of 1660.

What kind of government helped bring about something like the Industrial Revolution? O'Brien (1991) carefully credits them with sustaining legal and political conditions which turned out on balance to be conducive to bring about "the most efficient industrial market economy in Europe." Yet any policy objective aimed deliberately at promoting long-run economic growth would be hard to document in Britain before and during the Industrial Revolution. To be sure, certain statutes aimed at encouraging progress, from patents to prohibitions on the emigration of artisans and the exports of machinery remained on the books until deep into the nineteenth century. But many of these acts were directed toward increasing the economic rents of a successful political lobby and their overall impact on technological progress at best ambiguous. In terms of its spending and its attention, the British government was clearly still largely mired in colonial and foreign policies. In Britain the public sector by and large eschewed any entrepreneurial activity. During the heyday of the Industrial Revolution, even social-overhead projects that in most other societies were considered to have enough public advantages to warrant direct intervention of the state were in Britain left to private enterprise. Turnpikes, canals, and railroads were built in Britain without direct state support; schools and universities were private. The promotion of the "useful arts" (that is, applied science and technology) was largely left to voluntary organizations and local societies. Even the less invasive forms of state support, like the policies of William I of Orange in the Low Countries or the Saint-Simonians in France during the Second Empire, were notably absent in Britain. Until the end of the nineteenth century, the British government clearly was reluctant to invade what it considered to be the realm of free enterprise.

Providing a conducive environment in which business could operate to maximum effectiveness might seem a reasonable task for a modern economist and clearly contemporaries realized this.[46] Yet as far as contract enforcement and dispute arbitration were concerned, readers of *Dombey and Son* will not be surprised by O'Brien's (1991) assessment that "the English legal system did not offer speedy, cheap, and economically efficient" solutions to commercial disputes. Much of the system was, no doubt, self-enforcing. Reputation, moral codes, fear of stigma and religious scruples could not altogether prevent the occasional Uriah Heep from behaving opportunistically, yet they must have been sufficiently rare so that they did not constitute a brake on the economy. Informal arbitration within trade associations, chambers of commerce and a variety of other institutions cleared most disputes. When the state failed in providing public goods, spontaneous corrective action was common. Middle class associations to help in the apprehension of criminal and private detective agencies start appearing after 1770 (O'Brien, 1994, p. 217). Similarly, the private sector was able to correct the errors of the *public* one in the other area widely regarded today as a main function of the State: the supply of money. The management of the money supply in the eighteenth century is widely thought to have been inadequate with much inconvenience arising from the shortage of coins of relatively small denomination and the supply of legal money to be inadequate for the needs of an expanding economy (Ashton, [1955], 1972, p. 167). Copper coins were particularly in short supply. In the second half of the eighteenth century, lower denomination coinage was largely left by the government to the private sector (Sargent and Velde, 1998). Enterprising industrialists and entrepreneurs alleviated the problem by creating more means of exchange, both imitated coinage and inside money (such as Bills of Exchange and banknotes). Indeed, it is significant that the small change shortage was eventually relieved by

[46] Adam Smith in his chapter on the "Expense of Justice" in his *Wealth of Nations* realized that "the acquisition of valuable property ...necessarily requires the establishment of civil government. Yet he missed the point made by modern economics when he noted that "the benefit of the person who does the injury [to property] is often equal to the loss of him who suffers it." The social deadweight losses of uncertain and poorly enforced property rights imply that the gains are lower than the losses because injuries and uncertainty will affect the allocation of resources.

the adaptation of steam power to minting by no less a figure than Matthew Boulton in 1787, which spread quickly among private minters and eventually landed Boulton a contract to make copper coins for the government. In short, it may be that the greatest merit of the Hanoverian State was that while it did not do an outstanding job in providing the kind of public goods and institutional infrastructure needed in an expanding economy, it did not prevent the private sector from stepping in.

The success of Britain in the late eighteenth century is perhaps surprising to those who firmly believe that taxes and government debts are a guarantee of economic disaster. In 1788, British GNP per capita is estimated to have been about 30 percent higher than that of the French, though such comparisons are inherently hazardous. What is perhaps more surprising is that the tax burden in Britain was almost twice what it was in France: 12.4 percent of GNP as opposed to 6.8 percent. Moreover, the British national debt as a proportion of GNP exceeded that of the French by more than threefold; yet because French finances were much less sound than the British, the annual debt service ratio was comparable (all figures from Weir, 1989, p. 98). These figures do not explain the Industrial Revolution in Britain, but they should serve as a warning for simple-minded explanations that view high taxes and government debts as a prescription for economic disaster. Despite its high taxes and a government debt that climbed from 5 percent of GNP in 1688 to 200 percent of it in 1815, Britain had a viable and strong economy, strong enough to withstand a quarter century of fiscal stress following the French Revolution.

Different in emphasis but equally unequivocal in its certainty about the role of politics in Britain's Industrial Revolution is the view advanced by Mancur Olson (1982). Olson's theory of economic growth is based on the idea that political bodies are subject to pressure groups pursuing the economic interests of their members, even if they come at the expense of society as a whole. Olson is thus led to associate periods of economic success, such as the Industrial Revolution, with the comparative weakness of such pressure groups. Britain during the Industrial Revolution, maintains Olson, was relatively free of class differences and by comparison a socially mobile society so that loyalty to a particular pressure group was not yet very strong. The Civil Wars of the seventeenth century, moreover, had created a stable nationwide government, which made Britain into a larger jurisdictional unit in which it was more difficult to organize pernicious pressure groups (Olson, 1982, pp. 78-83, 128).

Despite a number of inaccuracies, Olson's insight that technological progress depended to a great extent on the political environment is valuable.[47] As I have

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[47]Olson writes (1982, p. 128) that the English Civil Wars "discouraged long-run investment" (a possible but wholly undocumented inference) but that "within a few decades after [the Civil War] it became clear that stable and nationwide government had been re-established in Britain [and] the Industrial Revolution was under way." "Under way" is, of course, an ambiguous phrase, but between the Restoration and the beginning of the Industrial Revolution, as commonly defined, a century or more (and not "a few decades") had passed.

pointed out elsewhere (Mokyr, 1994b), technological progress almost inevitably runs into resistance by vested interests who stand to lose some of their rents as a result of the revaluation of physical and human capital. It is natural and rational for these groups to organize and try to resist the changes. Because that resistance by definition has to use nonmarket mechanisms, the government plays a pivotal role here. First, the technologically conservative forces might try to use existing organizations, such as guilds or even the government itself, to pass and enforce regulations and legislation inimical to technological change. Second, they may try to use extralegal methods, such as violence, to try to suppress innovation. The attitude of the authorities is thus crucial in determining the outcomes of these struggles. On the whole, the British government during the Industrial Revolution consistently and vigorously supported innovation. Many of the obsolete laws and regulations that encumbered progress (for example by mandating precise technological practices in detail) were revoked. Labor organizations ("combinations" in the language of the day) that were seen as threatening the advance of technology were made illegal and had little effect. In 1809 Parliament revoked a sixteenth-century law prohibiting the use of gig mills in the wool-finishing trade, and five years later it did away with one of the pillars of regulation, the Statutes of Artificers and Apprentices. Violent protests, such as the Luddite riots, were forcefully suppressed by soldiers. As Paul Mantoux put it well many years ago, "Whether [the] resistance was instinctive or considered, peaceful or violent, it obviously had no chance of success" (Mantoux, 1928, p. 408). Challenges to law and order that could not be settled by local authorities were dealt with effectively and harshly.

Was Britain a laissez-faire economy, and does the Industrial Revolution therefore stand as a monument to the economic potential of free enterprise? In absolute terms, Britain certainly was not a pure laissez-faire economy. A large number of regulations, restrictions, and duties were on the books. But absolutes are not very useful here. Compared with Prussia, Spain, or the Habsburg Empire, Britain's government generally left its businessmen in peace to pursue their affairs subject to certain restraints and rarely ventured itself into commercial and industrial enterprises. Seventeenth-century mercantilism had placed obstacles in the path of all enterprising individuals, but British obstacles were less formidable than those in France. More regions were exempt, and enforcement mechanisms were feeble or absent. One such enforcement mechanism, widely used on the Continent, was the craft guild, yet by the time of the Glorious Revolution of 1688, the craft guild in Britain had declined and lost most of their political clout (Nef, 1957, pp. 26, 32). Market forces were more powerful than politics, even if they were constrained to operate within a framework of laws and institutions produced by political forces. Mercantilism and regulation in eighteenth-century Britain was alive and well, yet it never took the extreme forms it took in France under Colbert and in Prussia under Frederick the Great.

The general consensus among historians today is that the regulations and rules, most of them relics from Tudor and Stuart times, were rarely enforced. As the economy became more sophisticated and markets more complex, the ability of the government to regulate and control such matters as the quality of bread or the length of apprentice contracts without an expanding bureaucracy effectively vanished (Ashton, 1948, p. 95). The central government was left to control foreign trade, but most other internal administration was left to local authorities. Internal trade, the regulation of markets in labor and land, justice, police, county road maintenance, and poor relief were all administered by local magistrates. Although in principle these authorities could exercise considerable power, they usually elected not to. This de facto laissez-faire policy derived not so much from any libertarian principles as from the pure self-interest of people who already had wealth and were making more. By ignoring and evading rather than altogether abolishing regulations, Britain moved slowly, almost imperceptibly toward a free-market society. Except for its strictures against the state's intervention in foreign trade, *The Wealth of Nations* was a century out of date when it was published: What it advocated had already largely been accomplished (Perkin, 1969, p. 65).[48] Some regulations were more difficult to ignore than others. The usury laws, which set a ceiling on all private interest rates, are thought by some historians to have had considerable impact on the allocation of resources (Ashton, [1955] 1972, pp. 27-28; Williamson, 1984). There is, however, evidence indicating that the usury laws were sufficiently evaded to limit their impact on the economy.[49]

Even when mercantilist regulations were enforced, their net effects were ambiguous. The silk and light woolen industries tried to stop the import of cheap Indian cottons. This resulted in the Calico Act which prohibited the importation and sale of printed white calicoes, passed in 1721 and repealed in 1774, and a host of other measures and countermeasures. The maze of protection and subsidization was the confusing outcome of political pressures and counterpressures by interest groups that tried to keep out competition and keep in complements. Because

[48]The Statute of Artificers (of 1563), for instance, so detested by Adam Smith, required that workers serve a formal apprenticeship before their employment in a trade. Yet in 1777 the calico printers admitted that fewer than 10 percent of their workers had served because "the trade does not require that the men they employ should be brought up to it; common labourers are sufficient" (Mantoux, 1928, p. 453).

[49]Although the usury laws were not capable of holding down private interest rates to 5 percent at all times, they distorted the capital market to a substantial degree. A Parliamentary Select Committee concluded in 1818 that "the laws regulating or restraining the rate of Interest have been extensively evaded and have failed of the effect of imposing a maximum on such rate. . . . Of late years, from the constant excess of the market rate of interest above the rate limited by law, they have added to the expense incurred by borrowers on real security" (Great Britain, 1818, vol. VI, p. 141). See also Pressnell (1956, pp. 95, 318, 368, 428) and Cottrell (1980, pp. 7-8, 13).

fustians looked much like calicoes, the prohibition was widely evaded, although it remained a nuisance.[50] It has been argued that the mercantilist laws that prohibited the importation of calicoes stimulated the British cotton-printing industry and that high taxes and tariffs on white calicoes encouraged domestic production (Wadsworth and Mann, 1931, p. 144). More recently it has been argued that by encouraging fustians these regulations constituted a "legislative assistance that was important for the mechanization of Lancashire's growing industry," so that "British pragmatism appears in retrospect more productive than Dutch free trade or French style mercantilism" (O'Brien, Griffiths, and Hunt, 1991, pp. 415, 418). Yet evidence for any direct link between the protectionist measures taken and the technological breakthroughs in cotton is absent. What we know with certainty is that mercantilist bounties and encumbrances to trade distorted the operation of the free market, and as soon as Arkwright's patent was secured and his machines producing, he petitioned for repeal of the Calico Act and was granted it in 1774. Most of the important inventions in cotton, including the mule, cylindrical printing, the power loom, and the carding machine, followed in the decade after the repeal of these acts. Until more evidence is forthcoming, it seems reasonable to conclude that technological progress occurred *in spite of* rather than *thanks to* the meddling of a special-interest-driven Parliament in the price mechanism.

The Bubble Act, passed in 1720, required a private act of Parliament to establish a common-stock corporation. However, modern scholars have increasingly realized that this impediment, too, was more an inconvenience than a real obstacle to business activity (Cottrell, 1980, p. 10).[51] Even after the Bubble Act was repealed in 1825 and all remaining obstacles to joint-stock company formation were removed in the Joint Stock Companies Act of 1856, there was no sudden rush to create joint-stock corporations. The prohibition on incorporation was a less formidable obstacle to technological progress and industrial growth than might appear. The same applies to the restrictions on the export of textile machinery and the emigration of artisans (Jeremy, 1977; Jeremy, 1981, chap. 3). Business organization law remained a "mound of case law not tidied up until the end of the nineteenth century." Partnerships, the normal mode for business associations, increased the vulnerability of business, could only be bought and sold with unanimous consent, and could not sue as an Association without a private act of Parliament (O'Brien, 1994, p. 234). Yet the history of the Industrial Revolution is full of remarkably symbiotic relations between partners, and while some individual enterprises may have suffered from

[50]By 1736 fustians were explicitly exempted from the Calico Act, and by this time they contained two-thirds cotton and one-third linen, so that fustians "replaced Indian calicoes as the prime threat to light woollens and silks" (O'Brien, Griffiths, and Hunt, 1991, pp. 414-415).

[51]The Bubble Acts could be evaded by organizing companies under a trust deed, a legal form widely used in the woolen cloth industry in Yorkshire (Hudson, 1983).

cumbersome institutional relics, the system as a whole seems to have found workable (if not always cheap) ways around it.

Not all government intervention was equally ineffective, of course. A few government monopolies, such as the East India Company, survived well into the nineteenth century. Moreover, free trade remained a far cry from reality until well into the nineteenth century. During the Napoleonic Wars, tariffs were raised to unprecedented heights (peaking at 64 percent of the value of imports in 1822). A slow trend toward lower tariffs began in 1825, culminating in the abolition of the Corn Laws in 1846 and the repeal of the Navigation Acts, which had severely limited foreign freighters from carrying British goods, in 1849-1854. Yet in the first half of the nineteenth century, Britain's trade was more restricted by tariff legislation than France's (Nye, 1991a). To be sure, tariffs and navigational restrictions were widely evaded, too.[52]

Another area in which government intervention was important and the law far from a dead letter was poor relief. Here the difference between Britain and the Continent is striking. Nowhere in the world can one find a well-organized, mandatory poor relief system like the English one. The Old Poor Law, sometimes erroneously referred to as "Speenhamland" (in fact, the Speenhamland system of allowances in aid of wages was used in a minority of counties), has had a notably bad press. Three major criticisms have been raised against it. One was the Malthusian complaint that outdoor relief subsidized childbearing and thus increased the birth rate. A second criticism, already mentioned by Adam Smith ([1776] 1976, p. 157), was that the Old Poor Law (and particularly the Settlement Acts) encumbered the free movement of labor and thus hindered its reallocation in a society in which labor markets played an ever-increasing role (Polanyi, [1944] 1985, pp. 77-102; Ashton, 1948, p. 111). Finally, the standard complaint against the Old Poor Law was that it impaired the incentive to work by distorting the leisure-income trade-off, or, in the language of the time, encouraged indolence and sloth.

These criticisms have not fared well in recent years. Indeed, it seems likely that the effects of the Poor Laws on the Industrial Revolution were not nearly as negative as used to be thought. The demographic argument against them has been criticized by James Huzel (1969, 1980). More recently, however, the important work of Boyer (1990) has vindicated Malthus's approach. The use of multivariable regression shows that the introduction of child allowances after 1795 did have an

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[52]Smuggling was widespread, as can be verified from the fact that at times, when tariffs were reduced substantially, imports increased by a much larger proportion than the reduction of the tariff and a reasonable guess about the elasticity of demand would imply. For example, when the tariff on coffee was reduced by two-thirds in 1808, imports into Great Britain increased from 1.07 million to 9.3 million lbs. in 1809.

important effect on birth rates.[53] Whether the Old Poor Law was somehow responsible for the creation of an army of able-bodied paupers is still unclear and awaits further research. In the absence of any a priori idea of the effect of the increase in birth rate on the Industrial Revolution, however, it is unclear what the long-term economic implications of this higher birth rate were. Moreover, even in the absence of a poor law, population would have grown, and its demographic effects were the most pronounced in the south of England.

As to the geographical immobility imposed by the Settlement Acts, these were to some extent alleviated by the Poor Law Removal Act of 1795 (35 Geo. III (1795) c. 101), which expressly forbade the ejectment of poor immigrants unless they actually became chargeable to the parish. Even before 1795 the system was "by no means such a check on mobility of labour as some of the older writers . . . supposed," because as the option to evict was exercised in a haphazard and casual way (Styles, 1963, p. 62). Some contemporary opinion agrees with this finding. Sir F. M. Eden, whose opinion according to Redford was "as weighty as that of Adam Smith," thought that the Settlement Laws were too weakly enforced to constitute the hindrance to mobility alleged by Smith (Redford, 1964, p. 85). Perhaps the primary mechanism by which the Settlement Acts discouraged migration was their sheer complexity and the uncertainty that irregular enforcement implied for anyone contemplating migration. Since migration was, however, a risky undertaking under any circumstances, it is far from obvious to what extent the Old Poor Law made things worse.[54] More to the point, Boyer's analysis shows that the

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[53]The observed birth rate rose by 14 percent, according to estimates of Wrigley and Schofield (1981), between about 1780 and about 1820. Boyer estimates (1990, p. 170) that in the absence of child allowances, the birth rate would actually have declined by 6.4-9.2 percent. He concludes that allowances in aid of wages did to some extent "create the poor which they maintain" (p. 142). The numbers he provides imply that in the absence of the poor laws, English population would still have been larger in 1826 than it was in 1781, but it would have grown at a much slower rate after 1795. A rough computation suggests that on Boyer's assumptions the population of England and Wales in 1826 without a poor law would have been 9.78 million instead of the 12.4 million estimated by Wrigley and Schofield. Solar (1995) suggests that because the benefits were financed by poor-rates paid by local landlords, they had an incentive to try to reduce the number of potential recipients by discouraging large families, though it is unclear how successful such policies might have been. From a different perspective, McCloskey (1973) has also argued that the wage supplements paid under the Old Poor Law were likely to have reduced the supply of labor and thus may have raised wages, though the magnitude of this disincentive-to-work effect is unclear and the evidence for it rather weak.

[54]In 1832 out-migration was more important in Speenhamland parishes, which paid allowances in aid of wages or child allowances, in Kent than in non-Speenhamland parishes (Huzel, 1980, pp. 375-378).

overall magnitude of the Poor Law's effect on labor mobility bemoaned by Polanyi was neglibly small.[55]

As to the work-incentive effect stressed by T.R. Malthus and his followers, research carried out by Blaug in the 1960s has recently been reinforced by the work of Pollard (1978, pp. 109-110) and George Boyer (1990). They argue that the causality runs the other way: Wage-support payments were made in areas that suffered from seasonal unemployment and the decline of cottage industry, which explains the association of Speenhamland with the agricultural areas of England. Boyer's regressions provide little support for the hypothesis that outdoor relief caused an increase in voluntary unemployment, although it was not possible to estimate the relation between the two directly (Boyer, 1990, p. 142-143). The effect of poor-law variables on male labor income was statistically insignificant, which it could not have been if poor relief had been treated as a substitute for labor income.

Indeed, it could be maintained that the Poor Laws, despite their obvious flaws (in particular their nonuniformity), may have had some overall positive effects on the Industrial Revolution. A comparison with Ireland, which had no formal system of poor relief prior to 1838, bears this out (Mokyr, 1983). The social safety net provided by the Poor Laws allowed English individuals to take risks that would have been imprudent in Ireland, where starvation was still very much a possibility. In societies without such laws, self-insurance in the form of large families and liquid assets was widely held, whereas in England even the worst case rarely implied actual starvation. In a recent paper, Solar (1995) extends this argument to the creation of a wage-labor force. The main obstacle to the creation of a wage-labor force was the attachment of the rural population to land. Land served not only as a source of income but also as a form of insurance -- in times of duress it could be mortgaged or sold. It was also a form of old-age insurance; its inheritability made it a bargaining chip with which parents could persuade their children (or other heirs) to look after them in their old age (see also Guinnane, 1991). The existence of the British Poor Law provided a substitute for land for insurance purposes and thus reduced the need to cling to land at all costs, thus contributing to the creation of a proletariat needed for the factories and the railroad. The magnitude of this effect is of course not known, but it makes sense as economic analysis.

The Speenhamland system, by subsidizing workers in the off-season, assured a regular labor force during the busy seasons in agriculture (Boyer, 1990). A similar argument may be made for manufacturing: Workers could be laid off during periods of business slumps without fear of having the labor force emigrate or starve. Irish employers, on the other hand, complained about having to continue to pay their workers during slumps or risk losing them (Mokyr, 1983, p. 227). In

[55]The fact that the British Poor Law was a *national* system rather than a patchwork of local systems, as on the Continent, may have *increased* geographic mobility by reducing the uncertainty involved in migration (Solar, 1995).

addition, the practice of pauper apprenticeships and the recruitment of factory workers from workhouses run by local Poor Law guardians provided an important source of labor for the factories, especially in rural and small-town mills before 1800.[56] All this is not to argue, of course, that the Poor Laws somehow "caused" the Industrial Revolution. But it seems that a case can be made that their net effect was not nearly as negative as has been maintained and that they may have had hitherto unsuspected beneficial effects.

Another political difference between Britain and most other European countries was the lack of centralization of political power. Britain's system of government left most of the day-to-day management of affairs to local magistrates, who were, on the whole, respectable residents for whom administration was a form of leisure activity. Whether this government by amateurs was an effective way of providing government services is another matter, but one effect was the relative unimportance of London as an administrative and cultural center when compared to Madrid, Paris, St. Petersburg, or Vienna. In France, for example, Paris traditionally drained large amounts of talent from the provinces, and provincial centers of learning and technology were of small importance compared to those in the capital. This rural-urban brain drain would not have mattered, of course, if industrialization could have been concentrated near the capital of the country. Interestingly, this did not happen anywhere. Neither Brussels nor Paris, nor Berlin, nor Amsterdam, nor any other major capital city in Europe became a center of modern industry. Although some manufacturing activity developed around the capitals, the main centers of modern industry were usually elsewhere. As a result, a highly centralized state in which the capital city drained the countryside of ambitious and able men, strongly attracted to "where the action is," operated at a disadvantage compared to a decentralized state like Britain.[57] In Britain the situation was radically different; provincial institutions like the Manchester Literary and Philosophical Society or the universities of Glasgow and Edinburgh, located near centers of industry, were of central importance to the technological developments of the eighteenth century. Wrigley (1967) has argued more or less the opposite, ascribing to London a major

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[56]Some of the transactions between Poor Law authorities and mill owners resembled nothing as much as slave trade; e.g., the purchase of seventy children from the parish of Clerkenwell by Samuel Oldknow in 1796 (Mantoux, 1928, p. 411). Pollard ([1965] 1968, pp. 194-195) cites the sanctimonious claim by some notorious users of child labor that these pauper apprentices were "more expensive" than paid labor and that they were employed out of civic duty. For a similar view, see Collier (1964, p. 45). Recruiting agents were often sent to scour the surrounding countryside in search of workhouse labor, and some of these children were brought in from the other end of the country, which indicates that for some industrialists pauper apprentices were indeed a cheap and satisfactory form of labor.

[57]See Cardwell (1972, p. 126) for a similar argument. Interestingly, Ireland, with its centralized government in Dublin, conforms more to the Continental than the British model.

role in creating the conditions leading to the Industrial Revolution. The size of London relative to England's population and its enormous needs in terms of food, fuel, and other products seem to support his claim. Sheer size, however, is not necessarily an advantage. A top-heavy capital might just as well be viewed as imposing a major cost on the country. Wrigley's argument seems better suited to explain commercial development before 1750 than industrial development thereafter. During the Industrial Revolution, indeed, the demographic predominance of London declined somewhat. Between 1650 and 1750 London's share of English population rose from about 7 percent to 11.8 percent. By 1800 this percentage had declined to 10.5 percent.[58] All the same it would be wrong to ignore the importance of London; after all, it was a major industrial town in which much of Britain's beer was brewed, its silk thrown, its books printed, and many of the sophisticated machine tools made by Bramah and Maudslay were first conceived.

Some historians have argued that the British government stimulated the Industrial Revolution by creating a demand for military products, which led to rapid technological change in some industries (McNeill, 1982, pp. 210-212). It is true that some of these externalities can be identified. Cort's puddling-and-rolling technique was completed when its inventor was working on a contract for the Admiralty. Wilkinson's lathe, which bored the accurate cylinders needed for Watt's steam engines, was originally destined for cannon. The correct test for the net impact of military demand is, however, the question whether in the absence of military demand these innovations would have been substantially slower in coming. On that issue most scholars are wisely cautious. Moreover, what little innovation that can be directly attributable to the war had few civilian spillover effects. A case in point is the well-known Portsmouth manufacture of wooden blocks for pulleys to be used on naval vessels, designed by two of the greatest engineers of the time, Marc Brunel and Henry Maudslay. Despite the precocity of this plant, which pioneered interchangeable parts as well as continuous flow processes, it was too specializd to have spillover effects on the civilian sector. Scholars largely agree that favorable external effects were relatively small and that on balance the economic impact of the wars between 1756 and 1815 were negative (Trebilcock, 1969, pp. 477-478; Hyde, 1977, pp. 112-116). Moreover, any hypothesis of a substantial positive effect of the government's war-related activities on technological progress encounters a difficulty: If military efforts created major technological externalities, why did France and other Continental countries not benefit from them to the same degree that Britain did? Research on the French iron industry, for example, shows that the revolutionary and Napoleonic wars did little to stimulate technological progress (Woronoff, 1984).

To summarize, most economic historians would agree that politics was a positive factor working in Britain's favor, although the magnitude of the effect, as well as

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[58]The London population estimates are from Wrigley (1967, p. 44). English population data (less Monmouth) are from Wrigley and Schofield (1981).

its *modus operandi*, are still in dispute. The appropriate standard of judgment should be a comparative one, and it seems hard to disagree with the proposition that the specific form of government that had emerged in Britain created an environment that was more conducive to economic development than elsewhere. Some oppressive mercantilist laws were on the books, but most were successfully evaded. Britons were heavily taxed, but taxation was never allowed to become arbitrary and confiscatory. Most important, the right to own and manage property was truly sacrosanct, contrasting sharply with the confiscations and conscriptions on the Continent during the French Revolution and the Napoleonic era. Personal freedom —with some exceptions—was widely accepted in Britain. True, the Acts of Settlement remained on the books until 1834, but they were by no means as restrictive as the harsh requirements on the books in France and in Prussia, where workers were required to have *cahiers* or *Wanderbücher* in which their employment was recorded and which required them to ask for passes for journeys within the country. Serfdom was still very much in existence east of the Elbe in 1815. The cathartic revolutionary medicine administered to the Continent between 1789 and 1815 by the French was needed to prepare the rest of Europe for the modern age. But the medicine's immediate side effects were so painful that most of the Continent required many years and even decades to recover from the treatment and start to threaten Britain's lead. Britain did not need this harsh shock treatment, since it alone had learned to adapt its institutions to changing needs by more peaceful means, and the English Channel had sheltered it from undesirable political imports.

Britain's political stability contrasts sharply with the history of France, with its four major revolutions in the eight decades following 1789. But was political stability always an asset on the path toward modernization? If investors are wary of investment in politically unstable environments, political stability was an advantage and its absence had a negative effect on industrialization. But how important was that effect? The economic performance of powerful autocratic and "stable" regimes in Russia and Turkey was disappointing to say the least. Moreover, Olson (1982) has insisted that political stability is in fact a rather mixed blessing, because it permits the crystallization of pressure groups whose activities are, in Olson's view, the archenemy of economic development. It is thus unclear how much of the difference in economic development can be attributed to this factor.[59] Still, it is no exaggeration to say that nowhere in the world was property perceived to be more secure than in Britain. Such security is important in part because it included intellectual property rights, such as patents and pensions awarded in recognition of breakthroughs. Moreover, much technological progress

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[59]The revolutions in France may have increased the perceived insecurity of property and inhibited capital formation. Similarly, the continuous struggle between landlord and peasant in Ireland before the famine reduced the attractiveness of Ireland as a site for industrial capital (as is the case today in Ulster). The Civil War in Spain (1832-1839) and the Miguelite Wars in Portugal (1828-1834) had similar effects in the Iberian Peninsula.

required capital goods in which they were "embodied," from the machinery itself to buildings and sites. Clearly, security of these assets from taxation, confiscation or private trespass was necessary if such investments were to be sustained.

Finally, British society exhibited a degree of tolerance for deviant and heterodox ideas that was unusual, though not unique. Although tolerance was quite different from equal rights, Britain developed in the seventeenth century the ability to accommodate a high level of acceptance of different modes of thinking. The intolerance on the Continent toward dissidents led to the hemorrhage of technical talents from the southern Netherlands and France to countries where they were more welcome. As Landes (1983, p. 219) recounts it, after 1685 (when the Edict of Nantes was revoked) French industry was "crippled by the exodus of some of its best practitioners fleeing a wave of anti-Protestant bigotry and persecution." In many industries, France's loss was England's gain. The Belfast linen industry was, if not founded, certainly enhanced and developed by the technical know-how of Huguenot refugees, especially Louis Crommelin. Nicholas Dupin was an active promoter of companies and operated a number of paper mills in England. The great hydraulic engineer and lecturer John (Jean) Desaguliers, too, came from a Huguenot family as did Denis Papin, who had as much ground for claiming to be "the" inventor of the atmospheric engine as anyone. Crouzet, who has studied the financial activities of these refugees, states that the "persecution of the Huguenots [was] not only a crime, [it] was also a blunder, as France was impoverished by a brain drain which brought wealth to her rivals and enemies" (Crouzet, 1991, p. 224). The direct impact of these individuals on the aggregate economy may not have been vast, but that is less important than their significance as a symptom of the open-minded attitude of agreeing to disagree that flavors the British enlightenment. Such open-mindedness is essential if new technological ideas are to compete in the marketplace on their economic merits. The differences between Britain and the Continent were not absolute here either. At times Britain turned on its most innovative spirits, as it did to the inventor of the fly shuttle, John Kay, who ended up having to flee to France, and as it did to the great chemist Joseph Priestley, whose unpopular political views caused a mob to burn down his house and forced him to flee to the United States. On the whole, however, the atmosphere in Britain was comparably comfortable for rebels and deviants, of which inventors in some sense are a subspecies.

Demand vs. Supply

A large and venerable literature links, in one form or another, the British Industrial Revolution to the growth of the home market, the expansion of consumer demand, and the growth of a "consumer revolution." From the point of view of economic analysis, technological change, capital accumulation, and the rise of the factory are primarily supply-side phenomena. Demand-side factors are more difficult to integrate into the story. Yet economic historians, beginning with a famous paper by Gilboy (1932), have always felt intuitively that demand should be given a parallel role. In price theory it is typically assumed that demand and supply move independently of each other, so that an increase in demand means a movement *along* the supply curve. Any argument that links the Industrial Revolution with changes in demand relies on models that postulate a shift of the supply curve as a response to an increase in demand. North, relying on the work of Kenneth Sokoloff, has recently concluded that innovation and technological change are primarily determined by the "size of the market" (1990, p. 75; cf. Sokoloff, 1988). Less cautious writers have gone further and simply asserted that a "consumer revolution" was a necessary condition for the Industrial Revolution to occur. Thus in an influential paper stating the most extreme position on this question, Neil McKendrick (1982a) writes that "the Consumer Revolution was the necessary analogue to the Industrial Revolution, the necessary convulsion on the demand side of the equation to match the convulsion on the supply side."[60]

As I argued in a paper first published in 1977 (Mokyr, 1985b), supply and demand are not symmetrical in long-term economic change. In a historical event like the Industrial Revolution, demand factors can only play a role under certain assumptions that have to be examined carefully. To start with, it is important to distinguish between economic changes that affect economic growth in a fixed technology (for example, the expansion of trade due to growing markets) and those that actually change the techniques in use. While the two may be related at some level, they can be treated logically as distinct and the causal link between them has to be demonstrated. Secondly, if output increased and technology possibly changed because of a rise in demand for industrial goods, it has to be made clear *why* demand increased in the first place. Changes in demand are not exogenous to an economic system -- they occur for well-understood reasons. Population, of course, began to increase rapidly after 1750, but this was a worldwide phenomenon and it seems far-fetched to link it directly to the Industrial Revolution. In a technologically static world, population growth (as the Classical School firmly believed) would lead to declining living standards. Hence, population growth in and of itself would increase the demand for food products more than the demand for manufactured goods, and the combination of growing population, bad harvests, and disruption of foreign supplies led to sharply higher agricultural prices, hardly a stimulus for industrial demand.[61] Export demand, too, although of some importance in some industries, does not seem to have been the crucial element in the Industrial Revolution that some scholars have claimed. The role of foreign trade in the

[60]For a critique of McKendrick's view, see for example Fine and Leopold (1990) and John Styles (1992).

[61]The demand for agricultural goods was inelastic, so that increases in agricultural prices meant that a larger amount of income was spent on agricultural goods, reducing the amount left for manufactured goods.

Industrial Revolution, however, is sufficiently interesting and controversial to merit a separate discussion.

Secondly, the *modus operandi* of demand-side factors has to be specified and documented. For instance, an increase in aggregate demand due to, say, a rise in the propensity to consume or an autonomous growth in investment will only have an effect if the economy has large underutilized resources that can be brought into production. Such a Keynesian scenario may indeed have been of some importance. Evidence for large amounts of underutilized resources that were brought into production as aggregate demand expanded in the second half of the eighteenth century is, however, lacking. Or, if there were strong positive external economies between firms so that a sharp increase in demand led to an industry-wide decline in costs, demand would be directly linked to higher productivity. Yet the existence of such externalities is notoriously hard to demonstrate.

Thirdly, McKendrick's observations that the Consumer Revolution was somehow correlated with the Industrial Revolution seems open to a level of historical criticism from which it will not easily recover. Work by Lorna Weatherill (1988) suggests that if there was a Consumer Revolution at all, it peaked in the period 1680-1720. The long lag between that event and the Industrial Revolution makes any causal connection between the demand and changes in industrial technology difficult to support.[62] Equally damaging is the fact that consumer revolutions were taking place elsewhere in Europe. Seventeenth century Holland was, of course, the most obvious example thereof, but Cissie Fairchilds (1992) has employed probate records to show that France, like England, experienced a consumer revolution albeit fifty years later. The goods that the French bought were different, but on the whole the absence of an Industrial Revolution following the French increase in mass consumption leads Fairchilds to conclude that the two revolutions were largely independent of each other and that the changes in technology were shaped by supply, not demand side elements. In a recent paper Horrell (1996) has employed household budget studies to test whether an increase in home demand between 1801 and 1841 indeed did take place at all. She finds indeed an increase in aggregate demand, but that many of the changes associated with the Industrial Revolution such as increased urbanization and a declining subsistence sector led to a retrenchment of working-class demand into the products of traditional industries and reducing demand for the new industries. The increase in middle class demand was far more substantial and clearly created large markets for the new products. Yet, as Horrell concedes, this is not at all tantamount to a demonstration that such an increase in spending on nonessential items fed back into the processes that produced the increase in income. In a growing economy somebody has to earn and spend the increased incomes. The "demand" hypothesis suggests that such spending

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[62] Among the goods the consumption of which increased according to the probate records were knitted goods, pottery, pipes, clocks, mirrors, and fancy textiles.

helps increasing incomes per capita even more. It is this part of the story that remains unpersuasive.

The notion that somehow technological change takes place when the demand for it "arises" is thus clearly fallacious. Some scholars refuse to abandon the concept.[63] As T. S. Ashton argued long ago, invention was the mother of necessity, not the other way around (1948, p. 62).[64] All the same, it seems natural to pose the question whether technological change will occur without some prior knowledge that the goods produced will sell. Will it be possible to "find people with income and demand schedules capable of absorbing the increased output?" (Eversley, 1967, p. 211). It should be noted that unless the good produced is totally new and has no suitable substitutes (for example, aspirin), invention usually occurs in markets that already exist. When he improves an existing good or produces it at a lower price, the innovator taps into a market he already knows. By innovating, she undercuts her competitors or those selling close substitutes. The invention of the puddling-and-rolling technique or the continuous paper-making machines, for instance, can be represented as supply curves shifting to the right, with the market sliding down existing demand curves. An *autonomous* and *prior* shift of the industry demand curve is not an essential part of the story. Modern studies of contemporary technological progress have often claimed considerable evidence for demand-led technological change, but these studies are often flawed and biased. In their demolition of many of these studies Mowery and Rosenberg (1979, p. 142) note that "the demand-pull approach reflects an insufficient appreciation for the innumerable ways in which ... very small changes in production technology are continuously altering the ... structure of production cost."

Still, this does not mean that demand played no role in generating technological change. Adam Smith himself noted that the division of labor was limited by the extent of the market and strongly believed that the division of labor itself was the main agent of technological progress. He thought that highly specialized workmen

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[63]Braudel (1984, p. 566) writes flatly that "the efficient application of technology lags, by definition, behind the general movement of the economy; it has to be called on, sometimes several times, to meet a precise and persistent demand." Jan De Vries (1994, p. 255) notes that "the interest in a demand-side appreciation of early industrialization, beaten back in economic history, emerged again among social historians, among whom sightings of a 'consumer revolution' gained credence and has now found a comfortable home among cultural historians, where the triumph of the will of the consumer can overcome any scarcity."

[64]Economists and historians alike have treated the common wisdom that necessity is the mother of invention with contempt. For some examples of this literature, see Mokyr (1990a, p. 151, n. 1).

were more likely to come up with inventions.[65] Innovation usually involved substantial fixed costs, and thus a minimum level of sales was expected by the innovator. In 1769 Matthew Boulton wrote to his partner James Watt, "It is not worth my while to manufacture your engine for three counties only, but I find it very well worth my while to make it for all the world" (cited by Scherer, 1984, p. 13). Some minimum level of demand was thus necessary to cover the fixed costs of research and development. An expansion of demand, through the integration of markets or through a growth in population and income or through an increase in export demand, could thus have stimulated invention.

In fact, however, fixed costs, including those of R and D, remained relatively small in most industries, as the large number of firms indicates. The costs of invention were small relative to the costs of production. Although men like Crompton and Trevithick worked for many years on their inventions, these costs would still have been covered in a much smaller market. This was true whether industry demand was stationary, expanding, or even contracting. It is, of course, true that in a highly fragmented economy, with high transport costs or internal barriers to trade, the competitive model does not hold. Szostak (1991) maintains that the increase in demand engendered by improved transport led to regional specialization and an accelerated rate of technological progress. Yet, as he realizes, a more integrated economy is not quite the same as an expansion of market demand, even if for the individual producer they may be indistinguishable. In Szostak's model, the *primum mobile* is an improvement in transportation, itself a supply-side phenomenon.

Where changes in demand can and do matter is when demand shifts from an industry that is relatively impervious to technological change to one that is not. It is, for example, quite clear that of the three large textile industries—wool, cotton,

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[65]Smith supports this view by the story of a boy who, while operating one of the first steam engines, tied a string to the handle of a valve, allowing it to open and shut automatically. As Cannan points out in his notes, the story is apocryphal (Smith [1776] 1976, pp. 13-14). On the whole, Smith's ideas of the connection between the division of labor and technological change seem to be lacking in persuasion. He postulates that "the greater the number [of laborers in a workhouse], the more they naturally divide themselves into different classes and subdivisions of employment. More heads are occupied in inventing the most proper machinery for executing the work of each, and it is, therefore, more likely to be invented" (Smith, [1776] 1976, pp. 96-97). In some cases there may be merit to this argument. Some machines were made to mimic the motions of human arms, and the simpler the task, the more such imitation was possible. A division of labor between workers and engineers could create a special class of outsiders who could observe the production process and suggest improvements. Yet how much division of labor was necessary to create the conditions necessary for invention? It could just as well be argued that rigid specialization stifles the cross-fertilization between different activities that is the source of much technological creativity. Adam Smith's own career, incidentally, seems a good counterexample of his belief in the benefits of specialization (Brenner, 1987, pp. 109-110).

and linen—cotton fibers lent themselves best to mechanization (although worsted yarns were also well adapted to Arkwright's rollers). A change in demand in favor of cotton would increase output, and insofar as technological change was a function of the quantities produced (as in learning-by-doing phenomena), demand shifts could have affected the rate of technological progress. Demand for cotton, moreover, was price elastic, which means that for any given shift in supply a large increase in sales could be realized leading to further learning. Yet economic analysis sounds a warning bell: The elasticity of demand is important, but a single inventor in an existing competitive industry always faces a very elastic demand curve, much more so than the industry as a whole. All the same, the strong demand for cotton clothes, due in part to fashion, operated as a "focusing device," in Rosenberg's (1976) terminology, with inventors directing their energies to an industry that was expanding.

The same is true for the "leapfrogging" models proposed by Landes (1969) in which a sudden increase in the productivity of one activity (such as weaving) created a demand for improvement in the other, complementary activity (spinning). Sudden demand-induced imbalances may focus the attention of inventors on a profitable avenue, but they do not constitute a complete theory of technological change. Why are some "bottlenecks" solved by technological change while others have to be accommodated by massive reallocations of resources?[66] Markets for knowledge existed, to some extent, and a sudden surge in demand for technical knowledge might well have led to more technical innovations. Yet as Ian Inkster, in a recent criticism of this hypothesis points out, if this were the case we should have observed a *higher* price for this knowledge, which eventually would have choked off the rate of growth (Inkster, 1991, p. 69). Yet, if anything, the reverse was the case.

Economists interested in economic growth in the past few years have come to realize that the standard assumptions of constant returns in the production function and limited externalities do not hold in historical reality. Relaxing these assumptions leads to radically different insights into the dynamics of an economy. Minor shifts in demand could trigger the economy to move one way or another and thus could have been "causal" in the Industrial Revolution (O'Brien and Engerman, 1991). Alfred Marshall, as much as any neoclassical economist, realized the dangers that such "non-convex" production technologies implied for the static

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[66]Two examples will suffice: In the cotton industry, carding, spinning, weaving, and bleaching were all complementary, and improvements in one of these areas stimulated the others. Yet some activities defied mechanization: The planting and picking of cotton could not be mechanized, which had momentous consequences for the history of the southern United States. In coal mining, too, an increase in demand led to relatively few innovations in mining technology. Here markets replaced the innovation process: The proportion of workers in the coal and lignite mines in Europe subsequently increased everywhere, despite the rather obvious shortcomings of this employment.

market equilibrium that is at the heart of standard economics. Yet it is important to note that although such models are likely to increase our understanding of historical change, they depend on certain conditions to hold, none of which have ever been satisfactorily demonstrated to have been of great import in Britain during this period: economies of scale, strong externalities, learning effects, and similar sources of positive feedback.[67] A major source of such effects is found in modern technological systems, which require standardization. Such network effects are found throughout history but it is not till the Industrial Revolution that they became of central importance. Gaslighting, railroads, telegraph and later electricity, telephones, software and so on all came after the Industrial Revolution or in its later stages. They were not very important in the markets for consumer goods in about 1750. It should be added that increasing returns are not necessary to establish a positive feedback mechanism creating vicious or virtuous circles. Theoretical work in the economics of complementarity has shown that under some assumptions regarding the interactions between certain activities, once an economic system begins along a path of growth of some variables, it will continue forever on that path (Milgrom, Qian, and Roberts, 1991).

A different approach to the "demand hypothesis" has been proposed recently in a duo of papers by Jan de Vries (1993, 1994) in which he argues that changes in preferences could be of importance in explaining some of the economic changes in eighteenth-century Britain. De Vries argues, essentially, that the period was characterized by two distinct but related events: a *supply*-driven *Industrial* Revolution and a *demand*-driven set of changes in household behavior that he calls an "industrious revolution." The idea focuses on the household as a decision-making process: The household can allocate its resources to production for the market or to household production. In premodern Europe, as is still true today, the existence of household work makes the concept of leisure hard to define let alone measure. De Vries points out that market purchases and household production are imperfect substitutes for each other: Child rearing, food preparation, apparel making, and personal services can be purchased or homemade, but the products are not identical. An increased preference for the consumption of purchased goods requires cash, however, and thus implies greater labor force participation and market orientation. The resources thus reallocated were not idle before, nor were they absorbed by leisure, strictly speaking; they were simply deployed differently. The allocation between household and market depends simultaneously on

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[67] One tireless advocate of the role of demand in the Industrial Revolution (McKendrick, 1982a) speaks repeatedly of "mass markets," which suggests mass production, an important source of increasing returns. Yet as Styles (1992) has recently warned, applying modern terms of this nature to British manufacturing before 1850 -- manufacturing without interchangeable parts, without continuous flow processes, highly dedicated tools, or uniform standards -- is misleading.

preferences and on the relative efficiency of the household in producing for its own consumption or for the market.

The industrious revolution, in de Vries's view, was thus a change in allocation from production by, in, and for the household to a more market-oriented behavior. The net result was a vast increase in specialization on a microlevel: Workers came to produce, by and large, one or two products and buy everything else. It is tempting to attribute the shift to changes in preferences, although that would still not entirely justify Berg's enthusiastic claim (1994, pp. 134-35) that the shift in household behavior was necessary to the Industrial Revolution and her conclusion that "we must seek for the origins of the Industrial Revolution not just in women's labour but in women's wants and desires." Changes in preferences are notoriously hard to document. Moreover, while an exogenous change in preferences cannot be ruled out, such a redeployment could also have come as a result of technological changes.[68] First, better technology created and brought close to home some of the market-produced goods that the British consumer wanted to buy: cotton clothes, toys, adornments, tableware, kitchen utensils, clocks, books, and so on. As the array of goods that the consumer could buy increased, their quality improved, the uncertainty of their characteristics declined with standardization, and their price fell, the consumer would be more inclined to substitute cash income for housework. Second, the technological changes during the Industrial Revolution were biased in favor of production for the market. The factory was of course the obvious locus of the specialization of labor, but even those workers who remained at home found increasingly that they could do better by buying the goods they needed while producing for the market.[69] All the same, before 1800 or so the trend towards greater market participation accelerated and increased the effective labor input per worker by increasing the length of the labor year and intensifying the pace of work. The labor year could be extended in part by the reduction of seasonal unemployment through technical changes in the transport sector that made it possible to move materials and workers around with greater ease or through improvements in lighting technology that made it cheaper to work at night. Consumption of leisure declined as old and venerable institutions, such as "St. Monday" (the custom of taking Mondays off to recover from the weekend), were abandoned (Voth, 1998). There is also evidence collected by Clark that indicates

[68]De Vries points out that a change in preferences in favor of market-purchased goods would increase the marginal utility of money income. Yet reductions in the prices of these goods would have the same effect, because it is the *ratio* of marginal utility to the price of market goods that is the critical variable here.

[69]Some inventions, particularly those that revolutionized the household in the late nineteenth century, operated in the other direction. Thus the invention of the vacuum cleaner and the washing machine would lead to an increased production of these services by household members rather than buy them at the market.

that British workers worked at higher intensity than others (Clark, 1987a). Perhaps the most interesting alternative explanation of this phenomenon is the better level of nutrition that Britons enjoyed by this time, which permitted them to expend more energy in physical labor.[70] Whereas the Industrious Revolution hypothesis is demand based, the nutrition hypothesis should be regarded properly as supply-related insofar as it depends on increased availability of food. Below, I will discuss what kind of actual historical evidence exists to support De Vries's Industrious Revolution hypothesis.

Another aspect of the Industrious Revolution was an alleged increase in the participation of women and children in the labor market, which caused income as traditionally measured to increase (McKendrick, 1974). De Vries (1993, pp. 110-115) notes that the prominent role of woman and child labor during the Industrial Revolution represented a continuation and intensification of an already established trend toward greater paid labor force participation. As he points out, this movement did not start in 1750. It can be traced to the rise of market-oriented cottage industries ("protoindustrialization") in which women and children played a major role. As the Industrial Revolution progressed, the trend in labor force participation and contribution to household earnings seems to be subject to complex and often contradictory forces (Horrell and Humphries, 1992b). On the whole, the weight of the evidence suggest a rise in women and child labor beginning in the middle of the eighteenth century followed by a decline after 1815 or 1820, though the movements differed across regions and occupations. While the wives of elite workers in the formal sector such as factory operators and colliers could retreat to a quasi-middle-class homemaker's existence, those of outworkers and artisans experienced declining household income, forcing them to work harder. Yet at the same time the demand for their services declined. With income and substitution effects thus working in opposite directions on labor force participation, and with the labor force's structure changing, it is not surprising that the actual picture produced by the data is confusing.

Growing specialization and commercialization, an increasing reliance on the market, and the decline of "autoconsumption" preceded and accompanied the Industrial Revolution. As we have noted, to some extent these trends were themselves caused by the technical changes and to some extent they further stimulated additional technological changes. The idea of the "industrious revolution" is an important one, but it is not tantamount to restoring demand as a central factor in the economic changes that transformed the British economy. Much of the growing reliance on the market was supply driven, and although changing preferences toward market-produced goods buoyed demand for the products that the new technologies supplied, the contemporaneity of these two trends was only partial and to some extent accidental.

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[70] This point was first made in a pioneering paper by Freudenberger and Cummins (1976). For more recent work, see Fogel (1989).

Foreign Trade

On the eve of the Industrial Revolution, Britain was in many ways an open economy. It exported close to 15 percent of its GNP. Exotic goods, brought in from Asia, South America, and Africa, were widely consumed. Grain moved into the country in years of scarcity and out in years of abundance. People, both emigrants and tourists, came and went. Capital moved in and out of the country with ease. Intellectuals corresponded with their colleagues overseas, and ideas—technical and philosophical—moved back and forth over the channel and the Atlantic. It seems natural that this openness would have been an advantage for Britain, setting it apart from such comparatively closed societies as Russia, Spain, or Turkey. Yet the mechanism linking this openness to the Industrial Revolution is far from clear. Part of the difficulty is that during most of the period of the Industrial Revolution political and military conflict disrupted the international economy. Between 1760 and 1815 only two short periods of peace (1763-1776 and 1783-1793) punctuated an otherwise long era of war, blockades, and embargoes. There is also a logical question how trade affected other variables such as industrial technology beyond the obvious consideration of the importation of essential raw materials.

The role of foreign trade in the British Industrial Revolution is hotly contested. Part of the confusion results from disagreements about what variable foreign trade is affecting. In principle, exports increase economic performance either through the employment of resources that otherwise would have been idle, and through the fact that these exports are exchanged for imported goods that the economy cannot produce as cheaply (or not at all). If the economy is at full employment, and if the endowments and technology of the economy are quite similar to those of its trading partners, the gains from trade could be limited even if exports constituted a very large proportion of output. Conversely, even a small level of international trade can have a huge impact on growth if it supplies a crucial missing ingredient to the economy. Hence any inference regarding the "importance" of exports based on what proportion of output was exported is highly suspect. In any event, such Smithian gains are inherently static; the Industrial Revolution constituted a change in the technology and institutions of production, and linking these directly to the level or rate of change of foreign trade is not transparent.

Some of the most prestigious scholars in the field have vehemently denied any essential role for exports. Harley (1994, p. 306) calculates the gains from trade as the difference between what Britain ended up paying for the goods she imported and what she might have had to pay had she been self sufficient, and concludes that this might have been on the order of 6 percent of National Income by 1860, not a trivial sum, perhaps, but dwarfed by the growth of income in the previous century. Thomas and McCloskey (1981) start their essay by citing Deane and Cole to the effect that overseas trade was of central importance to the expansion of the economy and then add an ominous "we shall see," arriving ultimately at the conclusion that "the strongest effect between commerce abroad and industry at home was from industrialization to commerce, not the reverse. Trade was the child of industry." Trade theorists such as Charles Kindleberger (1964, pp. 264-266) and Ronald Findlay (1982) have come to the same conclusion. Many traditional historians are also of the same opinion, including the leading modern scholar of British overseas trade in this period, who writes:

> I share the view that overseas trade did not have an important *direct* role either in bringing about the Industrial Revolution or in supporting the first stages of its progress. . . . The initiative came from the supply side, from technical change. . . . Though a combination of changes made up the Industrial Revolution, the principal driving forces came from the nature of the inventions in the textile industry . . . and the efficacy of these inventions, which lifted the market for these inventions, at home and abroad, to an entirely new level. . . . Overseas trade made little contribution to the advent of the Industrial Revolution itself and was not essential in the early stages of its development. Its importance reappeared in the further expansion of the mature industrial economy (Davis, 1979, pp. 62-63).

Yet foreign trade as an essential impetus to the growth of the British economy is a tenacious concept. A recent paper by O'Brien and Engerman (1991) has tried to revive its importance by criticizing the assumptions made by economists who minimize the role of foreign trade. They appear to favor Adam Smith's "vent for surplus" theory of exports and even mercantilist ideas of "employment-creating" exports over the Ricardian notions of comparative advantage. They conclude that "domestic exports may be designated . . . as clearly important and necessary components of industrial growth that occurred in Britain in the eighteenth century" (p. 207). Javier Cuenca (1997, p. 16) has recently argued that "overseas demand in general provided the opportunity and the stimulus for technological innovation as the industry reached the limits of growth within a protected domestic market."

At least some of the sharp differences of opinion that arise between O'Brien-Engerman and their opponents result from different formulations of the question. Foreign trade was necessary if Britain was to import goods she could not produce for herself or could produce only at enormous cost. Tropical groceries (sugar, tobacco, spices, tea), European foodstuffs (wine, dried fish, corn in years of high prices), and raw materials (timber, hemp, high-quality ores, tar, and of course raw cotton) had to be brought in from overseas. O'Brien and Engerman (1991, pp. 201-202) point out that for this reason, in a closed economy Britain's real income would have been substantially lower, though it is hard to know precisely by how much without specifying what the next best substitutes were. The first difference between an open and a hypothetical closed economy was the "gain from trade," and it was of course large because trade occurred in large part with economies whose factor endowments were radically different from Britain's. Harley's calculation is important in underscoring the dangers of indispensability theorems in economic history, but it is difficult to see how Britons could have produced the raw materials for their textile industry and the tea and sugar for their breakfast from domestic resources.

Was the *growth* of exports an "engine of growth" in the period of the Industrial Revolution? The question seems somewhat moot, given that there is a growing consensus that growth itself was comparatively modest before 1831. The intellectual resources that have been dedicated to explain British economic growth before 1830 by growing exports may have been misallocated now that it turns out that this growth was far less impressive than was hitherto supposed. One way of testing the relationship is to see whether domestic supplies grew faster than foreign demand, so that foreign demand was in this sense more a passive than an active factor. After 1800, when more data become available, we can be more certain that British supply increased faster than foreign demand, because Britain's net barter terms of trade worsened continuously (Thomas and McCloskey, 1981, p. 101).[71] At the same time, it seems plausible that Britain's single factoral terms of trade (in which the prices are weighted by the productivity of domestic factors of production)

TABLE 1.2. Exports Growth, 1700-1851

Year	*Total Exports (£ millions)*	*Industrial Exports as a % of Industrial Product (Crafts)*	*Industrial Exports as a % of Industrial Product (Cuenca)*	
1700	3.8	24.4	13[a]	20[b]
1760	8.3	35.2	18	28
1780	8.7	21.8	25	33
1801	28.4	34.4	40	40
1831	38.9	21.9	49	45
1851	67.3	24.7	69[c]	n.a.

[a] Column using Crafts estimates of Industrial output

[b] Column using Cuenca estimates of Industrial output

[c] Actual point estimate (all other Cuenca data are 11 year averaged centered on date).

Sources: Computed from Davis (1979, pp. 88-89), Crafts (1985a, p. 132) and Cuenca (1997, table 1).

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[71]The somewhat more uncertain calculations made by Deane and Cole (1969, pp. 319-321) for the eighteenth century show a worsening of the terms of trade for the later 1780s and 1790s as well. This leads them to conclude (p. 83) that the "accelerated growth of foreign trade in the second half of the eighteenth century was associated with an *adverse* movement of the terms of trade."

improved, so that the purchasing power of the average Briton to buy imports continued to rise due to growing productivity.

Manufacturing products, of course, were exported in large quantities, and taken together foreign markets would have been difficult to replace. The ratio of industrial exports to gross industrial output increased sharply, from 24.4 percent to 35.2 percent between 1700 and 1760, a period in which output was growing only slowly. What happened subsequently? Whereas Crafts's figures suggest a sharp decline in the subsequent decades (with a sudden and unexplained peak in 1801), Cuenca's new computations draw a rather different picture.

Table 1.2 suggests that the importance of exports to manufacturing during the Industrial Revolution was most crucial in its "adolescent phase" after 1780. All the same, if export markets were more than just a trigger, their relative importance should have increased and not declined as the Industrial Revolution progressed. If Cuenca's new data are even approximately correct, the data seem to support his view. A closer look at Cuenca's time series does leave some questions open. Taking his own industrial output series as a denominator (which seems the reasonable thing to do), it turns out that the 11-year average of "official values" of industrial exports to industrial output is essentially flat at about 40-42% between 1800 and 1826. Moreover, during the period in which technological progress was at its most feverish (1760-85), Cuenca's official values ratio series was rising equally slowly, except for the years following the peace of Paris (1783). At first glance, therefore, the timing suggests that the causality may be running from technology to exports and not the reverse. Yet Cuenca clearly is correct when he complains that the movement over time of industrial exports relative to industrial output *cannot* be taken as evidence against the causal role of export markets.

Many scholars have argued that foreign trade did more for growth than the aggregate statistics suggest and that exports were more important in certain key industries. Cotton, above all, depended for more that half of its sales on foreign markets, and insofar as the technology developed for cotton spilled over to domestic industries, the foreign sector's role is understated by the statistics. O'Brien and Engerman also suggest that the wealth accumulated by merchants through foreign trade was invested in British manufacturing and overhead capital, though no evidence is provided to support this point and indicate how large this investment was.[72] O'Brien and Engerman resuscitate the Rostowian notion of a "leading sector" and designate industry in this role. Because exports were so important to manufacturing and because manufacturing dragged the other sectors behind it, they maintain, exports were essential to the entire economy, and "the attention should remain focused upon those forces promoting increases in the production of

[72] There is even less evidence for the statement that merchants "created and widened markets for British manufactured goods at home or abroad" (O'Brien and Engerman, 1991, p. 191), nor is there any suggestion as to exactly how merchants *create* markets as opposed to servicing them.

manufactured goods" (1991, p. 208). Apart from the somewhat poorly defined concept of a "leading sector," the problem with their logic is that it is consistent with any set of facts and thus lacks power as an explanation. When exports stagnated in the 1760s and 1770s, just when a number of key industries were taking off, "domestic demand maintained the growth of industry," which proves that "interactions also flowed the other way" (p. 208).[73]

A different way in which exports could have led to growth is if export industries employed labor that would otherwise have been unemployed. Thomas and McCloskey base their thesis on the "unimportance of exports," on the simple notion that exports used up valuable resources that could have been used for the benefit of domestic consumers but are the inevitable price a country has to pay for the imports it enjoys. This assumes, however, a fully employed economy in which each factor is paid its opportunity cost. Many of the manufactures of Britain during the eighteenth century, however, were produced by rural industry, by men and women whose opportunity cost in the off-season was low. Insofar as export markets provided these workers with employment, an expansion of output can indeed be attributed to exports. In other words, in a closed economy the same employment levels might not be sustainable, so that one of the benefits of trade was an increased demand for labor. It is difficult to prove this point decisively, but O'Brien and Engerman are correct to point out that contemporaries were far from impressed by the success of the domestic economy's in maintaining full employment and were obsessed by the specter of unemployment. As we have already seen, there is some evidence that people in Britain worked longer hours in 1800 than they did in the middle of the century.

Turning to the *dynamic* question, as already noted it is much more difficult to connect the openness of the British economy with technological changes. It is transparent that technological advances will stimulate exports. But is there a feedback from rising exports to further technological progress? As Krugman (1995, p. 55) has pointed out, once we consider such a feedback effect the answers become much more controversial. Export demand may have been a consideration for some innovators, but almost every individual entrepreneur could cover his expenses by the domestic market. The growing dependence of the cotton industry on foreign markets was an ex post phenomenon, not something that *caused* technological change. Ralph Davis argues that cotton expanded overseas after it had earned its spurs in the domestic market and that the export-driven expansion of the industry in the 1790s simply called for a larger number of similar mills (Davis, 1979, p. 67). All the same, the microinventions that kept improving the quality and reducing the

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[73]The concept of a leading sector itself may prove to be more lasting than the "take-off hypothesis." Wijnberg (1992, pp. 165-167) defines a leading sector as an industry that is "technologically contagious," that is, in which the conditions for successful innovation such as low barriers to entry and appropriability of inventions spill over onto others. Such explicitly dynamic models are necessary to a consistent "demand-side" interpretation.

prices of the goods produced may have been a function of output and thus of the size of the market. Learning by doing and experience were the sources of productivity increase after the big breakthroughs had been made. Insofar as export markets permitted expanded sales, then, they led to productivity increases and lower costs. Export-oriented industries in the post World-War II Asian economies have often been "high-tech" and so a large export market may produce a stimulus to the adoption of frontier technologies. The unresolved questions remain, however: Is this connection between exports and technological progress also true for a nation that is generating the new technologies, and not only adopting them? To what extent would the domestic market have been able to replace the foreign markets? What was the elasticity of cost with respect to sales (that is, how strong, really, were the marginal learning effects of overseas sales)?

Even if the nexus between foreign trade and technological progress thus remains something of a mystery, the open-ness of the British economy was a central feature that determined her economic fate. Open-ness is not a yes-or-no variable: few economies have ever been hermetically closed and few have been "entirely open" (if that concept could be defined). While open-ness was thus a matter of degree, this degree was of great importance. One example is the role of agriculture in the industrialization process. In a recent paper, Matsuyama (1992) demonstrates rigorously an intuition long prevalent among economic historians, namely that the relation between agricultural productivity and the rate of industrialization depends on the open-ness of the economy. In a closed economy, manufacturing depends on productivity growth in agriculture to produce a surplus that will permit the reallocation of resources from farming to industry and to provide a market for manufactured products. It has often been thought that an "agricultural revolution" was a necessary precondition for industrialization. Yet in an open economy this is clearly false: food can be imported and paid for by industrial goods. In fact, in an open economy a highly productive agricultural sector signals to the economy that its comparative advantage lies in farming, thus losing the (unforeseen) advantages of industrialization. This is in fact what happened in the Netherlands between 1815 and 1870: an open, free-trade economy with a highly productive agricultural sector, the opportunity costs of labor was just too high to render manufacturing profitable (Mokyr, 1976a). In Britain, despite growing agricultural productivity (the dimensions of which are still heavily disputed) this did not happen. Imports from the Celtic Fringe and the Continent made up the British food deficit (Thomas, 1985). Indeed, Matsuyama's model implies that in an open economy the Industrial Revolution occurred not *because* but *despite* the growth in agricultural productivity.

The open-ness of the British economy also meant that technology was continuously stimulated by ideas from the outside. We have already seen the wide influence of French science and inventions on British technology. Throughout the period, close cooperation with French, German, and Swiss manufacturers led to the continuous exchange of technological knowledge. Arnold Pacey (1990, pp. 117-120) has argued that Asian stimuli were of primary importance to the Industrial

Revolution. Indian calicoes and muslins could not be made in Britain using the laborious hand-spinning techniques of India, but they showed the British what could be done, and eventually Crompton's mule was able to produce yarns of Asian fineness. English entrepreneurs sent representatives to Smyrna to study the manufacturing of Turkey-red dye, and plants to produce it were set up in Manchester and Glasgow (Wadsworth and Mann, 1931, pp. 180-181). Technology was enriched by the infusion of foreign elements, and in the long run this exposure effect turned out to be one of the most lasting benefits of the open economy.

A separate issue often raised in this context is the impact of the British Empire. It seems somehow tempting for those who do not have much sympathy for British capitalism to link it with imperialism and slavery.[74] It is hard to see exactly how the imperial policies, which protected British merchants doing business overseas, could have had much impact on the Industrial Revolution beyond, perhaps, assuring favorable treatment in some markets. Empire and foreign policy seem to have conveyed at best a slight advantage. After all, Britain lost one of its richest colonies during the early stages of the Industrial Revolution, and yet after 1783 commercial relations with the young United States were none the worse for wear until complications in Europe drove the two apart again. India was an important market, but it never reached the size that would make it a sine qua non: In 1784-1786 Asia (that is, primarily India) absorbed 13.3 percent of British exports, a share that remained essentially constant until 1854-1856 (Davis, 1979, pp. 96, 100). To be sure, Asia did buy a larger than proportionate share of the output of Britain's most dynamic industry, cotton, but as late as 1854-1856 it bought 22.5 percent of Britain's cotton exports. This is substantial, but Europe, the Near East, the United States, and Latin America, where Britain competed on an equal base, remained equally important markets. Outside Britain, Switzerland and Belgium, two nonimperial nations, were successful industrializers, whereas Holland and Portugal, which controlled a large and rich set of colonies, remained behind. In short, trade with the empire may have been central before the Industrial Revolution, but it lost much of its primacy in the years after 1780, when it might have been needed the most (Cain and Hopkins, 1980, p. 474).

The classic attempt to link imperialism and the slave trade with the Industrial Revolution is the Williams thesis. Eric Williams (1944) argues that profits from the triangular trade (between Western Europe, Africa, and colonial America) helped finance the early stages of industrial capitalism. In particular, Williams argues that the slave and sugar trades encouraged British industrial production and capital

[74] As Engerman (1972, p. 430) put it, in this version history becomes a morality play in which one evil (the Industrial Revolution) arises from another, perhaps even greater evil, slavery and imperialism.

accumulation.[75] This thesis, which had long been regarded as discredited, has recently been resurrected, and a special issue of *The Journal of Interdisciplinary History* was dedicated to it (Inikori, 1987; Richardson, 1987; Solow, 1987; see also Inikori, 1989, Morgan, 1996). It can hardly be doubted that the West Indian sugar trade was highly profitable, as Adam Smith ([1776] 1976, p. 412) pointed out. Because the sugar trade depended on slave labor, the slave trade was, not surprisingly, profitable as well, although the high mortality of slaves and crew on these voyages raise some question as to the profitability of this activity (Morgan, 1996, p. 17). Commercial interests, shipbuilding, banking and insurance services, and industries catering to the triangular trade prospered, and the towns of Bristol and Liverpool consequently grew (Williams, 1944, p. 36, 62-64). Yet the links between Liverpool and Manchester do not prove Manchester's "tremendous dependence on the triangular trade" (p. 68) and recent work has not been very successful in substantiating Williams's claim that the profits from this trade "provided one the main streams of that accumulation of capital in England which financed the Industrial Revolution" (p. 52). The intuitive feeling that "the exploitation that really mattered was [that] of African slaves" (Solow, 1987, p. 737) is justifiable in that it surely mattered to the slaves themselves, as it did to Africa and to the areas to which slaves were shipped. Yet that does not necessarily mean that it "mattered" to the same degree to Britain and other European economies that were the main beneficiaries of the triangular trade system.[76] There is often a cruel asymmetry in the moment of injustices in the respective histories of the victim and the perpetrator, an asymmetry as clearly illustrated by the economic relations Britain had with the Caribbean as by its relation with Ireland.

Furthermore, the simple causal links drawn by Williams should be modified. Richardson (1987) points out that the slave trade depended on the demand for sugar, which itself was a function of economic changes in the sugar-consuming economies in Western Europe. Moreover, Ralph Davis's estimates show that in 1784-86 the West Indies purchased 11.3 percent of British manufacturing exports, rising to 19 percent in 1804-06, but falling back to 15.1 percent in 1814-16 and 9.1 percent in 1834-36. These numbers are not insubstantial, but they do not prove that

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[75] As has been often noted, it is not quite clear whether Williams referred to the slave trade alone or to the more extensive triangular trade.

[76] In a classic paper, Engerman (1972) demonstrated that the quantitative effects of the slave trade on the British Industrial Revolution were negligible. He computed (p. 440) that total profits from the slave trade in 1770 amounted to at most £342,000 (an alternative estimate has the number as low as £44,000). Total GNP in 1770 can be roughly estimated at about £166 million. (computed by applying Crafts's revised growth rates to Dean and Cole's estimate of GNP at £232 million in 1801). Gross capital formation was between 6 and 7 percent of GNP and thus came to about £11 million. Even on the most favorable assumptions, then, the profits of the slave trade, had they all been invested in Britain, would have contributed no more than 3 percent of capital formation in 1770.

the West Indies were more than just another market. Above all, however, the West Indies and slavery were important to Britain as a source of products that could not be produced locally. In the absence of West Indian slavery, Britain would have had to drink bitter tea, but it still would have had an Industrial Revolution, if perhaps at a marginally slower pace.[77]

If an element of slavery and the Atlantic trade were of essential importance to the Industrial Revolution, it was not due to the West Indies but to slavery in North America. Before 1780 most of the raw cotton came to Britain from the West Indies, but clearly their potential to supply it was limited, and after 1790 the industry depended increasingly on the southern states of the United States. Simply put, without U.S. slave labor it is hard to see how the elastic supply of raw cotton would have been secured. Certain processes in the cotton industry could be mechanized, including some concerned with the production of the raw material (using, for example, the cotton gin). But the planting and picking of cotton in the fields of the southern United States remained a manual process, and as the demand for cotton increased, U.S. slave plantations rapidly switched to cotton. Without U.S. slavery, the British cotton industry would have run into a severe bottleneck. It is here and not in the consequences of eighteenth-century triangular trade that slavery truly "mattered" for the Industrial Revolution.

Science and Technology

The notion that Britain was the first to undergo an Industrial Revolution because somehow British technological success was due to Britain's having more "advanced" science is unsupportable. The premise itself is in dispute (Kuhn, 1977, p. 43), but even if it were true, the technology developed during the British Industrial Revolution owed little to scientific knowledge, as Mitch's chapter below stresses. The inventions that set the British changes in motion were largely the result of mechanical intuition and dexterity, the product of technically brilliant but basically empirical tinkerers, or "technical designers" (a term suggested by Hall, 1974, p. 148), such as John Wilkinson, Richard Arkwright, John Smeaton, Richard

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[77] In a recent manuscript, Pomeranz (1998, ch. 4) re-assesses the Williams thesis and, much like Morgan (1996), concludes that while there may be something to the argument that profits from the West Indies ended up paying for some portion of the Industrial Revolution, the exact magnitude of this effect is hard to determine but is unlikely to be large. Pomeranz, however, also makes an important observation in that the main effect of the trade with America was the saving of land (ibid., ch. 5). The importation of sugar into Britain alone, he computes, saved by 1800 somewhere between 1.3 and 1.9 million acres just in terms of its calorific value. Adding to that the equivalent of other products of Britain's "ghost acreage" overseas, he computes the total equivalent of its colonial trade to be 3-4 million acres, adding around 20 percent to Britain 17 million arable acres. In this way, he maintains, Britain was able to avert the ecological consequences of its population growth. While such computations illustrate neatly the gains from trade between Britain and its colonies, they shed little light on the question why the Industrial Revolution occurred where and when it did.

Trevithick, and Robert Stephenson. In a few cases, such as Claude Berthollet's chlorine bleaching and Humphry Davy's safety lamp, inventions were made by scientists of note, but that correlation does not prove that science itself was of great importance. Leading scientists were not wholly specialized at this time and dabbled in technology, just as Galileo, Huygens, Hooke, and Leibniz had a century earlier.[78] Unlike the technologies that developed in Europe and the United States in the second half of the nineteenth century, science, by conventional wisdom, had little direct guidance to offer to the Industrial Revolution (Hall, 1974, p. 151). Gillispie (1957) points out that the majority of scientific endeavours of the time concerned subjects of limited technological use: Astronomy, botany, crystallography and early exploration of magnetism, refraction of light, combustion. Eventually, of course, many of those discoveries found economic applications, but these took place, with few exceptions, after 1830.

If science played a role in the Industrial Revolution, it was neither through the "pure" foundation of technology on scientific understanding nor through the role of scientists in invention but rather through the spillovers from the scientific endeavor. We may distinguish between three closely interrelated phenomena: scientific method, scientific mentality, and scientific culture. The penetration of scientific *method* into technological research meant accurate measurement, controlled experiment, and an insistence on reproducibility. This novel scientific method also taught engineers the "method of detail," analyzing technical problems logically by breaking them into components that could be more easily analyzed separately than as part of a whole (Pacey, 1975, p. 137). David (1997) has emphasized that scientific method by the late seventeenth century included communicating scientific advances and discoveries to the public at large, thus turning scientific knowledge into a public good. This sharing of knowledge required systematic reporting of methods and materials using a common vocabulary and consensus standards.

Even more important, perhaps, was scientific *mentality*, which taught engineers a rational faith in the orderliness and predictability of natural phenomena -- even if the actual laws underlying chemistry and physics were not fully understood (Parker, 1984, pp. 27-28). The scientific revolution of the seventeenth century taught a new approach to the study of nature, a mechanical philosophy in which natural phenomena were studied as independent units, increasingly separated from religious considerations. Without immediately abandoning the belief in a creator, it became increasingly possible to analyze nature without theology or magic. Because technology in its deepest essence involves the manipulation of nature and the physical environment, the metaphysical assumptions under which people

[78]The two leading Newtonians of the early eighteenth century, the Dutchman Willem Jacob s'Gravesande and the Englishman (of French descent) Jean Desaguliers, were both active in introducing and improving Newcomen engines in continental Europe (Jacob, 1988, p. 130).

operate are ultimately of crucial importance. The growing belief in the rationality of nature, the archtypical enlightenment belief, led to a growing use of mathematics in pure science as well as in engineering and technology. Scientific mentality also implied an open mind, a willingness to abandon conventional doctrine when confronted with new evidence, and a growing persuasion that no natural phenomenon was beyond systematic investigation.

Finally, scientific *culture*, the culmination of Baconian ideology, placed applied science at the service of commercial and manufacturing interests (Jacob, 1988, 1997). Science in the seventeenth century became increasingly permeated by the Baconian notion of material progress and constant improvement, attained by the accumulation of knowledge. Although such relations are impossible to quantify, it stands to reason that in that regard science laid the intellectual foundations of the Industrial Revolution by providing the tacit and implicit assumptions on which technological creativity depended. Engineers such as Thomas Telford, John Smeaton, and John Rennie moved effortlessly between experimental science and practical applications. George Stephenson, a remarkable example of this ability himself, wrote of the great Smeaton as having a "truly Baconian mind"—a description that fits an entire class of British engineers active between 1760 and 1830. As we have seen, lectures on scientific subjects drew eager audiences who met at provincial scientific society meeting places such as the famous Birmingham Lunar Society, coffeehouses, and masonic lodges to watch experimental demonstrations illustrating the application of scientific principles to pumps, pulleys and pendulums. Yet, as Robert Schofield (1972) has argued, these meetings were secondary to the networking and informal exchange of technical information between members. Scientific culture reinforced the entrepreneurial interests of science's audience by demonstrating how applied mechanics could save costs and enhance efficiency and thus profits. Much of this "provincial scientific culture," as Inkster (1991, p. 43) has called it, was private, meritocratic, non-elitist and thus in some ways in conflict with the social establishment. British science and scientists occupied a different position in society than elsewhere. As Thackray (1974) has shown for Manchester, the interest in science was a means for the upstart commercial and manufacturing class to assert and legitimize itself. Because science was a natural and not a moral discourse, it provided a neutral common ground for otherwise hostile subgroups of the urban elite to communicate and express a "cultural solidarity and social cohesion" to set them apart from both the working class and the landed elite (p. 693). All in all, it was one of the most obvious ways in which "culture" affected technology and, in the long run, economic progress.

Eighteenth century science tried to provide implicit theoretical underpinnings to what empirically minded technicians did, even if the complete scientific base had not been fully worked out. Thus the steam engine depended on the understanding of atmospheric pressure, discovered by Continental scientists such as Evangelista Torricelli and Otto von Guericke, which somehow must have filtered down to Newcomen despite the fact that his world was the local blacksmith's rather than the cosmopolitan academic scientist's. Chlorine bleaching depended on the discovery of chlorine by the Swedish chemist Carl Wilhelm Scheele in 1774. Phlogiston theory, the ruling physical paradigm of the eighteenth century, was eventually rejected in favor of the new chemistry of Lavoisier; but some of its insights (e.g., the Swede Tobern Bergman's contributions to metallurgy) were valuable even if their scientific basis was flawed and their terminology quaint to modern readers. Cardwell (1972, pp. 41-43) has shown that the idea of a measurable quantity of "work" or "energy" derives directly from Galileo's work on mechanics. The advances in water in the eighteenth century depended on a scientific base of hydraulics (Reynolds, 1983). Often, of course, bogus science produced bogus results, as in Jethro Tull's insistence that air was the best fertilizer. In the "development" stage of the basic inventions, in which engineers and technicians on the shopfloor improved, modified, and debugged the revolutionary insights of inventors such as Cort, Cartwright, and Roberts to turn them into successful business propositions, pure science played only a modest role.

Was British science somehow different from Continental science? As Thomas Kuhn states, the old cliché that British science was pragmatic and applied whereas French science was abstract, deductive, and formal seems to have survived the test of time (1977, p. 137; see also Inkster, 1991, p. 42). The origins of this phenomenon may be traced to an intellectual bifurcation of the seventeenth century, when British science came under the influence of Bacon whereas in France more Cartesian ideals triumphed. Bacon advocated that the purpose of science was to raise comforts and living standards, whereas the French traditions followed more lofty objectives. Bacon's science was empirical, experimental, and pragmatic whereas French science was theoretical and abstract. Such generalizations are inevitably hazardous, but water power provides at least one persuasive example. In Britain research on water power was conducted by practical engineers, such as Smeaton, John Banks, John Rennie, and William Fairbairn, in search of a better water mill. On the Continent work on water power was largely theoretical and carried out by mathematicians, such as Antoine Parent, Johann Euler, and Jean Charles Borda (Reynolds, 1983, pp. 196-265).

Yet the roots of the divergence between British and Continental science go beyond that. The Cartesian traditions in eighteenth-century France regarded the function of science to be to support the authoritarian state as the source of all order. In Britain, as Margaret Jacob (1988, p. 93; 1997, p. 113) has argued, the scientists in the 1660s and 1670s forged an alliance with the landed and commercial interests. After these interests triumphed politically in 1688, scientists in eighteenth-century Britain were on the whole part of the economic establishment, not of the opposition. They regarded it as a natural state of the world to cooperate with engineers and manufacturers to solve pragmatic technical problems.[79] The interactions between them, as we have seen, were institutionalized in the various scientific and philosophical societies that provided the meeting places, and informal contacts further strengthened these ties. Even some members of the landowning elite displayed a strong interest in technology, in part for economic reasons but also out of sheer curiosity. Such paragons of the aristocracy as the Earl of Dundonald, the Viscount of Dudley, and Ward, the Earl of Balcarres, were fascinated by the new technologies. There was a growing communication between scientists, engineers, and businessmen, and they engaged in a common effort to recognize technical problems and solve them. From the early eighteenth century on, scientists in Britain gave popular lectures on mechanical and technical issues, which were widely attended by audiences from the commercial and artisanal classes. The most famous of these lecturers was John T. Desaguliers, a noted physicist who made considerable contributions to the Newcomen steam engine and water power (Musson and Robinson, 1969, pp. 37-45; Reynolds, 1983, pp. 215-217, 280).

The state and official institutions in Britain had relatively little to do with these developments, the Board of Longitude being the most notable exception. The generation and diffusion of scientific and technological knowledge in Britain occurred spontaneously, by and for private interests. In France, by contrast, scientists depended on economic and personal relations with the *political* establishment, fostering an elitist and statist approach to science, which was thus particularly concerned with the engineering and technical needs of the state and above all with military needs. The French state subsidized and managed scientific enterprises, whereas in Britain the same role was carried out by the private sector (Gillispie, 1980, chap. 5). The counterparts to the British provincial societies in disseminating technical knowledge were the *grandes écoles*, which trained technicians and engineers. The first of these was the *école des ponts et chaussées,* founded in 1744, followed by the *école de dessin* in 1767 and the *école des mines* in 1783. After the Revolution, these were followed by the *école polytechnique* (1794) and the *école des arts et métiers* (1804) (Artz, 1966). All these institutions were run and funded by the government. In other countries, such as the Austrian Netherlands, the German states, and Russia, the direct intervention of the state was even more noticeable. Science and engineering were creatures of the state, meant first and foremost to serve the military and administrative organs of the government. In Britain, private interests dominated.

The difficulty in linking science and technology in this period is highlighted by one of the few quantitative measures of scientific output --periodicals. Although the

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[79] Perhaps the best example is the problem of measuring longitude at sea. In 1714 the Longitude Act promised huge financial awards to any individual who could devise a method or tool to measure longitude accurately. The commercial interests here were quite transparent, and applied science — in the person of watchmaker John Harrison — proved up to task (Sobel, 1995).

value of a periodical is of course proportional to its subject matter, the quality of research, and the scope of its circulation, it is striking that the vast majority of scientific journals published in the eighteenth century appeared not in England or France but in Germany. Kronick shows that over 61 percent of all "substantive serials" appeared in Germany, with France and England accounting for 10.7 percent and 6.9 percent, respectively. The actual gap was smaller, because German scientific journals were comparatively short lived, but correcting for this does not alter the picture (Kronick, 1962, pp. 88-89). Similar gaps, although not as large, hold for the proceedings of scientific societies. The only category in which England led, perhaps significantly, was "translations and abridgements" (pp. 114-115).

On the basis of this background it is easier to understand the dispute between those like Mathias (1979, pp 45-87) and Hall (1974; see also Hall and Hall, [1964] 1988, p. 219), who deny science any serious role in the Industrial Revolution, and those like Musson and Robinson (1969) and more recently Jacob (1988, 1997), who try to restore science's role in explaining Britain's uniqueness. David Landes (1969, p. 104) and others have reversed the causal connection and maintained that science owed more to technology that the other way around. The conventional argument that scientific knowledge was unimportant simply because much of what scientists knew was irrelevant to engineers and industrialists can no longer be maintained. Yet Jacob (1988, p. 181) may have gone too far in the other direction when she suggests that the Industrial Revolution occurred in Britain and not in France and the Netherlands because the lack of scientific knowledge on the Continent was such that there "many of the very men who had access to capital, cheap labor, water, and even steam power could not have industrialized had they wanted to: they simply could not have understood the mechanical principles necessary to implement a sophisticated assault on the hand manufacturing process." Certainly there was nothing in the inventions made between 1760 and 1830 that exploited a store of knowledge accessible only to the British. The physics and chemistry of the time were primitive, and the deeper theoretical principles behind such breakthroughs as the steam engine and soda making were not understood by anyone. France could and did generate highly sophisticated innovations, including the mechanical toys of Vaucanson, the Jacquard loom, the continuous paper machine, as well as the chemistry of Lavoisier and Berthollet. The difference, if there was any, was of degree, of emphasis, and above all of the depth with which technologically valuable knowledge had penetrated into the productive layers of society. More recently, Jacob (1997, pp. 132-33) has argued sensibly that some mechanical knowledge had to be part of one's mental world before mechanical devices could be invented and exploited, and that differences in scientific education across Europe went a long way toward explaining national differences in industrial progress. Yet the *average* level of scientific knowledge may not have differed all that much between England and France. What differed was its distribution, and its impact on the mundane needs of the "useful arts."

What accounts for the differences in the intensity of interaction between persons with knowledge and persons of business? Every civilized society contains individuals who are highly educated and think for themselves, and individuals who are skilled and produce goods and services that add up to income and consumption. Technologically creative societies are those in which these two classes mingle socially, communicate with each other, and are interested in similar issues. In Britain the bridge between natural philosophers and engineers was broader and easier to cross than in other countries, and more than anywhere else, Britain could count on able people who could effortlessly move between the world of abstraction, symbol, equation, blueprint, and diagram and the world of the lever, the pulley, the cylinder, and the spindle. Information also travelled easier in eighteenth century Britain than in France, thanks to better passenger travel and mail services (Szostak, 1991). Yet such bridges existed elsewhere (as one glance at Diderot's *encyclopédie* will demonstrate), and Britain's advantage here was as partial as it was temporary.

The Inputs: Labor and Capital

Economic growth can be decomposed into increases in the quantities of inputs and changes in the way inputs are utilized. Increases in output per worker consist of changes in productivity and the accumulation of factors other than labor. Separating the two is in practice quite difficult. A related question, equally controversial and studded with theoretical pitfalls, is the effect of the initial endowments of factors of production on the rate at which the modern sector grows. A satisfactory model would allow us to approach the question, Why was Britain first? from a different angle. The Industrial Revolution involved massive accumulation of capital and profound reallocation of labor. How did factor markets carry out these functions? How crucial was the supply of factors to the Industrial Revolution? Where did the inputs come from, and how did market mechanisms channel them to where they were needed?

The operations of factor markets in Britain during the Industrial Revolution have been examined by Williamson (1987a; 1990a, chap. 7). In this work, Williamson poses the question starkly: How much did the imperfection of labor and capital markets cost the British economy? Questions such as, Were markets perfect? or Did they fail? are somewhat ill posed; factor markets are far from perfect even today, and "failure" is obviously in the eye of the beholder. Williamson's approach is to compare the actual operation of factor markets with an ideal neoclassical world in which competition is perfect, factors flow effortlessly between regions and sectors and the allocation of resources follows the theoretical rules devised by economists. The latter, purely imaginary world is, obviously, more efficient, but theory gives us no guide as to the *size* of the difference. Williamson reasons that if the forgone output due to factor market imperfections was very large, it could conceivably have slowed down industrialization and growth. Working with a multisectoral general equilibrium model, he poses counterfactual questions: How much faster would GNP have grown and industrialization have proceeded if factors had been perfectly mobile? He concludes that these gaps were indeed significant. The labor market imperfection alone was responsible for a 3.3 percent loss of GNP compared with the ideal world, and the capital market for an 8.2 percent loss.[80] More important, manufacturing output would have increased over 60 percent if the capital market imperfection had been eliminated, and manufacturing profits by 114 percent. It should be noted that Williamson's imperfections are intersectoral only; his computations still assume that capital and labor can reallocate themselves effortlessly *within* the sectors. In that sense they represent an understatement of the true values.

Apart from the question of how efficient factor markets were, the roles of labor and capital have been the subject of an interesting and important literature.

Labor

There are two competing and apparently incompatible views of the role of labor in the Industrial Revolution. One of them sees labor as a scarce resource, in fact as *the* scarce resource, and therefore the Industrial Revolution had a better chance of succeeding in areas in which it was abundant and cheap. The other regards technology as responding to labor scarcity and thus implies that *scarce* labor was an advantage in the industrialization race.

The first model is based on a number of assumptions that should be spelled out.[81] Because the model is not strictly speaking a growth model (it has few implications for the overall growth rate of the economy) and deals more with the composition and technological practices of some sectors, I termed it a "growing-up" model (Mokyr, 1976b). The assumptions are as follows:

1. Capital goods "embodied" the new technology. Then, as now, that assumption seems almost too obvious to justify. Steam engines, mule jennies, blast furnaces, paper mills, chaff cutters, and threshers are all examples of a new technology requiring a large capital expenditure. One cannot have the new technology without making an investment in capital equipment. Above all, there were factories that had to be built, maintained, heated, lighted, and guarded. The modern sector was physically located, by and large, in large buildings. And in contrast with France and Belgium, in Britain there were no more monasteries to confiscate and convert. This is not to deny the importance of disembodied technological change. It implies, however, that a lack of fixed capital could have retarded the transformation, as I shall argue later. The reverse does not hold: An abundant supply of capital did not

[80] The combined loss does not equal the sum of these losses because in the model one market can adjust to compensate for imperfections in the other. Indeed, in Williamson's story eliminating both gaps would result in a lower gain in aggregate output than eliminating the capital market gap alone, an anomalous result he ascribes to nonlinearities in the solution of the model.

[81] Some of the following material is adapted from Mokyr, 1991b.

guarantee the adoption of technological changes and the emergence of factories, because the owners of the capital could not be relied upon to lend it to aspiring factory owners. What mattered was venture capital, not aggregate savings.

2. The rate of accumulation depended crucially on the rate of profit. In the simplest model, in which factory owners could not borrow and depended on retained profits to finance new investment, this conclusion is trivial. In models with financial institutions, however, this relation is not appreciably weakened as long as the past performance of the firm is used as an indicator of its future profitability.

3. Wages were the main cost to the firm. If labor productivity is primarily determined by technological parameters and the prices of output are given, the rate of wages is inversely related to the rate of profit through the factor price frontier. In other words, because the productivity of labor depended on the technology in use, assumed to be accessible to all economies, the main reason why profit rates differed across economies was different wage levels reflecting differences in economic structures or factor endowments on the eve of the Industrial Revolution.

4. Technological change was more or less independent of factor prices. This would be the case if there was little choice in the range of techniques; i.e., the "best practice" techniques at the onset of the Industrial Revolution were the most efficient for any realistic set of factor prices.

5. Goods were internationally mobile, but labor and capital were not. It is assumed that labor was mobile only *within* a region but could not migrate across economies. Neither of these assumptions exactly conforms to the historical experience; they are made only to simplify the story. Hence, if there were no important differences in the propensities of capitalists to reinvest profits in their firms, the model predicts that areas that for some reason started off with low wages would, all other things being equal, undergo an Industrial Revolution at a faster rate.

The growing-up model is different from the standard growth models in that it is a disequilibrium model. Its dynamics depend on the coexistence and interaction of the "old" and the "new" technologies. It applies to the European as well as to non-European contexts (Pomeranz, 1998). The traditional sector, which produces the same good (or a close substitute) as the factories, can continue its existence for a long time after the process has started, because the modern sector is still too small to supplant it altogether. As long as the two sectors coexist, the modern sector earns a "quasi-rent," a disequilibrium payment that will eventually disappear when the manual industries have disappeared. Through continuous reinvestment, this rent in its turn provides the fuel for further growth of the modern sector. This model suggests that high-wage economies would have lower profits, lower rates of accumulation, and thus a slower and later Industrial Revolution. The model also predicts that wages in the modern sector would grow slowly if at all as long as the traditional sector remained a large employer. In this sense, the model is comparable to the labor surplus models of Lewis and Fei-Ranis popular in the 1970s. In contrast to those models, however, the "growing-up" model does not have to make any *deus* *ex machina* assumptions about the wage rate. The modern sector is small enough relative to the rest of the economy to take the wage parametrically (that is, the sector can hire workers at a wage rate that is unaffected by the number of workers it employs) and hence the lower the wage set in the traditional economy, the faster the modern sector could grow.[82]

The second approach to the role of labor in the Industrial Revolution, most closely associated with the work of H. J. Habakkuk (1962), maintains that inventive activity in the nineteenth century was mostly labor saving and that scarce labor thus stimulated waves of technical change. This approach is based on a somewhat peculiar view of technological change, namely, that innovation was a process of choice between more or less equivalent alternatives, similar to the choice made by a firm facing an isoquant. Although Habakkuk was primarily concerned with the period after 1830, his approach extends naturally to the British Industrial Revolution. High wages and labor-supply constraints in Britain, in this view, stimulated the demand for labor-saving technological change (Landes, 1969, pp. 57-60). Yet the application of the model, at second glance, is fraught with difficulties. To start with, it is far from obvious that technological change during the Industrial Revolution was, on balance, more labor saving than capital saving: Von Tunzelmann (1981, p. 165) believes that, on balance, it was about neutral. MacLeod, examining the declared motives of eighteenth-century English patentees, found that only 3.7 percent of them stated that "labor saving" was the main purpose of the invention. Further, it always makes good sense to "search" for labor-saving innovations, even in low-wage economies, because labor always costs something, and thus innovations that reduce labor inputs increase profits. This is especially the case if, as was likely true in low-wage areas, production was highly labor intensive. In addition, as David (1975) has pointed out, the Habakkuk view implies that technological change is "localized" (that is, occurs in close proximity to the techniques actually used rather than over the entire range of feasible techniques). For the Habakkuk view to prevail, such localized technological change has to be stronger in the capital-intensive range of techniques than in the labor-intensive range. In that case a high-wage economy will naturally have chosen a less labor-intensive technique and will experience faster technological progress as the unintended by-product of this choice. Finally, although British wages were higher than on the Continent, some scholars (e.g., Flinn, 1966, p. 31) have insisted that the growth of population met the increased demand for labor and that there is no evidence for any labor scarcity.

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[82]The logic of the model has since been adopted by other writers interested in other regions. In his work on the cotton industry in the South, Gavin Wright (1987) explicitly points to the South's emerging as a "low-wage region in a high-wage economy" as the main reason for the South's success in establishing a successful textile industry after 1880 (pp. 76, 124). Much in Wright's analysis of the postbellum southern industry has analogues in the growing-up model, especially his assumptions about labor and capital markets.

Economists have examined the assumptions on which the two alternative theses are based and have made them explicit.[83] The seemingly obvious test of the low-wage hypothesis is that the areas of Britain that industrialized earliest should, at the outset, have had lower wages. The relevant variable here is *nominal* wages, because we are interested in the cost of labor, not in the standard of living. In this regard, at least, the hypothesis seems confirmed. The areas of Britain that industrialized first, the northwest counties of Lancashire and the northern midlands, had lower wages than the South in the middle of the eighteenth century (Hunt, 1986). During the Industrial Revolution this relation was reversed, so that by 1867 the industrial areas had higher wages. Yet although this pattern is repeated in a few other instances, such as the Low Countries (Mokyr, 1976a), it is far from universal. Ireland, by all accounts, had low wages but did not industrialize. Britain itself had higher wages than most of the European continent.

It must be, then, that the *ceteris paribus* clause in this model did not always hold. For instance, it is important to ask *why* labor was cheaper in one place than in another. If it was purely a matter of opportunity cost, as the growing-up model assumes, the implication that capital accumulation is faster follows. But if labor was cheaper in one place because it was less productive, the model encounters a difficulty. If wages were low because labor quality and thus productivity were low, the advantages of cheap labor vanish. Contemporary authors were aware of this. Arthur Young, writing in the late 1780s, notes that "labour is generally *in reality* the cheapest where it is nominally the dearest" (Young, 1790, p. 311).[84] In a paper dealing with a later period, Gregory Clark (1987a) shows the strong correlation of labor productivity with nominal wages, even using the same technology and capital intensity. Clark shows that the high labor cost in the Atlantic economies (always excluding Ireland) was essentially offset by the higher productivity of workers in high-wage countries. Clark concludes that "real labor costs turn out to be as high as those in Britain in most of the other countries except for the very low wage competitors in Asia. The per worker wage rate tells us very little about the true cost of labor" (p. 11).

Labor could vary in its productivity for a variety of reasons. Differences in education seem to have made relatively little difference in productivity, as Mitch's

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[83] The literature stimulated by Habakkuk's pathbreaking book is quite extensive. See, for example, Landes (1965); Rosenberg (1963, 1967); Saul (1970); Temin (1973). Most of the debate is carried out in the context of Anglo-American differences, with Britain, interestingly enough, considered the *low-wage* economy (though in the period of the Industrial Revolution it would, relative to the rest of Europe, be the high-wage economy). A comparison between Britain and the Continent during the Industrial Revolution would be worthwhile, but so far this has not been attempted seriously.

[84] For a survey of contemporary thinking about the "cheap labor is dear labor" issue, see Coats (1958).

chapter below points out. Another interpretation emphasizes diet: Low-wage workers could not buy enough food, and their malnourishment caused their work to be of low quality. Poorly paid workers could be poorly fed workers. The connection between caloric intake and energy output of workers is well known. Workers on an insufficient diet do not necessarily get sick or die, their entire metabolism simply slows down, to the detriment of their productivity (Scrimshaw, 1983).[85] The dietary model is attractive, because the so-called efficiency-wage model seems quite promising in explaining the failure of premodern, poor societies to develop. Unfortunately, the evidence produced thus far to support this promising idea is ambiguous.[86] Although recent scholarship has concluded that French workers were, in all likelihood, worse fed than British workers (Fogel, 1989, 1991), the same is not true for the Irish, whose potato diets assured them of a plentiful if somewhat monotonous fare (Mokyr, 1983).

Productivity, however, depended on more than nutrition. Adam Smith thought that "the wages of labour are the encouragement of industry, which like every other quality, improves in proportion to the encouragement it receives. A plentiful subsistence increases the bodily strength of the laborer . . . where wages are high, accordingly, we shall always find the workmen more active, diligent, and expeditious, than where they are low." (Smith, [1776] 1976, p. 91). What Smith seems to be describing, however, is an upward sloping supply curve of labor, which makes people work *more* if the wage is higher. The question is, however, what makes people work *better* or harder per unit of time?

Recent thinking about the efficiency-wage hypothesis has shown that labor productivity can depend on the real wage paid to workers in a variety of ways. A simple model of this type is the shirking model, in which it is expensive to monitor the effort the worker puts in. High wages are a mechanism by which the employer extracts more effort from the worker, because a worker caught shirking risks being fired and losing his or her high-paying job. High wages could also increase productivity through reduced turnover. Another model derives a correlation between productivity and wages through an "adverse selection" mechanism: the worst-quality workers agree to work for less (see Akerlof and Yellen, 1986; Weiss, 1990).[87]

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[85]For examples, see Allen (1992b); Freudenberger and Cummins (1976); Ó Gráda (1992); and Scrimshaw (1983).

[86]The inadequacy of British diets both before and during the Industrial Revolution has been recently documented by Shammas (1990, pp. 134-148). For a dissenting view that maintains that eighteenth-century diets were by and large sufficient, see Riley (1991).

[87]A recent and pioneering attempt to apply this class of models to the Lancashire cotton industry in the first half of the nineteenth century is made by Huberman (1992).

Differences in productivity in the early stages of the Industrial Revolution were also likely to arise from differences in workers' attitudes. Concentrating large numbers of workers (of both sexes) in one room and subjecting them to discipline, regularity, and the increasing monotony of the more advanced technique were some of the most difficult problems encountered by early factory masters (Thompson, 1967). Cheap labor was no advantage unless it could be effectively transplanted from the traditional to the modern sector. Sidney Pollard (1965, chap. 5) has pointed to the central paradox of the labor-supply question during the Industrial Revolution: "The lack of employment opportunities . . . existing simultaneously with a labor shortage is in part explained by the fact that the worker was averse to taking up the *type* of employment being offered, and the employer was unwilling to tolerate the habits of work which the men seeking work desired" (p. 196).

How a rural, mostly self-employed labor force was enticed to work in mostly urban mills is one of the most interesting questions in the debate on the Industrial Revolution, and yet it has not received much attention in the literature produced by economists. One answer given, ironically, by the social historian Perkin is purely economic: "By and large, it was the prospect of higher wages which was the most effective means of overcoming the natural dislike for the monotony and quasi-imprisonment of the factory" (Perkin, 1969, p. 130). Pollard (1965) and Thompson (1967) suggest a variety of alternative ways in which the factory owners educated their workers in their own image, trying to imbue them with an ethic that made them more docile and diligent. Punctuality, respect for hierarchy, frugality, and temperance were the qualities that the value system tried to convey onto the younger generation. The factory owners used a combination of approaches; they relied first and foremost on semi-compulsory apprenticed child labor from workhouses ("pauper apprentices") and on women driven out of their cottage industries by the rapid mechanization of spinning. Gradually, they created a more balanced labor force by a combination of higher pay and social control. An example is provided by the research of Huberman (1986; 1991; 1992; 1996). Huberman points out that although in the pre-1800 period the labor market in Lancashire worked in the classical fashion, with flexible wages equating supply and demand, employers soon found that they needed more than a labor force that was available. They needed a labor force that was loyal, reliable, and motivated. To insure this they paid wages that soon became institutionalized as "fair wages" and lost their flexibility. The emergence of such wage rigidity in some industries meant that when demand fluctuated, the adjustments would take place through quantity adjustments: layoffs and short-time became commonplace.

Aside from the question of the productivity of labor, the wages the factory masters had to pay were determined by the other forms of employment open to the workers.[88] The opportunity cost of labor was determined by its productivity in the traditional sector, which still dominated the economy. Before 1850 the modern sector was still relatively small and thus close to a price taker in the labor market. But there was more to the traditional sector than agriculture.[89] At different times the domestic weavers, spinners, nailers, frame knitters, and cutlers, whether they were in the putting-out system or working on their own account, found their economic position threatened as the Industrial Revolution progressed. As the factories gradually expanded, they drove down the price of substitutes and thus the incomes earned by the outworkers and independent artisans in the traditional sector. Slowly at first, but with increasing force, domestic industry was ineluctably transformed by the Industrial Revolution. The modern sector, in a sense, created its own labor force.

Ultimately, then, domestic industry was doomed, but during the long transition its relation with the modern sector was complex (Ogilvie and Cerman, 1996). In many industries, mechanized factory production and manual home production were complementary, and although the type of industrial commodities produced in domestic industry changed substantially, the outwork system showed a remarkable tenacity in its struggle with the factory system. The mechanization of spinning led to a short-lived boom in domestic weaving, and some domestic industries, like tailoring, frame knitting, nail making, and boot and shoe production, remained domestic until well into the second half of the nineteenth century (Bythell, 1978). In the woolen industry, Hudson (1983, pp. 135-136) notes a symbiosis between the company mills and the workshops attached to domestic clothiers' homes. Mass production needed special-purpose machinery that could not itself be mass-produced. Rising incomes maintained an upmarket demand for custom-made, high-quality products, such as handmade clocks, fine linen, and custom-made furniture (Sabel and Zeitlin, 1985). The wage rate in these "sweated trades" was often very low. Since domestic industry was open to anybody, it set the lower bound on the opportunity cost of labor.

To be sure, the wage rate in the modern sector was higher and rose faster than that in the traditional sector. Still, the wages earned were not entirely independent of each other, unless the labor market was subject to extreme segmentation. Thus the growing modern sector produced its own labor force, and although real wages

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[88]The exact alternative is not clearly defined, which makes the notion of opportunity costs, so beloved by economists, somewhat tricky. By 1815, for instance, emigration has to be considered as a possible factor in setting a floor to the real wage. In Ireland this lower bound was reached by more people than in Britain, and thus Irish migration already became quite substantial before 1850.

[89]This point is still not fully appreciated by many economic historians. Thus O'Brien (1996) interprets differences in long-term economic trends between France and Britain in terms of the ability of the agricultural sector to release labor.

ultimately could not be kept down, the slowness of their rise in spite of rapidly increasing labor productivity has to be seen as part of the interaction of the modern and the traditional sectors.[90] This sheds an important light on the role of cottage industry prior to the Industrial Revolution. The preexistence of cottage industries was neither a necessary nor a sufficient condition for the modernization of industry (Coleman, 1983). But as Jones (1968) and others note, cottage industries catering to distant markets tended to arise in areas where agriculture paid low wages. These were not necessarily areas in which agriculture was backward and poor. In the English Midlands the heavy soils were not suitable to the new husbandry based on mixed farming and stall-fed livestock. This left these regions at a comparative disadvantage in agricultural production, and they increasingly specialized in manufactured goods. In other areas cottage industries emerged because high population to land ratios reduced average farm size. Much of this specialization crystallized, as was argued in a seminal paper by Jones (1968) and as has recently been confirmed by Kussmaul (1990), in the second half of the seventeenth century. This specialization provided the historical background to the supplies of labor that ended up in the factories a century later.

Although the transition from domestic industry to modern industry was at times difficult and varied from region to region, the conclusion that the former was a positive factor in the establishment of the latter has been widely accepted.[91] A number of factors have been proposed as possible explanations of this nexus, including the supply of entrepreneurship by the domestic system, the preexistence of skills, a material culture more directed at the market and technological bottlenecks within the domestic sector that may have led to further innovations through their function as "focusing devices." Some of these, like the flying shuttle, increased the productivity of domestic workers. Others, like the power loom, were feasible only in a factory setting. Here, too, more detailed research is needed. Yet it is clear that the role of domestic industry in supplying a more abundant and elastically supplied labor force, especially from women and children, should become an essential part of this research program.

Above all, it is misleading to view the Industrial Revolution solely as the transition of labor from rural and agricultural occupations to urban and industrial occupations. The critical event was not the creation of an industrial labor force as such but its transformation. In the domestic system workers toiled at their homes, but they were usually only part-time industrial workers, cultivating small plots and hiring themselves out as seasonal wage workers during harvest time. In the modern

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[90] See Mokyr (1976b) for an algebraic representation of this interaction and some further implications.

[91] For some reflections, see Clarkson (1985, pp. 28-38); Kriedte (1981, especially pp. 152-154); Mokyr (1976b, pp. 377-379). A recent summary is provided by Hudson (1996).

sector the existence of a large fixed investment implied that part-time operation was uneconomical. The factory worker lost his or her freedom to allocate time between labor and leisure as he or she wished: either the worker wholly submitted to the requirements of the employers and worked the days and hours prescribed by the mill owner or he or she did not work. Although cottage industry in various forms supplied a portion of the labor force needed by the Industrial Revolution (Bythell, 1969, pp. 257-263; Redford, [1926] 1964, p. 41), there were workers, especially in rural areas, who hesitated to make the great leap. Only their sons and daughters realized the hopelessness of the situation and moved (Lyons, 1989; Redford, [1926] 1964, p. 186). Women and children constituted an essential part of the industrial labor force (Berg, 1994).[92] Goldstone (1996) has recently argued that the supply of cheap female labor aged between puberty and their (relatively late) marriage age provided Britain with a strategic advantage in terms of labor supply, especially in cotton mills. Precisely because young women could be paid very low wages (given their low opportunity costs), Goldstone notes, they often turned out to be a cheaper source of labor than adult men. Berg and Hudson (1992, p. 36) also point out that domestic industries released large reserves of cheap and skilled child and female labor leading to high proportions of women and children in the mills. Women fell outside the standard craft apprenticeship system, meaning that few of them could consider themselves skilled artisans, but obviously they were a cheaper source of labor. Moreover, factories needed dexterity, docility, and discipline, and women and children provided these disproportionately before 1850.[93] Children and women's work cushioned the disruptive effects that technological change had on the earnings and employment of married men and allowed the losing economic groups to adjust. Above all, however, youngsters had more malleable skills and personalities and could be conditioned. In 1835 Andrew Ure argued, no doubt with some exaggeration, that "even in the present day . . . it is found to be nearly impossible to convert persons past the age of puberty, whether drawn from rural or handicraft occupations, into useful factory hands."

What about immigration? In Ireland, where the collapse of domestic industry in the 1830s was swift and brutal, migration of workers to England and Scotland was widespread (Collins, 1981), and these immigrants were an important supplement to the British labor force during the Industrial Revolution (Redford, [1926] 1964, pp. 132-164). As Pollard (1978, p. 113) puts it, "[Irish emigrants] were, in many

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[92] For a recent summary of existing literature on women in the labor force, see Honeyman and Goodman (1991), Bythell (1993), Berg (1994), and Horrell and Humphries (1995a). Recent work on child labor includes Nardinelli (1990), Horrell and Humphries (1995b), and Tuttle (1997).

[93] Berg and Hudson also argue that these age and gender differentials influenced innovation and were influenced by it, but persuasive evidence for this interaction is thus far lacking.

aspects, the mobile shock troops of the Industrial Revolution, whose role consisted in allowing the key areas to grow without distorting the labor market unduly." Williamson (1986, 1990a) has questioned the importance of the Irish workers to British industrialization. His calculations assume that the Irish formed an unskilled labor force and that agriculture was more unskilled-labor-intensive than manufacturing. Consequently, he finds that the main impact of Irish immigration was on agricultural output. Although most Irish ended up in rural areas, Williamson points out that their arrival slowed down the migration of British rural workers from the countryside to the cities. It is possible to argue that further disaggregation could overturn this conclusion in some industries. The Irish tended to concentrate in certain sectors and industries, such as mining, construction, and transportation, and in these industries their labor may well have contributed more than Williamson's aggregate computations suggest.[94] On the whole, however, there is little reason to doubt Williamson's conclusion, simply because the number of Irish in Britain, though considerable, was simply not large enough to make a decisive impact on Britain's economy. On average, Irish workers were unskilled and few of them swelled the ranks of the entrepreneurial classes. In 1841 it is estimated that there were 830,000 "effective Irish" in Britain, of whom 415,000 were Irish born and the rest descendants of Irish emigrants. If we assume that all the emigrants and half of the others were in the labor force, the Irish would have added 620,000 workers, which out of a total occupied labor force of about 6.8 million would have amounted to about 9 percent; not a trivial addition, but not large enough to change the parameters dramatically.

Besides the question of the reallocation of labor from the traditional to the modern sector, there are many other loose ends to consider in the area of labor supply during the Industrial Revolution. One question is what happened to participation rates. We know little about these rates for the eighteenth century, and scholars have used population growth rates as a proxy for labor force growth rates. After 1801 the census provides figures for total occupied population that allow us to compute some very approximate participation rates. For what it is worth, the participation rate shows an initial decline from 1801 to 1831 and then rises until 1851 (Deane and Cole, 1969, pp. 8, 143). These changes are small and reflect

[94]Williamson (1990a, p. 160) points out in a long footnote that if regional and industrial labor markets had been highly segmented, the Irish emigrants might have had a larger impact than his estimates imply, because they entered through urban gates and thus at first, at least, would have depressed industrial wages more, thus raising profits and stimulating capital accumulation. Irish immigrants were highly concentrated in a small number of specific urban occupations (Lees, 1979).

primarily the changing age structure and measurement error.[95] The concept of a participation rate is in any case something of an anachronism, because it requires a worker to be able to declare himself or herself as either being in the labor force or not. In a society in which a large if declining percentage of the labor force was economically active in households (farms or workshops), this is not an unequivocal measure even if we had better data. It is thought that the Industrial Revolution mobilized a large part of its labor force by turning part-time workers into full-time workers and transferring workers from "disguised unemployment" to regular work (Pollard, 1978). What is clear is that in many of the more dynamic industries of the Industrial Revolution, including cotton, female and child labor predominated quantitatively in the early stages of the Industrial Revolution. What we do not know with enough precision is how many of these workers were drawn into the labor force altogether and how many were already active either in domestic manufacturing or agriculture. At some point after 1815 this reliance on non-adult-male labor began to decline, and by 1860 it was significantly lower than at the start of the century (Horrell and Humphries, 1995a, 1995b). As the cottage industries had gone into decline, participation rates, however defined, must have been significantly lower already by the middle of the nineteenth century than at their peak during the heyday of the Industrial Revolution.

On the whole, both cottage industries and factories practiced a division of labor between the genders. In the cottage industries women performed mostly low-skill jobs, left most of the skilled work to men, and were excluded from apprenticeship. Arguments that view the division of labor between genders as the outcome of attempts by men to maintain a social status in the family and the community have frequently been made, but hard evidence that would discriminate between this hypothesis and alternative ways of explaining the data is lacking so far. In some occupations, such as mule tending, women were excluded. Some technologies may have been especially designed to use female labor, and the evidence from the Birmingham toy trade suggests that women could even operate relatively heavy machinery (Berg, 1994, pp. 144- 156).

Changes in the amount of labor performed per worker were possibly of greater importance to the labor supply than changes in participation rates. It is also a variable for which aggregate information is the hardest to come by. Labor input per worker could increase by lengthening the laboring day and the number of days worked and by reducing involuntary unemployment. Did workers in 1830 work more than in 1760? This view is certainly part of the conventional wisdom. Pollard (1978, p. 162) has no doubt that this is the main explanation for the rise of family income before 1850. Jones (1974, pp. 116-117) and Freudenberger (1974, pp. 307-

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[95] Occupied population as a percentage of total population went from 44.86 percent in 1801 to 43.90 percent in 1831 and then rose to 45.28 percent in 1841 and 46.46 percent in 1851.

320) are equally certain that workers toiled longer hours during the Industrial Revolution.

De Vries's idea of an "industrious revolution," presented earlier in this chapter, also implies an increase in labor input per worker and less leisure. This account sounds plausible enough, but can it be sustained by evidence? Unfortunately, we do not know with any precision how many hours an average laborer worked in Britain before the Industrial Revolution in either agricultural or nonagricultural occupations. Some progress has been made in recent years, however. In a recent important paper, Voth (1998) has tapped a new source of data to examine what happened to the length of the work-year in England in the latter part of the eighteenth century. His finding from analyzing the Old Bailey court records is that a considerable increase occurred in the number of hours worked in London between 1760 and 1800, perhaps as much as a third. The reason for this increased diligence is in part a decline in real wages, which spurred workers to work harder to maintain their living standards and buy the new consumer goods that were appearing on the market at this time. If this finding is confirmed, an increase in labor hours per worker would explain what little growth of output per capita there was. Yet London was not the same as England, and in a paper based on two types of rural workers (threshers and sawyers), Clark and Van Der Werff (1997) conclude that work effort had changed little in England since the late Middle Ages. The sources and methodologies used by these two papers are quite different, and the findings may not be totally irreconcilable. As of now, however, they clearly depict very different pictures of changes in the rate of participation in formal labor markets. In the cottage industries the distinctions between work, leisure, and social life were not as sharply drawn as in our own time. Most accounts maintain that workers started the week slowly, then picked up steam as the weekend approached, often working very long days toward the end of the week (Hopkins, 1982, p. 61; Thompson, 1967, p. 50). The decline of "St. Monday" (Reid, 1976) could therefore have been less of a net increase in the working week than a rearrangement to distribute the effort more evenly.[96]

McKendrick (1974, p. 163) derides the idea that longer hours explain higher incomes, labeling it a "prelapsarian myth of the golden past," and asserts that premodern labor was "grinding toil," as bad as factory labor but less remunerative. It is indeed easy to document many cases of long and hard hours in cottage industries; days of fourteen to sixteen hours were common (Rule, 1983, pp. 57-61). It is not clear, however, how common such long days were and to what extent they did not make up for the customary long weekend or for usually low wage rates. Much of our information here comes from nineteenth-century sources, which may

[96]Voth's data (1998) show that in the 1750s Monday was a typical day off, not much different from Sunday, whereas by 1800 it had become a day that was not statistically different from other weekdays. This finding suggests that the decline of St. Monday was firmly located in the second half of the eighteenth century.

be biased because economic conditions were deteriorating for cottage industry. If labor supply curves were downward sloping or backward bending, as is widely believed, the declining wage rates in domestic industry in the nineteenth century led to longer working days. Still, the idyllic picture drawn by some (Medick, 1981; Thompson, 1967) of working conditions in domestic industry in the eighteenth century is probably unrepresentative of premodern labor conditions. The most recent attempt to answer the question is provided by Gregory Clark (1994), who concludes from the fact that weekly earnings rose faster than piece rates that workers in factories indeed worked longer.

One reason the comparison of factory and domestic work may yield misleading conclusions is that the representative industry discussed for the nineteenth century is often the textile industry, and especially cotton spinning. The laboring days of workers in the cotton mills before the mid-1840s were long, even by the standards of the time. The labor day was extended by as much as two hours and the number of working days per week was set at six, resulting in working weeks of seventy-six hours, compared to about sixty hours in most other industries. Official holidays were few, and unofficial leaves had to be made up with overtime (Bienefeld, 1972, pp. 30, 49). In mines, too, labor hours were increased during the Industrial Revolution. These extensions were, however, far from universal. A study of Birmingham and the Black Country has found no evidence of longer working hours, and the traditional workday of twelve hours including meals remained the most common practice (Hopkins, 1982). Only a small proportion of the labor force was actually employed in satanic mills or mines by 1840; most British workers were still employed in agriculture, domestic service, construction, and small workshops where work habits changed little.

Another possible source of labor was the reduction of involuntary unemployment. On the one hand, the amplitude of business fluctuations gradually increased after 1760, and as slumps became more severe, short-time and layoffs became more common. On the other hand, improved transportation and communication allowed a more efficient organization of the economy, thus reducing the problem of seasonal unemployment. The notion of large reserves of unemployed workers awaiting a rise in labor demand is much in dispute, although O'Brien and Engerman (1991) and others rely on contemporary opinion that Keynesian unemployment was a serious problem in the eighteenth century.[97] The evidence, however, is not wholly persuasive (Blaug, 1968, p. 15). Of similar interest is the question to what extent modernization reduced the multitudes of unemployables: vagrants, beggars, prostitutes, and other persons on the fringes of

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[97] Keynes himself, in a famous statement, expressed the view that the writings of the mercantilists suggest that "there has been a chronic tendency throughout human history for the propensity to save to be stronger than the propensity to invest. The weakness for the inducement to invest has been at all times the key to the economic problem" (Keynes, 1936, p. 108).

society. A glance at Henry Mayhew's description of London in the late 1840s suffices to warn us that the Industrial Revolution did not eliminate these people and possibly caused an increase in their proportion of the British population during the period.

Capital

The role of capital is not less controversial than that of labor. Recent work has concentrated on three issues. The first is the question of how capital markets worked during the Industrial Revolution and what effect they had on the process of technological change and accumulation. The other two issues have been raised primarily by economists, namely, the speed at which capital accumulated and the changes in its composition (circulating vs. fixed). On the issue of how capital markets worked, Larry Neal (1990) has pointed out that in the eighteenth century there was in fact an international capital market that funneled funds between different countries and that was clearly integrated, except when disrupted by war. There are also signs that British internal markets improved their operations during the Industrial Revolution: Buchinsky and Polak (1993) find that after 1770 there was a growing correlation between London interest rates and Yorkshire property transactions, though they find no sign of integration before that. Hoppit (1986) has reached a similar conclusion based on bankruptcy statistics. Although it would be premature to speak of a well-integrated capital market by 1800, clearly the capital market was becoming larger, more efficient, and more "modern" during the years of the Industrial Revolution.

Whereas the role of capital markets in the British economy as a whole is indisputable, their importance to the Industrial Revolution, properly speaking, is more difficult to assess. The biggest borrowers in Europe in this period were governments that needed to finance deficits. The demand for credit also came from merchants with bills to be discounted, entrepreneurs active in canal and road construction, landowners in need of funds for the purpose of enclosure and other improvements, and construction interests. There was some inevitable overlap between these borrowers and what we would consider the "modern sector," but it was relatively small. Moreover, the smallness of the modern sector relative to the entire British economy meant that its demand for loanable funds did not loom large relative to the needs of the economy. Dealing with the supply of savings on an aggregate level, however, is even more misleading than an aggregate analysis of labor markets. Such an analysis assumes the existence of *a* capital market that allocated funds to all competing users, presumably on the basis of an expected rate of return and riskiness. Certain developments, especially the growth of transport networks, would have been slowed down considerably, and possibly aborted, had it not been for capital markets. As far as the manufacturing sector is concerned, however, matters are quite complex.

How did the Financial Revolution, which preceded the Industrial Revolution, affect it? The standard view of the interaction of "the two revolutions" has been that they had very little to do with each other. Postan argued in 1935 that "within industry almost every enterprise was restricted to its own supplies. The Industrial Revolution got under way while capital was not yet capable of moving between 'alternative employments'" (1935, p. 74). This view is now recognized as too simple: Financial markets were far more complex and subtle and their impact more pervasive than the earlier writers assumed. Yet there is little evidence that these financial markets were instrumental in helping modern industry more than vice versa.

Regarding the supply of capital, the most thorough work has been carried out by François Crouzet (1965, 1972, 1985b), complemented for the later period by Cottrell (1980). This work demonstrates that the capital needs of the modern sector during the Industrial Revolution were met from three sources. First were the internal sources in which the investor borrowed, so to speak, from himself using his private wealth (or that of his family) for start-up and plowing his profits back into the firm. Second, there were informal, or "personal," capital markets in which borrowers turned to friends, relatives, or partners for funds. Third, there was the formal capital market in which the borrower and the lender did not meet and in which attorneys, brokers, and eventually financial institutions (banks, insurance companies, stock markets) fulfilled their classic functions of intermediating between lenders and borrowers, concentrating information, and diversifying portfolios. The questions we must ask are, how important were these three forms of finance in the Industrial Revolution? and how can we explain this complex and seemingly inefficient mechanism? Students of the Industrial Revolution agree that most industrial fixed capital originated from internal finance. Crouzet (1965) concludes that "the capital which made possible the creation of large scale 'factory' industries came . . . mainly from industry itself . . . the simple answer to this question how industrial expansion was financed is the overwhelming predominance of self-finance" (pp. 172, 188). In a later paper he qualified this conclusion somewhat but insisted that it remained "broadly valid" (Crouzet, 1972, p. 44; Crouzet, 1985b, pp. 147-148).[98]

In the early stages of the Industrial Revolution, the fixed-cost requirements to set up a minimum-sized firm were modest and could be financed from profits accumulated at the artisan level (Crouzet, 1965, p. 165; Pollard, 1964). Plow-back then provided a regular, almost automatic mechanism by which profits augmented the capital stock. As technology became more sophisticated after 1830, the initial capital outlays increased, and it became increasingly difficult to rely on internal finance to start a business. For railroads this was of course out of the question. For existing industrial firms, retained profits usually remained central to the

[98]For similar statements, see, for example, Mathias (1969, p. 149) and Cameron (1967, p. 39). Cameron goes so far as to assert that "the rate of growth of capital is therefore a general guide to the rate of profit," though he concedes that alternative investment opportunities for the factory master could upset that correlation.

accumulation of capital. Even in a world in which firms relied exclusively on retained earnings, an intersectoral capital market could function. Individuals who made their fortunes in commerce, real estate, or the slave trade could use these funds to diversify into manufacturing. There were examples of merchant princes entering modern manufacturing, such as the case of Kirkman Finlay, an overseas merchant who entered cotton spinning between 1798 and 1806, and the Wilson brothers who established the Wilsontown ironworks. On the whole, however, these cases were exceptional (Crouzet, 1985a, pp. 99-100).

The second source of funds, the informal capital market, can easily be illustrated with examples, but it is not known how important this form of finance was relative to other sources. Postan (1935) argues that capital was still a very personal thing, which most people wanted to keep under control. If one lent it out, it was only to an intimate acquaintance or to the government. Even partnerships, which were frequently resorted to in order to raise capital while avoiding the costly process of forming a joint-stock company, were usually closely tied to family firms. The taking in of strangers as sleeping partners merely for the sake of getting access to their wealth was relatively rare at first (Heaton, 1937, p. 89). This caution slowly dissipated during the Industrial Revolution, but active partners often bought out the others, and the advantages of partnership were as much in the division of labor as in the opportunity to raise credit. Many of the most famous characters in the Industrial Revolution had to resort to personal connections to mobilize funds. Richard Arkwright got his first loan from a politician friend, and James Watt borrowed funds from, among others, his friend and mentor, Dr. Joseph Black. Although the phenomenon was thus widespread (Crouzet, 1965, p. 184; Mathias, 1969, pp. 150, 162-163), personal loans are as much of interest as a symptom of how the system operated as for the fact that they were a major channel through which funds were mobilized. Crouzet points out how exclusive and selective these personalized credit markets were: To have access to these informal networks one needed to be a member of them and be "known and well thought of in the local community" (1985a, p. 96). The market for capital can thus be seen once again to have depended on the market for information.

As the modern sector grew, intrasectoral flows of funds between firms became more important, especially flows occurring within the same industry. Insofar as these mechanisms only reallocated funds among different industries in the modern sector, the upper bound that the rate of profit imposed on the rate of growth of that sector did not disappear. Instead of constraining the individual firm, the supply of funds now constrained the modern sector as a whole. Although there were important exceptions, by and large the modern sector pulled itself up by its own bootstraps.

The third mechanism for obtaining capital, the formal credit market, operated primarily through merchants, wholesalers, and country banks.[99] The consensus on the role of the banks is that, with some exceptions, they rarely figured in the financing of long-term investment. Their importance was mainly in satisfying the need for working capital, primarily by discounting short-term bills and providing overdrafts (Flinn, 1966, p. 53; Pressnell, 1956, p. 326). Pollard has made a case for the reexamination of the importance of the banks on these grounds. Given that banks provided much short-term credit, firms short of capital could use all their internal funds on fixed investment (Crouzet, 1965, p. 193; Pollard, 1964, p. 155). Pollard, however, assumes that fixed capital grew at a rate much lower than implied by Feinstein's figures. His own earlier estimates imply a rate of growth of fixed capital of 2.4 percent per annum between 1770 and 1815, whereas Feinstein's fixed capital estimates grew at 4.2 percent per annum in the same period (Feinstein, 1978, p. 74). In manufacturing and trade the discrepancy is larger; according to Feinstein, gross fixed capital formation grew between 1770 and 1815 at 6 percent per annum, as opposed to Pollard's 3.4 percent (Feinstein, 1978, p. 74; see also Feinstein and Pollard, 1988). Thus financial constraints on capital accumulation may have been more stringent than Pollard originally presumed because he underestimated the needs. A study of the cotton industry suggests that the ratio of fixed to total capital in the mechanized spinning industry may have exceeded 50 percent (Richardson, 1989). Moreover, substituting fixed capital for circulating capital may have been less simple than he thought, because as industrial output increased, the demand for circulating capital grew as well. Feinstein shows that between 1760 and 1830 fixed capital in industry and commerce increased from 5 percent of domestic reproducible capital to 18 percent, whereas circulating capital in industry and commerce increased from 6 percent to 7 percent in the same period. Was the activity of banks enough to finance an increase of 164 percent in working capital over seventy years? Cottrell (1980, p. 33) concludes cautiously that there are indications that industrial growth before 1870 may have been blunted by shortages of circulating capital. Honeyman (1983, pp. 167-168) maintains that small businessmen found banks unreliable, and that even for circulating capital, kinship and friendship groups were preferred. The difficulty in obtaining funds led to the selective weeding out of the industry of entrepreneurs of humble origins who did not have access to these informal sources of funding and thus failed to survive crises during which working capital was hard to obtain. From a different point of view, Cottrell speculates that short-lived firms had better access to formal capital markets than firms that

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[99] Joint-stock companies were exceedingly rare, in part due to the Bubble Act that mandated they could only be incorporated through Parliament, but also because promoters defrauded their stockholders, and managers usually mismanaged the companies (Pollard, [1965] 1968, p. 25; Robb, 1992). There were a few exceptions, such as the British Cast Plate Glass Co., established in 1773, which imitated the French Royal St. Gobain manufactory, although it remained a private company.

survived. The sharp fluctuations in the financial sector dragged into bankruptcy many industrial firms, and this effect may result in an underestimate of the importance of the plow-back of profit as a source of investment, because the firms that left records would tend to be *less* dependent on external finance (Cottrell, 1980, pp. 35, 253-255). Yet it remains to be seen whether enough evidence can be produced to jeopardize the widely held belief in the predominance of internal financing in this period.

Thus capital scarcity and biases in the capital markets slowed down the rate of accumulation and the speed of industrial growth. The reliance on plowed-back profits for investment clearly meant a slower growth rate compared to a world in which borrowers could access savings regardless of its source. In spite of these qualifications, it is still true that if credit markets had not existed at all, the accumulation of fixed capital would have been somewhat slower, though the rehabilitation of the banking system does not go far enough to allot it a truly strategic role in the Industrial Revolution.[100]

To what extent can economic theory explain the picture of the plow-back of retained profits and self-finance? The limited willingness of commercial banks to finance long-run projects is understandable. Banks needed their assets in liquid form to be able to pay depositors on demand since there was no lender of last resort.[101] This constraint was a result of the nature of commercial banks. Investment banks and other forms of financial intermediaries did not have to maintain liquid portfolios. Why such institutions were relatively unimportant in Britain (compared to Continental countries) is still an unanswered question. Yet the reliance on internal finance during the Industrial Revolution is not surprising. Firms tend to prefer internal over external finance, even though economic theory suggests that the reliance on retained profits is inefficient. In the post-World War II United States, too, firms have obtained over 70 percent of their finance from internal funds (MacKie-Mason, 1990).[102] The use of internal funds during the Industrial Revolution is thus not a historical anomaly.

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[100]See Cameron (1967) and Crouzet (1972). It is possible that further work on the asset composition of British banks may revise this conclusion for the period after 1844, which might explain Good's (1973) finding that the ratio of banking assets to GNP was relatively high in Britain compared to later industrializers (see also Collins, 1983).

[101]The necessity for banks to preserve liquidity was made into a virtue by the so-called real-bills doctrine, which stipulated that if banks confined themselves to short-term, self-liquidating loans (such as discounting commercial bills), the price level would remain stable. Regardless of whether there was any merit in this theory in the short run, in the long run it confined commercial banks to supplying, almost exclusively, circulating capital.

[102]Calomiris and Hubbard (1991), studying the years 1936-1937 found that firms were in fact willing to pay a substantial tax on their invested retained earning rather than go outside for funding.

Economic theory has in recent years provided substantial insights into the reason for the persistent "imperfection" of capital markets. In earlier theoretical work such as Hicks (1946) and Scitovsky (1971), firms were perceived to face upward-sloping supply curves of loanable funds, which would be consistent with internal financing. These models were not pursued, however, and their microeconomic foundations were never quite made clear. More recently, though, with developments in the economics of information, our understanding of the economic processes involved has improved.

For instance, Mayshar (1983b) argues that it is not risk per se that causes real-world capital markets to deviate from the theoretical constructs but divergences of opinions among potential lenders with respect to the rate of return. Such divergences would of course gradually disappear in a stationary world in which no new information was created. But in a world of rapid technological change, shifting demand patterns, and a changing political environment, divergences were not only possible but in fact inevitable. Thus rapidly changing conditions during the Industrial Revolution effectively precluded the efficient operation of capital markets. Mayshar pictures savers as forming concentric circles around the entrepreneur, with his own funds in the center and next those of the people closest to him (friends and relatives), who were the sources most likely to lend to him. The farther one gets from the center, the more the expectations tend to diverge from the entrepreneur and the higher the rate of interest that he has to pay. Similarly, Stiglitz and Weiss (1981) show how the informational asymmetry between lender and borrower can lead to adverse selection in which a rise in the interest rate causes the borrowers with the safest projects to drop out of the market. This means that interest rates will generally not clear the credit market and credit rationing may be quite general. Under credit rationing, many entrepreneurs found themselves rationed out of the market and hence had no choice but to rely on self-finance. Whether potential borrowers preferred to rely on their own resources or whether they were rationed out of the credit market, the experience of the capital market during the Industrial Revolution clearly shows the applicability of these models.

The assumption of asymmetric information seems especially apposite. Because much of the technology was new, the information gap between entrepreneur and saver or banker was even greater than in our own time. A banker in 1790 would have much less information about the economic potential of a mule or a modern calico printer than he would about the quality of an investment in, say, a flour mill or a fence around enclosed land. Many firms, as well as their technologies, were new and had no reputations of creditworthiness. Young, growing firms tend to be the most severely credit-rationed. Consequently, some of them ended up establishing their own banks (Crouzet, 1985a, p. 19).

On the questions of the size and composition of the capital stock, our knowledge has been increased by Feinstein (1978) and Feinstein and Pollard (1988), who, with their collaborators, have created a data base to investigate the quantitative aspects of capital formation in this period. Feinstein's data permit us to test two hypotheses that have dominated the literature on capital in the Industrial Revolution. One hypothesis is the Lewis-Rostow claim that the investment ratio doubled during the Industrial Revolution. The other is the Hicks-Ranis-Fei view that the truly fundamental change was the shift from predominantly circulating to fixed capital. Both hypotheses have been criticized vigorously, and we are now in a position to assess these criticisms.[103] Feinstein's data imply that the dismissal of Rostow's hypothesis was premature. The ratio of total gross investment as a proportion of GDP rose from 8 percent in 1761-1770 to 14 percent in 1791-1800, and after a temporary setback in 1801-1811 returned to 14 percent for the half-century after 1811 (Feinstein, 1978, p. 91). More recently, Crafts (1983a) has revised Feinstein's estimates, criticizing in particular the price deflators that Feinstein used. Crafts's figures still show a doubling of the investment ratio from 5.7 percent in 1760 to 11.7 percent in 1830; this reproduces the Lewis-Rostow prediction of its doubling with dead accuracy, though somewhat more gradually than Rostow thought, which is hardly surprising in view of the highly aggregative nature of this ratio.

As to the Hicks-Ranis-Fei hypothesis, fixed capital rose from 30 percent of national wealth to 50 percent between 1760 and 1860, while the corresponding ratio of circulating capital declined mildly from 11 percent to below 10 percent. In industry and commerce the ratio of total circulating to total fixed capital fell from 1.2 in 1760 to .39 in 1830 and .30 in 1860 (Feinstein, 1978, p. 88). The absolute amount of circulating capital increased as well during the Industrial Revolution, but its growth was dwarfed by the rise in fixed capital. In this sense, then, the Hicks-Ranis-Fei view is corroborated. The economic reasons for the change in the composition of capital are rather obvious. Improved transportation, communications, and distribution reduced the need to hold large inventories of raw materials, fuel, and finished products. There are well-understood economies of scale in the holding of inventories and cash, so that it is clear that larger firms needed less circulating capital per unit of output than domestic industry. This may have been partially offset by the requirements of new inputs, such as fuel and spare parts. A second factor in the relative decline of circulating capital is the decline of output prices due to productivity growth, which reduced the value of goods in progress and raw materials relative to that of buildings and equipment.

The importance of capital in the Industrial Revolution was not identical to the importance of the Industrial Revolution in capital formation. In current prices, in the early days of the Industrial Revolution (1761-1770), manufacturing and mining accounted for only 12.5 percent of gross domestic fixed capital formation. Although the annual investment in industry increased almost 15-fold between 1760 and 1830, the share of mining and manufacturing in 1831-1840 was only 21.1 percent (Feinstein, 1988a, p. 429). Yet without capital the modern sector would not have

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[103] The Rostow hypothesis was criticized, among others, by Habakkuk and Deane (1962). For a critique of the importance of fixed capital in the Industrial Revolution, see Pollard (1964).

been able to grow. The unit setup costs of firms was rising steadily, and the number of firms, as the industry expanded, was growing rapidly. Consequently, in iron, cotton, steam, and transport gross capital formation increased by huge factors, and the stock of capital mushroomed to unprecedented levels. In mining, for example, gross capital formation in 1830 was 15.6 higher than in 1760 (Pollard, 1988, p. 63). In cotton the *stock* of capital in 1788 was only 12 percent of its level in 1833 (Chapman and Butt, 1988, pp. 124-125). All the same, fixed capital in cotton in 1833 was only 1.5 percent of the national stock of reproducible fixed assets. The smallness of the share of the modern industries in the economy is in and of itself not sufficient to show, however, that they were not capital constrained.

Oddly enough, the total factor productivity estimates seemingly imply that capital formation was a comparatively minor factor in the macroeconomics of the Industrial Revolution. The most recent figures produced by Crafts and Harley (1992) suggest that capital accounted for about half of the aggregate growth of the economy between 1760 and 1830. Because capital grew at about the same rate as output and only slightly faster than labor, however, it contributed little to growth proper. In the period 1760-1800 the rise in the capital to labor ratio and in total productivity each accounted for half the rise in per capita income; after 1800 the contributions fall to 30 percent for capital and 70 percent for productivity. Feinstein, who was the first to notice this, rejects this interpretation and points to the importance of capital as the "carrier" of technical progress. Insofar as capital and technological progress were complementary, the arithmetic of total factor productivity estimates are misleading, since these computations assume that the contributions of capital and productivity are additive and independent. A more accurate estimation would try to take into account the interaction between the two.

How important to the course of the Industrial Revolution were the failings of the capital market? Crouzet has concluded that "the eighteenth century capital market seems, to twentieth century eyes, badly organized, but the creators of modern industry do not seem to have suffered too much from its imperfection. . . . English industry, compared with that of the Continent, seems to have overflowed with capital" (Crouzet, 1965, pp. 187-188). This conclusion may be ripe for some reexamination. First, while the comparison with the Continent is probably accurate on the whole, there were important exceptions (Mokyr, 1975). On the Continent, too, self-finance was the norm, and it is not quite clear whether Britain was much better supplied with capital than, say, Belgium. Moreover, it seems inescapable that the Industrial Revolution in Britain would have occurred faster and more efficiently if financial constraints had been less stringent. Given that the modern sector as a whole was at first rather small compared with the rest of the economy, the capital market's imperfection meant that from the outset the rate of profit set a ceiling on the rate of accumulation. The existence of *some* capital markets does not necessarily refute this argument. If these markets channeled savings from one firm to another in the modern sector, the constraint on the sector as a whole remained in force, and fixed capital had to grow by pulling itself up by the bootstraps. Postan put it well in his classic article: "By the beginning of the eighteenth century there were enough rich people in the country to finance an economic effort far in excess of the modest activities of the leaders of the Industrial Revolution. . . . What was inadequate was not the quantity of stored-up wealth but its behavior. The reservoirs of savings were full enough, but conduits to connect them to the wheels of industry were few and meager" (Postan, 1935, p.71).[104]

The Factory and the Modern Industrial Firm

The creation of the workplace, in which many workers were assembled together under one roof to jointly produce an output and were subject to discipline and coordination, has become one of the symbols of the Industrial Revolution. To some extent this is a myth: Some large factories did exist before 1750. The great silk mills in Derby and Stockport, the ironworks of Ambrose Crowley in Newcastle, and metalworks of John Taylor and Matthew Boulton employed many hundreds of workers before 1770. Yet such large plants were rare. Large capitalist enterprises were far more common, but they typically left most of the work to be carried out in workers' homes, and only a few stages of the product were completed in centralized sites. In wool, for example, a large employer like Samuel Hill in Yorkshire in the 1740s employed 1,500 workers, mostly in putting-out.

Part of the story of the Industrial Revolution is that these employees were brought to work in centralized plants, thus changing the nature of work and with it the basic functioning of the family and the household. Increasingly, households became specialized units designed for consumption only, whereas production was carried out in a firm, geographically divorced from the home and often subject to different rules and hierarchies. Why did this happen? Some economists, such as Oliver Williamson (1980), declare that by saving on transactions costs, factories were simply more efficient than cottage industries (whether putting-out or independent producers), and thus their rise was inexorable. Such a simplistic approach cannot possibly do justice to the historical reality (S.R.H. Jones, 1982; Szostak, 1989). After all, the domestic system survived for many centuries, and its demise was drawn out over a very long period. Its advantages were many: It kept families geographically intact, it was flexible and more adaptable to fluctuations in demand and supply, and it left the workers free to choose any point on the leisure-

[104]Crouzet's statement that the early factory masters "did not suffer" seems oddly incompatible with his own evidence. Two paragraphs below this statement, Crouzet cites the cases of two highly successful firms, the Walker brothers and McConnel and Kennedy, who paid themselves miserably low salaries in order to maximize the income available for plowing back (Crouzet, 1965, pp. 188-189). Some of the most famous inventors and entrepreneurs (Cartwright and John Roebuck immediately come to mind) foundered for lack of working capital, and Richard Arkwright's success is often attributed not to his technical skills but to his virtuoso ability to remain afloat in the treacherous currents of finance during the early stages of the Industrial Revolution.

income trade-off rather than forcing them into rigid work schedules and the discipline of the factories. Geographical centralization of production under one roof and the imposition of factory discipline did not always go hand in hand and need to be explained separately. If the Industrial Revolution, as it did, replaced a predominant domestic organization of manufacturing by one that was largely concentrated in specialized workplaces away from homes, it stands to reason that something changed in the economy that accentuated the advantages of centralized work places relative to the advantages of domestic production.

The most obvious candidate for the cause of such a shift is that the new technologies changed the optimal scale of the producing unit and introduced increasing returns where once there were constant returns. Some equipment could not be made in small models that fit into the living rooms of workers' cottages and thus required large plants: iron puddling furnaces and rollers, steam and water engines, silk-throwing mills, chemical and gas works -- all required relatively large production units. Heating, lighting, power supply, security, equipment maintenance, storage facilities, finance, and marketing were all activities in which scale economies were obviously the result of technical considerations. Long ago Usher wrote that "machinery made the factory a successful and general form of organization. . . . Its introduction ultimately forced the workman to accept the discipline of the factory" (Usher, 1920, p. 350). Landes (1986, p. 606) has recently restated this argument in unambiguous terms: "What made the factory successful in Britain was not the wish but the muscle: the machine and the engines. We do not have factories until these were available." Both would agree, of course, that factories without machinery were not only possible but actually existed; in the long run, however, their success depended on technology. Maxine Berg, who has argued forcefully for the viability of small-scale production until the 1830s and beyond, concludes that the transition to the factory system "proceeded at a much faster pace where it was combined with rapid power-using technological innovation" (1994, p. 207).

Others have rejected this position: Stephen Marglin (1974) set the tone, which was echoed by others as diverse as Berg (1980), Cohen (1981), and Szostak (1989, 1991). Their argument is that technological change was not necessary for the establishment of centralized workshops, which in fact preceded the great inventions of the last third of the eighteenth century. Berg (1994, p. 196-97), Hudson (1992, p. 28), and Szostak (1989, p. 345) point to industry after industry that established centralized workshops employing practically the same techniques as cottage industries: wool, pottery, metal trades, even handloom weaving and framework knitting. Rosenberg and Birdzell (1986, p. 186) feel that "more and more control would have devolved upon the factory master" had the steam engine and semi-automatic machinery never been invented. Marglin's own view is little more than a Marxist tale of woe according to which factories enabled employers to exercise more control over their workers and to squeeze more profits out of them. Technological progress in this interpretation tended to be a by-product of the intensification of social control. The fact that in many industries workshops preceded the emergence of new technologies does not prove, of course, that technological factors were unimportant in the development of the factory, only that they were not the *only* factors. The large workshop's occurrence may have preceded mechanization in many industries, but surely its ultimate triumph was a result of the growing advantage that new technologies bestowed on factories. Marglin's argument is further undermined by the fact that from the point of view of employer control, the distinction between factory and domestic workers is not as sharp as is usually supposed. Many of those workshops were not factories in the traditional sense of the word -- they imposed no discipline, observed no tight schedules or regulations, and paid workers by the piece. The employer hardly cared if the worker worked hard or not, if he or she arrived at work on time, took Mondays off, or drank on the job. These workshops were purely "rent and charges" kinds of places and thus were quite different from Marglin's oppressive and tightly controlled mills (Clark, 1994). On the other side of the equation, social control gradually invaded the domestic economy during the years of the Industrial Revolution. A series of acts passed between 1777 and 1790 permitted employers to enter the workers' premises to inspect their operations, ostensibly to curb embezzlement. Unwin (1924, p. 35) concludes that by this time "there was not much left of the independence of the small master, except the choice of hours."

All the same, while technology clearly played a role, it cannot account for the entire phenomenon. What needs to be explained is not why factories were superior to domestic industry, because they clearly were not under all circumstances and not in all products and processes. Manufacturing was sufficiently diverse and variable to let the degree of plant-level economies of scale vary all over the map, both over time and over a cross section at a specific moment. A more cogent complement to the technological determinism of Landes is provided by economists such as Millward (1981), Szostak (1991), Clark (1994), and Langlois (1995). Some of this reasoning derives from the economics of information. The organization of production by wage labor under any system depends on information that the employer can amass on the effort the worker puts in. Paying workers a piece rate — uniformly practiced in putting-out industries — solves this problem if the employer has no difficulty assessing the quality of the final product and if there are no cross effects between workers' productivities (so that the effort of one worker does not affect the output of another). In the domestic system, employers faced a double problem: Workers could increase their earnings by cutting corners on quality and finish, and the embezzlement of raw materials (which usually belonged to the capitalist) was a widespread complaint (Styles, 1983). The problem of embezzlement, like quality control, was one of information costs; measuring the precise quantities of yarn supplied to a weaver and comparing those with the final output was itself costly, and had to be correlated against normal losses of raw material during the process of production, which the employer did not observe directly. As the division of labor became tighter and the final products more complex, the decentralized division of labor practiced in the putting-out system became increasingly costly. Factories, too, usually paid piece rates, but the monitoring of quality was much easier because the employer could inspect the inputs and the production process as well as the output. Factories also reduced embezzlement and capital costs incurred by workers' negligence. In addition, in factories there was the option of paying workers a time rate, which would be necessary if the marginal product of labor was hard to assess or beyond the worker's control. The problem is, however, that embezzlement and quality control were age-old problems and it is far from clear what changed around 1750 to tip the balance of advantages gradually in the favor of factories.

Moreover, economists have increasingly realized that all systems in which one individual works for another — that is, all capitalist systems — are subject to an agency problem: The employer (or "principal") has to design the incentive system to ensure that his worker ("agent") operates as much as possible to maximize the profits of the enterprise. Workers usually care little for the profits of capitalists as such and employers have to somehow manipulate them to behave as if they do. Factories dealt with the agency problem by imposing direct monitoring of labor by supervisory personnel overseeing the efforts put in by the workers, their use of raw materials, and the care with which they carried out their tasks. Thus the main advantage of factories in this view was that it permitted the employer to ascertain whether fluctuations in output were due to the worker's effort or to a circumstance beyond his or her control. The incentives set up by the factory system to solve the agency problem were largely negative: A negligent or dishonest worker could be fined, dismissed, or even punished physically (Pollard, [1965] 1968, p. 222).

Some specific examples of this general problem have been proposed as explanations for the rise of the factory system. Szostak (1989, 1991) argues, for example, that the employer used centralized workshops to produce standardized goods of more uniform quality, because more integrated markets and changes in distribution methods in the eighteenth century required these changes (see also Styles, 1992). Szostak links the rise of standardization to the growing integration of the British market for manufactures, which he attributes to improvements in transportation. Standardization and uniformity demanded a special kind of quality control, which required continuous supervision and thus factories. Alternatively, as new technology was embodied in more sophisticated and expensive capital goods, the employers became more concerned with the workers' treatment of these machines, because negligence and sabotage became increasingly costly to the firm. Factories may also have induced innovation directly. Some writers, beginning with Adam Smith, strongly believe that a finer division of labor leads to mechanization because the division of labor splits production up into simpler parts, and simple processes are easier to mechanize. Moreover, in the domestic system the entrepreneur rarely observed actual physical production as it was occurring. Once he actually observed the interaction of his labor, his equipment, and his materials, as happens in centralized workplaces, he was more likely to come up with ideas how to save all three than the absentee putting-out merchant manufacturer. A variation on this theme is provided by Langlois (1995) who argues that an increase in demand led to an increase in volume, which made standardization possible. Langlois notes that a sufficiently large number of products makes it worthwhile to invest into a standardized way to mass-produce using jigs or dies which represent fixed costs. With higher fixed costs, argues Langlois, workers' shirking becomes more costly and it becomes more imperative for the firm to monitor the workers' efforts and thus process supervision eventually becomes economical.[105] While ingenious, this explanation might be viewed to depend on an autonomous increase in the demand for manufactures after 1750 as a deus ex machina, which, as we have seen, is not devoid of difficulties. Perhaps a combination of growing population and improvement in transportation à la Szostak will provide some of the primum movens here. It is more likely, however, that such an increase is indeed not independent of changes in technology. After all, major changes in technology in one industry will be perceived as shifts *of* the demand curves in a complementary industry: a sharp decline in the price of cotton yarn resulting from technological change in spinning will lead to an increase in the demand for weaving on one side and carding on the other.

A third explanation of the rise of the factory has to do with the division of labor and is logically independent of the technological and informational interpretations (though in reality the three were closely intertwined). Dividing labor into small tasks carried out by specialists has a number of advantages. The first, stressed by Adam Smith, assumes that all workers are the same at first but that the division of labor enhances productivity because specialized workers get better at what they do through learning and experience, because time is saved in moving work between workers rather than workers between different tasks, because of the simplification of tasks allowing more routinization, and because of the putative effect that the division of labor has on invention. Routine and repetitive work tends to be less skill-intensive, cheaper, and possibly more productive. The second advantage, emphasized by Charles Babbage, assumes that workers differ inherently in their abilities and that the division of labor maximizes productive efficiency because workers can specialize in those tasks in which they have a comparative advantage. Specialization assures that workers are not asked to carry out tasks for which they are overqualified (which would be wasteful) or underqualified (leading to costly errors). A third advantage, stressed by Becker and Murphy (1992), notes that there are limits on the total amount each worker can know, and so labor is subdivided if the total amount of relevant knowledge is larger than what a worker can learn in a

[105] As Langlois realizes, his theory only holds if the worker's marginal product is costly to measure; as long as marginal products are cheap to measure, fixed costs will not lead to factory discipline. Properly speaking, therefore, Langlois's theory belongs to the information-based theories of factory work.

reasonable time span. The Becker and Murphy view would still predict a division of labor even if all workers were identical and no learning on the job took place.

The advantages of the division of labor have been challenged by Marglin (1974), but when all is said and done his attack on one of the oldest and most widely believed tenets of economics has been beaten back without causing serious damage. Landes (1986) points out that Marglin fails altogether to deal with the Babbage argument and that his "evidence" for the falseness of Adam Smith's famous pinmaking example is based on a misreading of the literature. Experience and learning by doing are simple facts of life. Perhaps in a pin factory or an automobile assembly plant, the simplest jobs can be learned quickly and little more is learned after a few weeks, but in most skilled jobs, years of apprenticeship are required. Whether the difference between me and my dentist is due to innate abilities or to training, in neither case is it likely that productivity would be enhanced by us swapping jobs.

Yet the division of labor did not require factories. Domestic industries practiced it, and a large part of the function of the merchant entrepreneur was to shuttle goods in process from one cottage to another. In activities where technical factors made domestic production infeasible, such as fulling and calico printing, the manufacturer carried out the work in a "mill." Domestic industry did the rest. Decentralized specialization had advantages, but it also had costs, such as the transport costs of goods in process and the transactions costs of measuring and counting output at each stage.[106] As the division of labor became finer, the final products more complex, and the equipment more expensive, the costs of geographical dispersion rose, and firms switched from decentralized to centralized production.[107] The biggest advantage of rural domestic industries was their ability to switch labor back and forth from industrial to agricultural activities and thus exploit off-season labor. In effect, this means that outwork had access to cheaper labor than factories. It has been argued that the long survival of domestic producers in Britain, as opposed to the swift victory of the factory in the United States, was due to the differences in the seasonality of the demand for labor as British agriculture relied more on grains with its highly seasonal labor demand pattern (Sokoloff and Dollar, 1997). As the short-term mobility of labor increased with transport improvements, this advantage gradually diminished. The long-term decline in transportation costs tipped the

[106]S.R.H. Jones (1982, p. 126) minimizes the importance of transportation costs, but he fails to take into account that the geographical dispersion of work involved more costs than just the direct transport costs. Bad weather, for example, could totally disrupt the supply of raw materials and goods in process and thus wreak havoc on production and delivery schedules.

[107]A detailed summary of the advantages of the two systems can be found in Szostak (1989).

balance in favor of the factory in other ways.[108] The rise of factories and changes in technology during the Industrial Revolution can be seen as a prime example of co-evolution. Knowledge and business organization are both subject to autonomous innovation and selection processes, but also affect each other. Technological progress led to lower prices and better or new products, which increased demand and thus expanded the market; an increase in the extent of the market further led to a finer division of labor which increased productivity further and led to changes in industrial organization. This kind of positive feedback process serves as a good illustration how the Industrial Revolution can be seen as a self-reinforcing process.

All the same, the transition process took a long time and was far from monotonic. For many industries, factories did not mean the instant end of domestic industry but its temporary expansion, because when some activities were moved to mills, there was increased demand for the output of those production stages that remained for the time being in workers' homes. In some industries growth occurred through the expansion of the domestic industries.[109] Berg (1994, p. 274) points out that in the Birmingham metal trades, the industry's growth brought about a bifurcation in which large firms, some of which worked through factories, and domestic producers expanded at the expense of "substantial artisans." The final collapse of domestic industry did not come until the middle of the nineteenth century. In the long run, however, the triumph of the factory was as complete as it was inevitable.

The large industrial mills, emerging during the Industrial Revolution, created new management problems not hitherto encountered. Before the large factories there had been large firms, but these firms had been primarily commercial in purpose, and rarely operated facilities larger than warehouses or merchant ships. Agricultural estates, too, were often managed on a large scale but did not require the degree of coordination and direct control needed in manufacturing. The factories created a demand for a new skill hitherto largely confined to military commanders and sea captains, the need to organize, coordinate, and "run" substantial groups of people engaged in complex tasks in which the action of each individual affected those of all others and the nature of the outcome. They created new problems of labor and information management, including cost accounting, internal communication within the firm, coordination with other firms in the industry, negotiations with external suppliers and workers, and technical information management such as staying up-to-date on new industrial practices and other innovations.

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[108] Declining transport costs basically led to an increased division of labor, and while a rough division of labor was consistent with putting-out, as the division became finer the advantage moved toward factories. More integrated markets also led to a greater demand for standardized products and for quickly changing national fashions; here, too, factories had an advantage. See Szostak (1989, p. 348).

[109] An example is the career of Peter Stubs, a Lancashire filemaker, whose business was largely based on a network of outworkers run from the inn he kept in Warrington until he built his first workshops nearby in 1802.

Managerial ability was a form of human capital, and by all accounts it was not in generous supply in the British economy during the Industrial Revolution. There was not much separation between management and ownership: the entrepreneur usually was in charge. If anyone else was to be delegated any power, they would be in most cases be partners, a status awarded mostly to sons of partners or investors, although in a few cases technical expertise helped too.[110] But how did he carry out his day-to-day tasks of coordination and management? The managerial revolution, in which large corporate structures were managed according to reasonably well-understood principles of the flows of information and authority that could be taught and diffused was still many decades away, and the "visible hand" as Alfred Chandler termed it was still rather shaky in the early stages of modern manufacturing.[111] Much of it was improvised, learned by experience, stumbled into. Often, serious and costly managerial errors were made, especially due to primitive accounting.[112] Most managers, including Watt and Wedgwood, carried out their own correspondence and much of the clerical work. Indeed, in retrospect it is surprising that things worked out as well as they did. Some scholars have cited Josiah Wedgwood as an example of a successful and modern innovator of management techniques, though Hudson (1992) rightly points out that the great potter from Burslem was anything but a typical entrepreneur.

To some extent, factory masters coped with management problems by subcontracting. Pollard, in his classic and unique work on the subject, points out

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[110]Some of the famous partnerships of the Industrial Revolution were based on close personal trust and complementarity between the two partners allowing a division of labor that often was the key to success. The most famous partnership was that of Matthew Boulton and James Watt, the classical wedding of business acumen and technical genius. At the Scottish Carron works, a somewhat similar symbiosis emerged between Samuel Garbett. and John Roebuck. At the Etruria pottery works, Josiah Wedgwood's partner, Thomas Bentley, took care of sales, with Wedgwood dealing mostly with the production side.

[111]Alfred Chandler (1977, p. 70) has argued that early cotton mills in the United States were "run by merchants for merchants." He shows that apart from a few exceptional firms, the first examples of modern management occur in railroads where the needs for control and coordination were especially acute and that the management techniques of the modern corporation originated in the railroad industry. Things in Britain were not much different and Berg (1994, p. 207) concludes that the Chandler thesis can provide no exclusive model of the development of eighteenth and nineteenth century industry.

[112]A good example is the otherwise well-run firm of Boulton and Watt, where nobody had a clue as to which departments were earning or losing money, and the Scottish Carron iron company in which one manager estimated a profit of £10,500 when in fact £10,000 had been lost (Pollard [1965], 1968, p. 267). Overproduction and other errors of judgment occurred so often that one thoughtful economic historians sighs that they "can hardly fail to diminish any estimates of the commercial acumen of the cotton entrepreneurs" (Payne, 1978, p. 189).

that subcontracting, a remnant of the domestic system, survived into the factory age "if not as a method of management, at least as a method of evading management" (Pollard [1965] (1968), p. 52). By subcontracting, entrepreneurs could shift the risk around, make others responsible for their mistakes, and reduce overhead costs. But specialization and comparative advantage were important too. Master mechanics and builders came to the factories to install, maintain, and repair equipment on their own time, with their own tools, accompanied by their own paid assistants and carried out the job according to their own judgment and taste. Coal, cloth, and cotton yarn were produced using this system.[113] Technologically complex tasks were farmed out to mechanical or civil "consulting engineers" whose status as independent consultants crystallized in the last third of the nineteenth century. William Lazonick (1991, p. 140) has extended this thesis by pointing out that on the shop floor itself many of the functions that eventually were to be carried out by management through a hierarchical structure of foremen and supervisors were still carried out in the first half of the nineteenth century by a "labor aristocracy" of skilled, well-organized set of operatives. These operatives exerted a fair amount of independent discretion over both the laborers and the equipment under their control even if formally the entrepreneur owned the capital and employed the workers.

Subcontracting or "out-sourcing" as it is called today is neither inefficient nor a sign of "incomplete development" but was a rational result of specialization. In a world of costly and asymmetric information it often makes mores sense for a firm to hire an outsider to carry out a certain activity rather than do it by itself. All the same, there may have been cases in which subcontracting occurred largely because supervising a large number of people and activities was difficult in a age before large-scale modern management. Especially in coal-mining this may have been a problem and that sector was almost entirely run on a subcontracting basis. Subcontracting also relieved the firm from the need of computing complicated payrolls and by definition farmed out much of the labor supervision to lower levels.

The importance of the factory as a social institution can hardly be overestimated. The divorce between household and workplace imposed substantial costs on the industrial worker, from the psychic costs of having to witness family members supervised and monitored by others to the very real costs of the time spent on commuting (Smelser, 1959). The introduction of discipline and order into the lives of workers was another dramatic novelty. Until the Industrial Revolution discipline was largely a family matter. Industrial workers, whether they were independent artisans or part of a putting-out system, rarely encountered the phenomenon. Even on board merchant ships discipline could only be enforced by means of harsh penalties. The transition was not sharp; many factory owners hired whole families

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[113]In 1833, half the child workers employed in cotton spinning were employed by the mills, the rest worked for other operatives (ibid., p. 58).

and used the family as a tool to enforce discipline.[114] Yet workers detested the mills and resisted discipline, and employers were often desperately looking for solutions to the stubborn problems of absenteeism, drunkenness, sloppiness, and unruliness. "The concept of industrial discipline was new, and called for as much innovation as the technical inventions of the age," writes Pollard ([1965] 1968, p. 217). Firms designed incentives to bring about the discipline, but they also preferred to hire women and children, who were believed to be more docile.

The advantages of introducing worker discipline were not identical to those realized by the factory system as such, as the two were not always coincidental. The gains of discipline have traditionally been regarded as the advantages of coordination. Factories required coordination between different activities of the laborers, as well as between labor and capital. Equipment such as steam engines, overhead costs such as heating, lighting, and fuel, and maintenance and supervisory personnel were fixed costs in the short run, and so if workers were absent or lazy there was costly waste involved. Above all, employers needed workers to be punctual.[115] Discipline was also necessary, however, to maintain quality standards, to avoid embezzlement, to prevent fights between workers, and to deliver goods in time. The equipment handled by workers was expensive, so that errors could be very costly for the capitalist. Industrial and mining accidents due to workers' negligence could be expensive and led to strictly enforced rules. Discipline, by regulating and equalizing the amount of time and effort supplied per worker, also saved on hiring costs (as workers were made more uniform) and reduced the variance of labor input and thus of output. Discipline, as a substitute for monitoring, saved on costs as it internalized into the worker's behavior the objective function of the firm. To be sure, it can be argued that some of the costs of the absence of discipline could be overcome by holding larger inventories and by adjusting hiring practices to absenteeism (Clark, 1994). But apparently such alternatives were expensive and the advantages of discipline were such that most of the famous entrepreneurs of the time, including Josiah Wedgwood, Richard Arkwright, Samuel Oldknow, and Matthew Boulton struggled with the problem. Clark's argument that discipline was a means to extract a greater effort from workers and could be viewed as advantageous to them if it raised their income is interesting but does not contradict the more technical advantages of discipline (Clark, 1994).[116]

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[114] For instance, Robert Peel's factory in Bury employed 136 workers in 1802, of whom 85 belonged to 26 families (Smelser, 1959, p. 185).

[115] Employers reserved their harshest fines for latecomers, whereas the prize for good (probably docile) workers, not surprisingly, was a clock (Landes, 1983, p. 229).

[116] Clark's view of factory discipline is tantamount to an "Alcoholics Anonymous" view of workers in which they willingly commit themselves to a system that coerces them to work harder (and thus eventually earn more), than they would if left to themselves. As Langlois notes, this is comparable to the teams of bargemen in pre-Revolutionary China who

Finally, it seems plausible that the "authority relations," to use Williamson's (1980) term, that came to dominate interactions between capitalists and employees in factories were instrumental in overcoming resistance to technological progress. In the extreme case, the employer not only controlled labor, inventories, and fixed capital but could also choose the technique of production by himself. Outworkers tended to be at the forefront of resistance to new technologies out of fear that labor-saving machinery would reduce the demand for their labor (Calhoun, 1982). Authority and discipline might have reduced, at least for a while, the ability of labor to resist technological progress. The factory, however, did not solve the problem of resistance altogether; unions eventually undermined the ability of the capitalist to exploit the most advanced techniques. Collective action by workers imposed an effective limit on the "authority" exercised by capitalists. Workers' associations tried to ban some new techniques altogether or tried to appropriate the entire productivity gains in terms of higher piece wages, thus destroying the incentive to innovate. On the other hand, such strikes often led to technological advances aimed specifically at crippling strikes (Bruland, 1982; Rosenberg, 1976, pp. 118-119).[117] On balance, it is hard to know whether the decentralization of the putting-out industry, with its obvious potential of "divide and rule," was less conducive to technological change than factories -- yet this dimension has been altogether missed by scholars absorbed by static efficiency gains and transactions costs.

The Consequences: The Standard-of-Living Debate

The standard-of-living debate concerns what happened to living standards during the Industrial Revolution. It is one of the most lively yet most inconclusive debates in the entire Industrial Revolution literature. The discussion has been complicated in part because it became intertwined with political and ideological elements, the "optimist" school largely finding its supporters among the conservatives, the "pessimist" school mostly drawing upon socialist and left-leaning scholars. The philosophical question whether industrial society has been a positive development in human history reaches beyond the boundaries of economic history. What should have been a purely quantitative debate about numbers and deflators has divided scholars deeply on lines that correlate strongly with ideological positions. Those

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allegedly hired an overseer to whip them. In standard neoclassical models such behavior can only be understood if the utility function has a very unusual non-concave shape (so that local maximization does not lead to a global optimum) or if there were strong interdependencies between workers' productivities, so that each worker would only work hard if he or she knew that discipline would make other workers work just as hard. The latter explanation seems by far more plausible but oddly enough seems to be rejected by Clark.

[117] The most famous example of an invention triggered by a strike was that of the self-acting mule, invented in 1825 by Richard Roberts at the prompting of Manchester manufacturers plagued by a strike of mule operators.

like E. P. Thompson and E. J. Hobsbawm, who have regarded industrial capitalism as enslaving and alienating, have tried to round off their position by arguing that it was also immiserizing. Those like T. S. Ashton and R. M. Hartwell, who are sympathetic to bourgeois capitalism and the achievements of free-market societies, have insisted that industrialism was liberating as well as enriching. Some of this ideological baggage seems to have been shed in the past decade, but scholarly opinion has remained divided.

Beyond that, however, there is a certain ambiguity regarding the terms on which the debate is being conducted. This ambiguity has been explained well by Hartwell and Engerman (1975) and further refined by Von Tunzelmann (1985). Three logically separate debates can be distinguished:

1. The factual debate, which is concerned with what actually happened in Britain between 1760 and 1830 or 1850;
2. The counterfactual debate, which tries to identify the *net* effect of the Industrial Revolution on living standards. This question is logically equivalent to asking what would have happened to British living standards if everything had been the same in the period in question except for the technological changes of the Industrial Revolution; and
3. The hyper-counterfactual question, which asks whether, given everything that happened, it would have been possible to follow a set of economic policies that would have made economic welfare more than it actually was.

The answer to the *second* question, whether without the Industrial Revolution living standards would have held up as much, is eloquently answered in a famous passage by T.S. Ashton in the closing paragraph of his little book (1948, p. 111): "There are to-day in the plains of India and China men and women, plague-ridden and hungry, living lives little better . . . than those of the cattle that toil with them . . . Such Asiatic standards, and such unmechanized horrors, are the lot of those who increase their numbers without passing through an Industrial Revolution." A simple calculation confirms Ashton's eloquence: If we take the weights computed by Crafts for labor, capital, and natural resources, we can compute the change in income per capita that would have occurred due to the growth of population and its pressure on other resources in the absence of a productivity increase.

The counterfactual exercise is set up as follows: Assume that labor and resources changed at their actual historical rates and constrain productivity growth to zero. We have to make some assumptions about the counterfactual rate of capital accumulation. Three alternative assumptions will be employed: (1) the capital/labor ratio would have remained the same (requiring a savings ratio higher than the actual one), (2) the savings ratio would have remained at its historical level (that is, rising gradually), and (3) the savings ratio would have remained fixed because of the lack

TABLE 1.3 Counterfactual Decline in Income per Capita "Without" an Industrial Revolution (annual changes, in percentages)

Period	*Assumption 1*	*Assumption 2*[a]	*Assumption 3*[b]
1760-1800	0.045%	0.125%	0.185%
1800-1830	0.15%	0.41%	0.46%
Income in 1830 (1760=100)	93.9	84.1	80.9

[a] Assuming savings rates equal means for period.
[b] Assuming savings rates equal actual ones for first decade in the period.
Sources: Rates of change and shares from Crafts (1985a, p. 81). Savings rates from Feinstein (1981, p. 131). Cols. 2 and 3 required the estimation of capital/output ratio, computed from data in Mitchell (1988, p. 864) and Feinstein (1981, p. 136).

of suitable investment projects and the changing age structure of the population. Table 1.3 below presents the decline of income per capita implied.

The calculations in Table 1.3 actually understate the hypothetical decline in living standards slightly, because they do not take into account the war-related shocks and the string of poor harvests that plagued Great Britain. All the same, they indicate that in the absence of an Industrial Revolution, a rising population — as Malthus had predicted — would have encountered declining living standards.

Yet the picture is more complex than that. The closest we can get to a controlled experiment of an economy that had a history similar to Britain's in terms of population growth and supply shocks, but without the Industrial Revolution, is Ireland's. Ashton used the example of Ireland as a warning against what could happen without industrialization, but there are no such simple lessons to be learned from the Irish example. In fact, *average* living standards in prefamine Ireland did not decline much, even if there was a sharpening in the inequality of the distribution of income (Mokyr and Ó Gráda, 1988). The Great Famine, of course, was a hugely traumatic event that might well have been, if not averted, much mitigated had Ireland developed more of a modern sector. Had the potato blight not happened, however, our verdict regarding this example of a nonindustrializing country that experienced population growth might have been less harsh. Much of continental Europe also experienced population growth in this age, yet experienced neither an intensive rate of industrialization nor grievous famines. The best we can do is to conclude that Ireland may have been more *vulnerable* to accidental shocks because of the absence of an Industrial Revolution.

Turning to the *third* question, the hypercounterfactual one, modern research has clarified the issues and made an argument regarding the possibility that a more enlightened policy could have soothed the pains of industrialization. Two of the most prominent cliometricians have made, from quite different points of view, arguments to the effect that "the thesis of the Hammonds that a suitably enlightened government could have brought about higher living standards is vindicated" (Von Tunzelmann, 1985, p. 221). Von Tunzelmann employs dynamic programming to show that it was possible for the British economy to have attained the final values of 1850 and yet have supported a higher consumption level. In the actual experience, in this view, industry tended to be too capital intensive in its early stages. Of course, such an optimal path could only be achieved by the deliberate interference of the government into the price system. Such an interference would, however, have had further ramifications that Von Tunzelmann does not explore. His important insight that things *could* have been better than they were does not necessarily support an argument that government interference would have moved the economy's path from the actual to the optimal. In a slightly different vein, Jeffrey Williamson (1990a) argues that Britain underinvested in its overhead capital, especially in urban areas. The rate of return on social overhead capital was very high, but Williamson argues that an unfair and inefficient tax system led to what he calls "public sector failure." As a consequence, Britain's standard of living was affected by an imbalance between private and public goods. Overhead projects such as sewage, water supply, fire protection, public health, and other "urban amenities" were undersupplied. Williamson's thesis is similar to John Kenneth Galbraith's analysis of the U.S. economy in his famous *The Affluent Society*.

The first of the three debates, the actual standard-of-living debate, is the main battlefield on which scholars have argued for decades. A summary of the debates and some of the best-known papers can be found in Taylor (1975). By the mid-1970s the debate had reached something of an impasse in which neither camp had scored an all-out victory and most other scholars turned elsewhere with their interests. In the 1980s, however, a number of important contributions were made by economists. The debate has bifurcated into one concerning purely economic indicators and a more inclusive set of biological indicators. The most important contributions to the economic evidence in the 1980s were made by Feinstein and Crafts, who examined aggregate consumption, and by Lindert and Williamson's work on real wages.

The message that these economists drew from their evidence was remarkably consistent. Their conclusion is that living standards remained more or less unchanged between 1760 and 1820 and then accelerated rapidly between 1820 and 1850, so that by the middle of the century living standards had improved considerably for a number of decades. Feinstein (1981, p. 136) estimates that consumption per head in 1841-1850 was 72 percent higher than in 1811-1820, and Crafts estimates the rate of growth of per capita consumption between 1821 and 1851 at a lower but still respectable 45 percent (1985a, p. 95). Lindert and Williamson estimate real wage growth between 1819 and 1851 at 80 percent for all "blue collar workers" and 116 percent for "all workers" (1985a, p. 187). Crafts has revised these estimates as well, tempering but not overturning the new optimist message.

Yet these economic indicators failed to sweep the field. Although it is reasonable to conclude that standards of living did not *decline* for extended periods of time during the Industrial Revolution, the optimist victory declared by Lindert and Williamson has turned out to be premature. For one thing, the optimists have essentially conceded the entire period before 1820, thus focusing the debate on the three-and-a-half decades between the Battle of Waterloo and 1850. Yet even for this period, ambiguities remained. The aggregate consumption data produced by Feinstein and refined by Crafts are residuals, the difference between highly speculative data of output and investment. By construction, they cannot account for changes in income distribution, and Feinstein warned that "the basic estimates are far from reliable" and that they should be used with caution. To be sure, they were lent much reinforcement by the Lindert-Williamson wage data, but most scholars felt that more confirmation was needed to disperse remaining doubts.

Such confirmation has not been forthcoming. On closer inspection, the real wage data is found to suffer from a number of rather serious defects. One is that they cover only limited data points and that the choice of the end year (1851) by Lindert and Williamson is unfortunate, because that happened to be a year of unusually low prices.[118] The nominal wages fluctuated a lot but their secular movement was quite stationary in this period, so that the rise in real wages came almost exclusively from falling prices. Hence, the optimist conclusion is highly sensitive to the correct specification of the price deflator, and its deficiencies weaken the optimist finding even further.[119] When those two biases are corrected together, real wages rise so slowly that Huck (1992, chap. 2, p. 22) concludes that "1850, or some point in the 1840s, should be seen as the key turning point, as opposed to [the] 1820s."[120] Some of the new series produced are illustrated in Table 1.4.

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[118]The only price index covering the entire nineteenth century, the Rousseaux index, points to 1851 as the cheapest year before 1885, and the index is about 17 percent lower than the average for 1840-1850. Had Lindert and Williamson chosen 1847—an unusually expensive year—the rise in real wages would have been half of what they report.

[119]This point was made by Crafts (1985d), who points out that Lindert and Williamson use only cotton as their textile price and that cotton prices fell faster than wool. Correcting for these defects, he concludes that the index rose slower before 1820 and fell slower after 1820 than Lindert and Williamson estimate.

[120]Lindert and Williamson's nominal wage series shows virtual stability: In 1819 the wage of all "blue collar workers" was 101.84 (1851 = 100). The revised price index they themselves propose in response to Crafts's critique is 166.6 in 1819 and 141.4 in 1847 (1851 = 100). If we assume that nominal wages in 1847 and 1851 were the same, the implied rise in real wages between 1819 and 1847 is only .52 percent per year. To be sure, 1847 was a year of extreme dearth (although less so than 1839), but the rate of deflation proposed by Lindert and Williamson is sharper than that of Crafts.

TABLE 1.4 Nominal Wages, Real Wages, and Prices, 1787-1851 (Lindert and Williamson data)

	Nominal Wages (male adults)	*Real Wages (Blue Collar)*	*Real Wages (all)*	*Real Wages (blue Collar, revised)*	*Cost of Living, Revised*
1797	58.97	53.61	42.48	60.6[a]	146.3[b]
1805	75.87	51.73	40.64	—	177.5
1810	84.89	50.04	39.41	—	207.1
1815	85.30	58.15	46.71	—	164.3
1819	84.37	55.68	46.13	69.9	166.6
1827	83.11	69.25	58.99	79.5	131.9
1835	88.77	83.43	78.69	88.0	109.4
1851	100.00	100.00	100.00	100.00	100.0

[a] - 1781.
[b] - 1795.
Sources: Cols. 2-4: Williamson (1985, pp. 14, 17). Col. 5: Huck (1992, p. 48) Col. 6: Lindert and Williamson (1985b, p. 148).

Most wage data used by Lindert and Williamson pertain to adult male wages. The justification for this is explicitly stated by them (Lindert and Williamson 1985, p. 194) to be that wage rates of women and children advanced as fast as those of adult male farm laborers (which was considerable slower than that of "all workers"). This conclusion, they felt, will not be overthrown by correcting for changes in employment. Recent research, however, has been divided on this issue. Horrell and Humphries (1992) confirm Lindert and Williamson's findings about the rise of adult male real wages, though not without some misgivings.[121] Yet their work clearly shows that male and female earnings did not move all the time in the same direction. Robert Allen (1992b, pp. 255-256, 296), who has studied the fate of rural laborers, has emphasized the sharp decline in employment opportunities suggesting

[121] Horrell and Humphries add that secular income growth was interrupted by setbacks that tend to be underestimated by trend analysis based on a limited number of observations. They also note, as we have before, that the optimist findings depend crucially on price movements (they deflate their nominal series by Lindert and Williamson's "best guess" cost-of-living index), and insist that questions still hang over the speed by which price falls filtered down to the working class.

that family income fell relative to male earnings. As Allen's males hardly experienced much real income growth, he concludes that before 1850 real family income in rural Britain declined.

In a series of recent papers, Charles Feinstein has recalculated the real wage series de novo. His coverage is considerably wider and deeper than the Lindert and Williamson calculations and his deflators corrected many of the defects that mar the Lindert and Williamson figures.[122] Feinstein's finding are nothing short of devastating to Lindert and Williamson's newly discovered optimism. As table 1.5 shows, the increase of real earnings shows a much slower increase from the end of the Napoleonic wars till the mid 1840s, and accelerates in the third quarter of the nineteenth century, although this movement is still full of leaps and bounds. Feinstein himself summarizes his findings that "it was not until the mid-1840s that real earnings broke away and by the middle of the nineteenth century they had moved to a new level" (1997, p. 45).

A major defect in Lindert and Williamson's calculations and corrected by Feinstein as much as possible is that the wage data cover only selected workers. By definition it covers only those employed in the "formal" sector, that is, receiving a wage. Under labor market equilibrium conditions, this objection is unimportant because the wage rate in the formal labor market and the implicit wages earned by the self-employed would move together. But much of the argument for the "modernization" of industry suggests that while factory wages were rising, the real income of most domestic workers and independent artisans were falling (Lyons, 1989). This discrepancy constituted the market "signal" that the death bell was sounding for much of the traditional sector; for our present purpose it means that using formal wages as a proxy for "labor income" may be quite misleading. Furthermore, not all formal market wages are equally useful. The estimates of agricultural wages are especially fragile, and because agricultural workers still constituted over 20 percent of the labor force in 1841, their fate is quite important. The income of farm laborers was determined in part by other factors, such as access to commons and a growing seasonal unemployment, especially of women (Allen,1992a; Huck, 1992; Snell, 1985). Thus rising *wage rates* might well have been accompanied by falling *incomes* and *living standards* as growing redundancies in agriculture were not met by a rising demand for labor from nonagriculture, leading, in Allen's words, to "structural unemployment rather than increased manufactured output" (1992, p. 32). This complication was exacerbated by the decline in the custom of paying workers partly in kind, so that the rise in observed real wages could in part be spurious. Changes in nominal wages in agriculture

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[122] Among the many corrections introduced by Feinstein in his new cost of living index is the use of a chained indices rather than single based indices, the inclusion of a host of products omitted by Lindert and Williamson, the introduction of a new index for clothing and a replacement for Lindert and Williamson's very weak component for rent.

TABLE 1.5 Nominal Wages, Prices, and Real Wages, 1787-1872 (revised), Five year averages, 1778-82 = 100

Period	*Average full-time nominal earnings (Great Britain)*	*Cost of Living Index*	*Full employ-ment real earnings (Great Britain)*	*Real earnings adjusted for unemp-loyment (Great Britain)*	*Real earnings adjusted for unemp-loyment (United Kingdom)*
1770-72	92.6	97.4	95	96	97
1773-77	94.2	99.3	95	96	96
1778-82	100	100	100	100	100
1783-87	100.2	99.1	101	102	101
1788-92	107.4	101.4	106	106	105
1793-97	129.6	119.2	109	108	105
1798-1802	154.6	153.8	103	103	99
1803-07	173.5	151.1	115	114	109
1808-12	188.7	181.8	104	103	98
1813-17	185.9	178.6	105	102	97
1818-22	166.5	150.9	111	108	102
1823-27	156.6	139.2	113	111	104
1828-32	154.5	135.1	114	111	104
1833-37	155.9	126.2	124	121	113
1838-42	164.9	140.2	118	114	107
1843-47	167.8	133.4	126	124	118
1848-52	166.4	121.5	137	133	129
1853-57	189.3	146.6	129	129	128
1858-62	193.8	140.4	138	137	139
1863-67	207.3	144.7	143	143	146
1868-72	220.3	147.5	149	149	154

Source: All computed from Feinstein (1998) differed from a 13 percent fall in the east to a 10 percent rise in the southwest between 1824 and 1851.

Furthermore, rising real wages may have different interpretations. Even a firm believer in the efficiency of labor markets will concede that a rise in real wages may not be an indication of rising living standards if these rising real wages were a compensation for deteriorating labor conditions. If factory work and life in industrial towns and villages became more onerous, dangerous, or unpleasant, rising real wages would have the interpretation of a compensating differential. This effect has been measured in an ingenious paper by Brown (1990), who, like Lindert and Williamson, finds a significant rise in real wages yet concludes (pp. 612-613) that "there was virtually no improvement in living standards until at least the 1840s and perhaps the entire first half of the nineteenth century."

One way to try to circumvent these and similar problems is to look at microeconomic series for the consumption of a popular and income-elastic consumer good. Any such series would have the advantage that it would reflect living standards of both employed and self-employed workers and take into account both the level of income per capita and the inequality of its distribution. Food consumption series are shrouded in rather serious statistical uncertainty. Recent work on the problem, based on fragmentary and indirect data, seems to cast growing doubt that food consumption per capita was rising sharply during the Industrial Revolution.[123] More accurate are the series for domestic consumption of imported consumer goods, such as tobacco and sugar. After correcting for changes in prices and other effects, we can employ these data to infer what kind of income data (given estimated income and price elasticities) would have generated these consumption figures (Mokyr, 1988). The results lend no support to the view that living standards increased before the late 1840s. These findings have been corroborated recently by Horrell (1995) who has computed the change in consumption levels of the British working class from a sample of budget studies. She found (p. 580) that for working class families, real expenditures per household between 1787-96 and 1840-54 increased by about one half of a percentage point per annum, and that in fact they declined from the 1830s on, the period for which Lindert and Williamson argue that the highest rate of growth in real wages occurred.The dilemma is thus clear: If real incomes of the bulk of British workers increased, and yet they did not eat appreciably more, lived in crowded and unhealthy houses, drank no more sweetened tea, smoked no more pipes—where did this money go? The consumption of a few small items like hard soap and iron goods may well have increased, but many of the commodities on which we have data, such as bricks, coal, and glass, were as much investment as consumption goods and cannot be used

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[123] A detailed attempt to patch together existing data is carried out by Helling (1977), whose estimates of per capita grain and meat consumption show no improvement until the mid 1840s. Lindert (1992) argues that workers spent their incomes on rapidly expanding nonfood items. Clark, in his essay later in this book, concludes that given what happened to British agricultural output, sharply rising food consumption is unlikely.

readily for the standard-of-living debate. The only commodity that clearly figures prominently as an item in the improving budgets of workers is cotton textiles.[124]

An alternative approach to the standard-of-living problem is to look at biological indicators of the standard of living. It has long been recognized that indicators such as life expectancy and physical health are strongly correlated with economic living standards. Indeed, some economists (notably Sen, 1987) maintain that such physical measures *are* the standard of living. Thus in the absence of unambiguous economic measures of living standards, economic historians have increasingly turned to biological measures to try to test the hypothesis of rising economic welfare before 1850. On the whole, these measures have failed to support the optimist case. The broadest measure is the crude mortality rate, which declined more or less in the same period identified by the new optimists as the period of rising living standards: At about 1760, the crude death rate for England was still about 27.5 per 1000, declining steadily (with a few reversals) to about 22.5 per 1000 by 1850. Gross mortality rates, however, are flawed indicators for many reasons, primarily because of their dependence on the age structure of the population. A better measure is the life expectancy at birth. This variable, too, shows some improvement over the entire period, but its rise stops in 1820, and it remains essentially static at about 40 years until 1860 (Wrigley and Schofield, 1981, p. 529). The sharp rise in consumption and real wages claimed by the new optimists should have produced, through improved nutrition and better living conditions, a rise in life expectancy, perhaps lagged by a few years. Nothing of the sort happened. Data on infant mortality, though not available on a national basis, tell very much the same story. In a sample of seven parishes, Huck (1992) finds rising infant mortality rates in the period between 1813 and 1836, with no appreciable decline until 1845, precisely the years identified by Lindert and Williamson as the period of rapid improvement. More recent data reported by the Cambridge Group, based on family reconstitution and thus more representative of England as a whole contain no consolation for the optimists: infant mortality rates (acknowledged by Williamson (1982) himself as a good indicator of the standard of living) was hovering around 160 per 1000 between 1750 and 1780, declined to around 150 in the 1790s and 135 in the first two decades of the nineteenth century eighteenth century, but then rose to over 140 in the years leading to 1837 (Wrigley et al. 1997, p. 215).

A biological indicator that has enjoyed considerable interest in the last few years is human height. It has become widely accepted that height is a function of net nutritional status, that is, the amount of food taken in by children and adolescents net of demands made on their bodies by labor and diseases. All other things equal, a child born in a family that enjoyed a higher standard-of-living would grow up to

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[124] Of some interest here is the very peculiar paper published by Clark, Huberman and Lindert (1995) in which they face the problem that under the premise that real wages increased as rapidly as Lindert seems to believe, British workers were not spending their higher incomes on food either. The paper goes through a number of rather contrived arguments to settle this "puzzle." There is no puzzle, of course, once we realize that the premise is false and that the food consumption data, much like those of tea, sugar, and tobacco, neatly track the real wage data delineated by Feinstein.

be taller. The idea that observed height data could therefore be used to approximate the elusive standard of living was proposed by Fogel (1983) and his associates and has since then stimulated a large number of research projects. The research that is most pertinent to the standard of living debate in Britain is Floud, Wachter, and Gregory (1990) and Komlos (1997, 1998). Their finding is that net nutritional status, as measured by stature, increased between about 1760 and 1820 and then went into a secular decline for half a century. Indeed, the cohorts born in 1850-1854 are shorter than any cohort born in the nineteenth century, and the levels attained in the first decades of the century are not attained again before the last decade (Floud, Wachter and Gregory, chap. 4, passim). Based on this evidence, they maintain, the debate on living standards during the second and third quarters of the nineteenth century is still very much open, and (p. 305) "if there were significant gains in real incomes for the working class between the 1820s and the 1850s they were bought at a very high price." Komlos's figures are even more pessimistic, and prompt to regard this as a major "puzzle" in economic history. In other words, if there were economic gains, they did not lead to *physical* improvements in the lives of English men and women.

The incongruity of the biological indicators, which tend more to support the pessimist case, and the aggregate economic indicators, which on the whole present a mixed case, can be reconciled in three different ways. One is that the biological indicators pertain to the population as a whole, including the domestic sector, paupers, and the "informal" economy of the urban poor, whereas the real wage data pertain largely to the modern and formal sector and thus are not as representative. To put it differently: The Industrial Revolution brought forth losers and gainers. Real wage data alone tend to reflect more the situation of male employed workers, who were predominantly gainers, than upon domestic workers, many of whom were female and self-employed and who, by and large, ended up on the losing side. The failure of microlevel consumption data to reflect the rise in real wages is consistent with this view. A complementary explanation may suggest that while real wages improved, other aspects of living standards deteriorated. These would reflect not only urban living conditions and the harsh conditions of factories but also some less obvious factors, such as the loss of flexible choice between leisure and income brought about by the factory system. Thus rising real wages simply compensated the workers for other losses and there is no obvious case for "improvement." Moreover, as Komlos notes, rising real incomes could be consistent with changes in relative prices that made healthy (protein-rich) foods more expensive. Finally, it can be argued, of course, that biological indicators such as height, while easy to measure and estimate, are difficult to interpret and that economists should treat them with even more caution than wage or income data (Mokyr and Ó Gráda, 1996).[125] In view of the fragility of much of the statistical material on aggregate

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[125] A particular difficulty with interpreting height data is that changes in measured adult height reflect changes in living standards in the past, but any attempt to time this accurately is difficult, since physical growth occurs over more than two decades (and possibly longer, since malnourished women tended to have babies who grew up shorter) and

income and consumption, however, this view seems difficult to sustain. At this stage, therefore, it has to be inferred that the evidence of a rise in living standards before 1850 is simply too weak to be convincing.

The pessimist case itself, however, should be tempered by acknowledging the well-known pitfalls involved in measuring changes in living standards in an age of rapidly changing technologies. All quantitative studies of living standards measure in the final analysis quantities of goods that incomes can buy. They fail to account for changes in quality. A typical textile product in 1830 was not only cheaper than in 1750 but was also better in terms of the evenness of its fabric, its durability, its ability to absorb and maintain color, its ease of laundering, and so on. The same was true for a wide range of products, from iron pots to glass to steel pens to printed illustrations in books (Landes, 1998, p. 197). Moreover, a number of inventions made during this period created completely new products, making welfare comparisons very difficult: Traditional measures of real wages and national income do not adequately capture the economic value (or additional consumer surplus) of the decline of smallpox, the introduction of gaslighting, or the use of anesthesia during surgery. Against this we have to weigh the increased adulteration of the food and drink bought by the working class (Burnett, 1966, pp. 99-120), the negative effects of the 'disamenities' of urbanization, and the loss of outdoor relief with the reform of the poor laws in 1834. Feinstein (1997, p. 47) reckons that these three effects reduce the gain in standard of living of the average family in the United Kingdom between the 1770s and the 1850s from about 28 per cent to 8-13 per cent. At the same time, it should be added that certain highly aggregative measures of economic well-being such as the Human Development Index (Crafts, 1997) paint a more optimistic picture. Crafts's index rises steadily and in rather stable fashion from 1760 to 1850. Even corrected for changes in equality and the disparity in the achievements of genders, the various indices display a steady rise. A closer look at the Living Standards Indicators produced by Crafts does, however, weaken his optimist inferences regarding the critical years between 1815 and 1850: Height of army recruits show a decline, while the critical demographic variables show no improvement. Much of the effect clearly derives from the sharp increase in GDP per head, a variable that is still in serious dispute. Moreover the HDI is computed additively and thus trades off demographic variables and income per capita linearly against literacy. Given the somewhat questionable role of literacy in this age (being able to read may not mean much if people rarely actually read), this procedure is thus not wholly satisfactory and certainly does not rehabilitate Lindert and Williamson's now-discredited optimism.

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any prolonged "dietary insult" could lead to stunting. Moreover, height was also determined by morbidity, and such exogenous changes as changes in disease regime could contaminate the relationship between observed health and anything resembling an economic standard of living (see e.g. Voth and Leunig, 1996)

Part of the standard-of-living controversy is the debate over what happened to the inequality in income distribution. The famous Kuznets curve hypothesis (Kuznets, 1955) suggests that during the first stages of industrialization, income distribution became more unequal, eventually reaching a peak and then improving afterward. A worsening income distribution is one obvious way to reconcile rising per capita income and stagnant living standards for the majority of the population. The argument is discussed by O'Brien and Engerman (1981, p. 174), who maintain that given the rate of growth of income per capita between 1800 and 1850, an unchanging income level of the bottom 80 percent of earners would have meant that their share in income decreased from 75 percent in 1800 to 41 percent in 1850. Such a sharp worsening being unthinkable, they dismiss the argument. The revision of per capita growth rates, however, makes this argument less compelling. At a per capita income growth of perhaps 0.7 percent per year between 1800 and 1850 (instead of the 1.2 percent estimated by Deane and Cole and used by O'Brien and Engerman), a relatively slight sharpening in income distribution might have reduced the growth of income of the bottom of the income distribution to little more than a trickle.[126] The most dedicated proponent of the applicability of the Kuznets curve to Britain during the Industrial Revolution is Jeffrey Williamson (1985), although this belief in part undermines his view that living standards improved rapidly after 1819. There is, however, some doubt about what precisely happened to income equality during the critical years between 1800 and 1867, and until this doubt is cleared up, it is hard to draw any firm conclusions about how changing inequality affected living standards.[127] In a critique of Williamson's work, Feinstein (1988b) denies the applicability of the Kuznets curve to the British experience during the Industrial Revolution and argues that inequality remained more or less unchanged. Some complicating factors, however, still have to be fully accounted for. For instance, there is a difference between the inequality of the distribution of income among households and the distribution among individuals. If poorer families tended to increase family size over time relative to richer families, a constant distribution over household would in fact imply a growing inequality among individuals. A

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[126]Using the rise in inequality estimated by Lindert and Williamson (1983a) and assuming the share of the poor was little changed between 1850 and 1867 yields a growth of slightly over 0.4 percent in the incomes of the bottom 90 percent of the income distribution between 1800 and 1850. However, the decline of the share of the bottom 90 percent from about 54 percent to about 47 percent is, by Lindert and Williamson's computations, entirely accounted for by the sharp decline in the earnings of the people in the bracket between the bottom 65 percent and the bottom 90 percent, that is, the upper bracket of the bottom 90 percent. Removing these "lower middle class" people and concentrating on the bottom 65 percent reverses the picture, and incomes in this group increased by 0.90 percent per year.

[127]Allen (1992b, p. 285) argues that in agriculture landlords were the only gainers from the agricultural revolution before 1850.

further complication is the decline in poor-relief support prompted by the Poor Law Reform Act of 1834, when spending on poor relief fell from over 2 percent of national income to about 1 percent (Lindert, 1992). Obviously, the reform sharpened the after-tax distribution of income, but it is as yet unclear to what extent changes in the poor law affect the standard-of-living overall.[128] Horrell's work (1995), although based on a very different set of sources, lends some indirect support to the Williamson view of sharpening inequality before 1850, as she finds steeply increasing consumption by middle class families but practically none for the working class. It might be added that there is something ironic about the historiography of inequality here. The debate between Williamson and Feinstein has been about real wages and inequality. Whereas Williamson has argued for steeply rising blue collar wages, he has also maintained that inequality increased; Feinstein has taken the opposite position on both issues. Yet rising blue collar wages might have been, at first glance, more consistent with declining or at least constant inequality. This paradox may be resolved once Feinstein completes his project of estimating National Income. If his results lower estimated growth rates significantly, stagnant real wages may well be consistent with no dramatic changes in inequality.

An Assessment

The New Economic History has traditionally been iconoclastic, and the Industrial Revolution has not been immune from attacks on the usefulness of the concept. Such attacks are to be welcomed because they force a reconsideration and reevaluation of the conventional wisdom. The Industrial Revolution may not, in fact, have been nearly as abrupt and as sudden as some of its historiography suggests. Furthermore, there has been a tendency among some economic historians to identify the economic history of Britain in the century after 1750 *as* the Industrial Revolution. Such an identification is misleading and a-historical. Much, perhaps most, of what happened in the British economy at that time had little or nothing to do with the Industrial Revolution. Before 1830, most of Britain's land and the majority of its population were only affected by it in a roundabout way, many perhaps were not affected by it at all.

Yet its importance in economic history stands undiminished. Before the Industrial Revolution technological change and economic growth did occur sporadically in the experience of Europe and Asia but were invariably checked by stronger forces. Much of the growth that other scholars observe in Europe before the Industrial Revolution was due to the expansion of commerce, itself largely a function of institutional change and propitious political circumstances. Such cases

[128]The estimates of the share of the bottom 40 percent in income distribution range between 10 and 14 percent of income (Williamson, 1985, p. 71). A decline in poor-relief transfers from 2 percent to 1 percent would have, by itself, reduced the incomes of the very poor by something between 7 and 10 percent.

were usually slowed down or even reversed by institutional breakdowns or military events. Technology, by its very nature, is much less reversible and less likely to run into diminishing returns than commercial expansion. What the Industrial Revolution meant, therefore, was that after 1750 the fetters on sustainable economic change were shaken off. There were lags and obstacles to overcome before technological creativity and entrepreneurship could be translated into sustained economic growth and higher living standards, but the secular trend pointed clearly upward. What ultimately matters is the irreversibility of the events. Even if Britain's relative position in the developed world has declined in recent decades, it has remained an urban, sophisticated society, wealthy beyond the wildest dreams of the Briton of 1750 or the bulk of the inhabitants of Africa or Southern Asia in our own time. Britain taught Europe and Europe taught the world how the miracles of technological progress, free enterprise, and efficient management can break the shackles of poverty and want. Once the world has learned that lesson, it is unlikely to be forgotten.

Regarded with the critical eye of statistical analysis, the events of the Industrial Revolution themselves may seem to us small and even insignificant because they affected only limited areas and products. But historians' judgment is inevitably colored by hindsight and rightly so. Examining British economic history in the period 1760-1830 is a bit like studying the history of Jewish dissenters between 50 B.C. and A.D. 50. At first provincial, localized, even bizarre, it was destined to change the life of every woman and man in the West beyond recognition and to affect deeply the lives of others, even though the phenomenon remained confined primarily to Europe and its offshoots. Although the center of the stage has long been taken over by others, Britain's place of honor in the history books is assured: It will remain the Holy Land of Industrialism.

2

The Fable of the Dead Horse; or, the Industrial Revolution Revisited

David S. Landes

Now without intending to depreciate in any manner the heroic efforts of the French Revolution and the immense gratitude the world owes the great men of the Republic, we think that the relative position of France and England with regard to cosmopolitism is not at all justly delineated in the above sketch [by Louis Blanc]. We entirely deny the cosmopolitic character ascribed to France before the Revolution, and the times of Louis XI and Richelieu may serve as proofs. But what is it M. Blanc ascribes to France? That she could never make predominant any idea except it was to benefit the whole world. Well, we should think M. Louis Blanc could not show us any country in the world which could do otherwise than France is said to have done. Take England, for instance, which M. Blanc places in direct opposition to France. England invented the steam engine; England erected the railway--two things which we believe are worth a good many ideas. Well, did England invent them for herself or for the whole world? The French glory in spreading civilization everywhere, principally in Algiers. Well, who has spread civilization in America, in Asia, Africa and Australia, but England?

— Friedrich Engels
The Northern Star, XI, No. 530 (18-12-1847)

When in teasing mood I sometimes suggest to my students that the beginning of the end of the Ancient World is to be found not in Alaric's capture of old Rome in AD 410, not in the Turkish sack of new Rome in 1453 nor, indeed, at any of the much canvassed dates in between, but in an event which occurred in England in the early eighteenth century, they tend to look blank, baffled or bored according to temperament. Yet the case can be argued that the division between Ancient and Modern was marked in 1709 when at Coalbrookdale in Shropshire, Abraham Darby first successfully smelted iron with coke, for it was this development which launched mankind, slowly at first, but with progressively increasing rapidity, into the totally new world of an expanding and innovatory technology and introduced into the human consciousness the wholly novel concept of self-sustaining growth, both technical and financial.

— Donald C. Earl, *On the Absence of the Railway Engine*

What may well be the first use of the term "Industrial Revolution" dates from 1799, when a French envoy to Berlin with the German name of Otto wrote that his country had already entered upon the industrial revolution.[1] As the name came into wider use, especially among such political economists as N. Briavoinne, it was intended to convey the sense that a number of European countries had passed, were passing, or were about to pass through a profound and momentous change that would alter them forever.[2] What is more, this was a change of universal import: no corner of the globe was immune to its effects, which were seen by many, including radical political dissenters, as intrinsically and "objectively" progressive. As the epigraph above shows, this was true even of Friedrich Engels, but also of Karl Marx, for all their denunciation of the abuses and suffering that accompanied the rise of "modern industry" (Engels 1845, Marx 1867).

In those days the Industrial Revolution was not yet a theme of scholarly analysis and debate, although the name itself was soon consecrated by use and the political-social-economic implications of these changes became matter for state policy and political polemic. Thus there is a substantial body of literature, going as far back as the late 18th century, dealing with the strategic, national implications of the new industrial technologies and the urgent necessity for other countries to follow Britain (Alexander Hamilton, J.-A. Chaptal, Friedrich List, Gustav Mevissen, *et al.*); and another literature from about the same period describing and debating the social and moral conditions and consequences of the new industrial system.

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[1] "*La révolution industrielle est commencée en France.*" Louis-Guillaume Otto (1754-1817) was a career diplomat whose highest post was that of ambassador to Vienna from 1809 to 1813. I owe the Otto reference, which is the earliest use of "industrial revolution" to come to my attention, to François Crouzet, who has it from Annick Pardailhe-Galabrun, *ingénieur* of the Centre National de Recherche Scientifique and member of the Centre de Recherches sur la Civilisation de l'Europe moderne, Université de Paris-Sorbonne (Paris IV). My thanks to both. The document in question is from a Mémoire attached to a letter of 18 messidor An VII (6 July 1799), France, *Archives des Affaires étrangères*, Mémoires et Documents, Angleterre 136, f. 352.

[2] "Revolution," as used in the text above, has the sense of "an instance of great change or alteration in affairs or some particular thing" — *OED*, s.v., III, 6, b) — a sense that well antedated, by a century and a half, the use of "revolution" to denote brusque or abrupt political change. The same anteriority is true in French, where the Littré cites among other examples the Abbe Raynal's prescient remark (*Histoire philosophique et politique des établissements et du commerce des Européens dans les Deux-Indes* [1770-1773], XIV, 47) that "a great revolution is under way in the commerce of Europe, and it is already too far advanced not to be consummated." This was as close as pre-Revolutionary France could get to the term "industrial revolution," for the word *industrie* was then used primarily to denote diligence. It was routinized in its modern sense of a sector of the economy, particularly that sector concerned with manufacturing, only in the second quarter of the nineteenth century (Sée 1925; Hauser 1931). On the word *commerce* as subsuming industry in the eighteenth century, Viennet 1947, p. 3, n.2.

Scholarly Disagreements

It was not until the 1880s, about a century after the introduction of machines and factories into the manufacture of cotton textiles, that people whom we might describe as academic scholars began to look back on this development and assess its effects. One dates the beginning of this new stage with Arnold Toynbee's *Lectures on the Industrial Revolution* (1884), which were intended for night students in Manchester (hence largely working men continuing their education after a day's labor) and took as their theme the unhappy influence of the new mode of production on the condition of the working class. Toynbee saw the Industrial Revolution as sudden, rapid, and drastically unfavorable in its reorganization of labor and its larger social effects. This regretful point of view was sustained and continued by the work and writing of other social-activist scholars — Sidney and Beatrice Webb for example, partners in Fabian socialism, and J. L. and Barbara Hammond — and it remained the dominant orthodoxy for almost half a century, into the 1920s. (Note that this discussion dealt exclusively with the British experience. There were, however, Continental students of economic change who were less negative in their judgment, at least in their comparisons of the European experience with the British [Gustav Schmoller, Max Weber, Paul Mantoux].)

The first major breach in this pessimistic construction came from John H. Clapham, then Fellow of King's College and later professor of economic history at Cambridge University. In a comparative study of France and Germany (1921; 2d ed. 1923), to which he gave the still unaccustomed title of *Economic Development*, he contrasted the swiftness of German industrialization to France's "leisurely movement" in that direction. Clapham presented this transformation as a natural and inferentially desirable aspect of modernity: the French, he implied, had paid in wealth and strength for the slowness and incompleteness of their development, retarded in his view by want of coal and the high cost of fuel (1923, pp. 56, 234-35). Not that they had stood still or wanted for "inventiveness, endurance, or organising capacity" (p. 232). They had changed, but it was more evolution than revolution. In the meantime, the people of both countries had benefited from "the solid economic gains" of the 19th century. This, he asserted, was "a purely historical conclusion, . . . which involves no blessing and no cursing of the social system of Europe in the first decade of the twentieth century" (1923, p. 407).

Then, beginning in 1926, Clapham brought out a major study in three volumes of the *Economic History of Modern Britain* that made the point that the Industrial Revolution in Britain was less cataclysmic than had been maintained; that rather it was partial and gradual. Basing himself on the census of 1851, he noted that even in the mid-19th century, at the time of Britain's triumphant Great Exhibition, the most numerous occupations were the old ones, agriculture and domestic service; and that even industry was still organized predominantly in small units using older methods and sources of power (1952, ch. ii).

Different but in the same tradition was T. S. Ashton, professor in the London School of Economics, who continued the emphasis on empirical data and argued explicitly that the Industrial Revolution had been a good thing, not only in its effects on the standard of living (hence directly contradicting the Hammonds) but even more in terms of what might have been. In a highly influential little handbook of 1948, *The Industrial Revolution 1760-1830*, much used as a school text, he contrasted the condition of Britain with that of the poor, overpopulated parts of the world and stated that there but for the grace of modern industry went we (p. 161):

> There are today on the plains of India and China men and women, plague-ridden and hungry, living lives little better, to outward appearance, than those of the cattle who toil with them by day and share their places of sleep by night. Such Asiatic standards, and such unmechanized horrors, are the lot of those who increase their numbers without passing through an Industrial Revolution.[3]

The work of Clapham, Ashton, and others really turned the debate on the social consequences of industrialization around. Instead of seeing modern industry through guilt-blurred eyes, people had to face the fact that the empirical data supported the optimists, that is, those who saw the bottom line as positive. The pessimists hung on by shifting ground and arguing on the basis of subjective appreciations: even if real wages rose, they said, the quality and security of life diminished. This was an ironic turn for Marxists and *marxisants*, who had always stressed the primacy of the material. In the long run, however, the judgment had to be favorable if only because there was no denying the evidence: the British working classes did not live well, but they lived better and longer than their ancestors, and, as Ashton put it, they certainly lived better than they would have, had their numbers increased without the gains in productivity made possible by mechanization, inanimate power, and factory manufacture.

That still left the question open whether there had not been a transitional phase of deterioration. This was what Eric Hobsbawm argued, for example, saying that things got worse until the 1840s and then improved. The rejoinder came that if things got worse temporarily, this decline was concentrated in the first two decades of the 19th century and was the result of war rather than industrialization; or that the picture was mixed, with some (most) sectors or branches improving, while others (hand-loom weaving, for example) shrank and suffered. Whatever . . . such arguments were a far cry from the unrelievedly bleak judgment of an earlier generation, or for that matter, from the absolute immiseration thesis (the condition of the working classes getting steadily worse) put forward by some Marxists.

All of this, however, has not put an end to the controversy. The standard of living question is the stuff of eternal disagreement, not so much because the facts are or are not ascertainable—although they are complex enough to sustain a variety

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[3]This point of view has since been supported by the demographic researches of E. A. Wrigley and R. S. Schofield (1981). See above, p. 13, and n.5 below.

of interpretations; or because scholars will not rest so long as there is something to argue about—although that is also true. No, what keeps the controversy going in my opinion is that the two adversary opinions are also seen as shibboleths, as clues to and tests of political stance (Landes 1976).

The Industrial Revolution as Rupture

Ashton's ode to industrialization announced a period of positive emphasis on the Industrial Revolution as a major break in the course of history, the opening of an era of sustained technological change and economic growth. It also continued and was reinforced by an older tradition, going back to writers of the 19th century and summed up by such students of the history of technology as A. P. Usher and Lewis Mumford, that stressed the material content and definition of the Industrial Revolution.

I count myself in that group. The Industrial Revolution, as I defined it in the *Cambridge Economic History of Europe* (the manuscript went back to the mid-1950s but was not published until 1964), was a complex of technological advances: the substitution of machines for human skills and strength, the development of inanimate sources of power (fossil fuels and the steam engine), the invention, production, and use of new materials (iron for wood, vegetable for animal matter, mineral for vegetable matter), and the introduction and spread of a new mode of production, known by contemporaries as the factory system. The emphasis was on the gains in productivity and quality these changes made possible, their cumulative character, their ramification from a few leading branches into other industry and into transportation, their stimulus to creativity and innovation, and lastly the consequent gains in product and income per head. What is more, the argument went, these changes could not be and were not limited to the British Isles. Rather they changed the relative wealth and power of nations and so doing compelled those who pretended to commercial and political parity with Britain to follow suit . . . which they did. The British example was not the model for the rest of the world: given its originality and particular circumstances, it could not be that. But it was both challenge and a source of knowledge, ideas, and experience—positive and negative.

In short, by this thesis, the Industrial Revolution was seen as a major break of worldwide significance. In my own work, I described the transition from pre- to post-Industrial Revolution as the puberty of nations. Others argued along similar lines, in particular Walt Rostow, who invented the term "takeoff," which he defined as simply another way of saying "industrial revolution." This had the merit of being catchy—always an advantage in the contest for attention—and of figuratively emphasizing the notion of sustained growth (flight) as a result of passage from level motion to an upward trajectory. Unfortunately, it also conveyed a sense of rapidity, metaphorically telescoping the work of decades into the image of a fast-climbing aircraft.

For Rostow, the Industrial Revolution was a stage that all countries would pass through on their way to higher levels of development, with Britain and Europe leading the way to the laggards. Along these lines, Rostow described his influential essay on *The Stages of Economic Growth* as a "non-communist manifesto" — one that would show the world how the West could bring growth and economic advancement more efficiently than could the Soviet Union. Such a deliberate challenge caught the attention of readers, but it was also a lightning rod that drew strong ideological opposition. One does not attack a religious icon like *The Communist Manifesto* with impunity.

How Fast is Slow?

Yet it is not political adversaries who have given Rostow and indeed the whole discontinuity school (the Industrial Revolution as a major break or breakthrough) their hardest time. Criticism has come from academics as well, and it began and has rested with new techniques of quantitative, macroeconomic analysis. Just as numbers turned the standard of living controversy around, so it is numbers that have overturned (or pretended to overturn) the orthodoxy concerning the character and significance of the Industrial Revolution.

The first manifestation of the difficulty came with the perceived incompatibility of one of Rostow's key assertions with the empirical data, and this perception in turn was the result of the application of national income accounting to the distant past. Here the prime mover was Simon Kuznets, who with his colleagues in the National Bureau of Economic Research had shown what could be done by way of reconstructing past national accounts for the United States and who was mobilizing similar research projects in other countries. Among those laboring in this vineyard: Phyllis Deane, then a lecturer in Cambridge University, who brought out in the late 1950s a number of articles estimating British economic growth in the 18th century.

In 1961 the International Economic Association brought together a group of economic historians, historical economists, and straight economists in Konstanz (Switzerland) to assess and discuss Rostow's *Stages*. Such special attention was no small honor, and Rostow was justifiably delighted. What's more, he managed to maintain this happy, sweet demeanor throughout the meeting in the face of a barrage of heavy and not always sympathetic criticism (I couldn't have done so) and even edited the volume of proceedings, which was published two years later (Rostow 1963).

Among the papers presented was one by Phyllis Deane and H. J. Habakkuk on the takeoff in Britain that addressed itself to the effect, among other things, of the Industrial Revolution on the accumulation of capital. Their target in this regard was an assertion by Walt Rostow (drawing on an observation [speculation] of Arthur Lewis) that one of the salient characteristics (manifestations) of industrialization is a sharp rise in the rate of saving and investment, a shift from under 5 per cent to 10 per cent or more of income, and that this was in fact what had happened in Britain. Now this was presumably a verifiable hypothesis; and Deane and Habakkuk questioned it, if they did not disprove it. Using reasoning as much as data, they argued that the accumulation of capital in Britain was slower than the Rostow thesis seemed to require ("the Rostow model of the take-off requires that it should have been largely compressed within the space of two decades"). Their language was cautious: "It does not seem reasonable to suppose . . . . It is difficult to credit that a change of this order of magnitude could have occurred . . . . The contemporary estimates are, of course, highly speculative, and we have little evidence against which to check them" (1963, pp. 74-76). Nevertheless the sense conveyed was of slow increase covering decades. They did not address themselves to the later years (the second and third generations) of the Industrial Revolution); nor did they pretend to contradict the accepted orthodoxy "that the crucial transformation occurred fairly rapidly — certainly within the century between 1750 and 1850, probably in a considerably shorter time" (p. 63). But they did stretch and blur the chronology: "In the end it seems that the most striking characteristic of the first take-off was its gradualness. Professor Nef has traced the process of industrialization back to the sixteenth century. The sustained rise in the rate of growth in total output probably dates back to the 1740s" (p. 82). As for capital formation, the sense that emerged was that it was not until the building of the capital-hungry railways after 1830 that the rate rose close to the level asserted by Rostow.

That was then a little cloud, no bigger than a man's hand, but it became a tempest. In subsequent years, further research (Pollard, Feinstein, Crafts, Harley) seemed to show that, just like capital formation, all the macroeconomic variables grew slower than the "revolutionary" character of the Industrial Revolution might have led one

TABLE 2.1 Great Britain: Growth Rates in Real Output, 1700-1860 (per cent per year):

	Industrial Output		*GDP*	
	Crafts	*Deane and Cole*	*Crafts*	*Deane and Cole*
1700-1760	0.7	1.0	0.7	0.7
1760-1780	1.5	0.5	0.7	0.6
1780-1801	2.1	3.4	1.3	2.1
1801-1831	3.0	4.4	2.0	3.1
1831-1860	3.3	3.0	2.5	2.2

N.B.: Figures for 1700-1801 are for England and Wales; thereafter for Great Britain.

to expect and slower even than the Phyllis Deane series.[4] See, for example, the comparison of growth estimates offered by Crafts in a recent essay (1989, p. 66), presented in Table 2.1.

Note moreover that these rates are not of growth per head. These would show even slower increase, even a decline for some of these years. Jeffrey Williamson (1990, p. 1), apparently building on Crafts, Leybourne & Mills (1989), reminds us that British national income, when deflated for population, grew at about 0.3 per cent per year in the last decades of the 18th century — "hardly impressive." Compare Jackson 1992, p. 4, Table 2, growth for the period 1770-1815. This contrasts sharply with Deane & Cole 1962, p. 78 (see Table 2.2), which shows annual growth in "real output" per head of 1 per cent from 1770 to 1800, and "industry and commerce" of 1.4 per cent over the same period. But this in turn may well be too high: Deane & Cole have strange and, to me, improbable dips in a number of categories (see figures below for 1770 and 1780; also Jackson 1992,

TABLE 2.2 Index Numbers of British Real Output, 1760-1800 (1700 = 100)

			Industries		*Industry and Commerce*	
	Real Output	*Per Head*	*Export*	*Home*	*Total*	*Per Head*
1760	147	130	222	114	179	158
1770	144	119	256	114	199	164
1780	167	129	246	123	197	152
1790	190	134	383	137	285	201
1800	251	160	544	152	387	247

Source: Deane & Cole 1962, p. 78, Table 19 and n.1.

[4]Feinstein's estimates of the investment ratio (domestic investment as a proportion of gross domestic product) and its course also differ considerably from those of Deane 1961, 1962, 1965 (and by implication Deane and Habakkuk 1963). Deane has capital formation growing at an average of no more than 3 per cent per year in the 17th and early 18th centuries; this rate begins to rise in the middle decades of the century, rising in the last quarter to "a sustained average of more than 5 per cent," maybe a bit over 6 per cent; and then the rate goes up again in the 1830s with the coming of the railway, reaching about 10 per cent in the late 1850s. Feinstein's timing is the reverse: his is a picture of rapid increase in the last decades of the 18th century, from 8 per cent in the 1760s to a peak of 13 per cent in the 1790s, followed by a slight reduction and leveling off throughout the first sixty years of the next century. Feinstein 1978, pp. 30, 91.

pp. 4-5 and Table 2), which make growth very sensitive to choice of end points. These and other aberrations signal as well as anything the errors built into these macrostatistical manipulations. To be sure, Great Britain was then experiencing a population miniexplosion (five to ten times the rate of increase of the first half of the century [Deane and Cole 1962, p. 8; Komlos 1989, p.209]), and it could be argued that the very fact of being able so to multiply without incurring a Malthusian rupture — very different from earlier historical experience--was in itself evidence of the unprecedented power of the new technology (North 1981; Komlos 1989). Wrigley and Schofield, the primary researchers in the field, have put it quite emphatically (1981, p. 412):[5]

> . . . the possibility that the period before 1800 can be subdivided should not be allowed to obscure its general uniformity of experience, nor the decisive nature of the break occurring during the industrial revolution, a change so decisive that it must reflect a dramatic rise in the rate of growth of the economy as a whole . . . . Perhaps for the first time in the history of any country other than a land of recent settlement rapid population growth took place concurrently with rising living standards. A basic feature of the human condition had changed. . . . England crossed a threshold into a new era.

Still, if we focus, as many new economic historians do, on the arithmetic of income aggregation, a rate of 0.3 per cent is very small. If one took into account margins of error, it could be something; but it also could be nothing. Along with this diminution of the spurt, this reduction of the mountain to a hillock, has gone a renewed emphasis on the long and impressive preparation that made the Industrial Revolution possible. On the level of technology, this approach went back to J. U. Nef's tale (1933, 1934, 1943) of Britain's precocious recourse to fossil fuel, which he called a first industrial revolution. But there was also the early example of mechanized factory production afforded by the Lombe silk-throwing mill in Derbyshire (1719); Thomas Savery's steam pump (late 17th century) and Thomas Newcomen's engine (ante-1712); Abraham Darby's successful use of coke to smelt iron (1709) — these and other inventions and innovations occurring well before the cluster that we commonly denote as the Industrial Revolution (1760s on). And on the level of growth, the argument has been made that pre-industrial Britain was not standing still, that growth was an old story. The latest estimates in this area, by Graeme Snooks (1990) in a communication to the Tenth International Congress of Economic Historians at Leuven, build on Domesday Book (1086) and Gregory

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[5]See also Wrigley and Schofield's Figures 7.11 and 7.12, on the combined effect of fertility and mortality in determining intrinsic rates of population growth, and especially Figure 10.4, charting the coincidence over time between population growth and real wages. The discontinuity of the late eighteenth century and the exceptional character of the nineteenth are unmistakable. I want to thank Claudia Goldin for drawing my attention to this material.

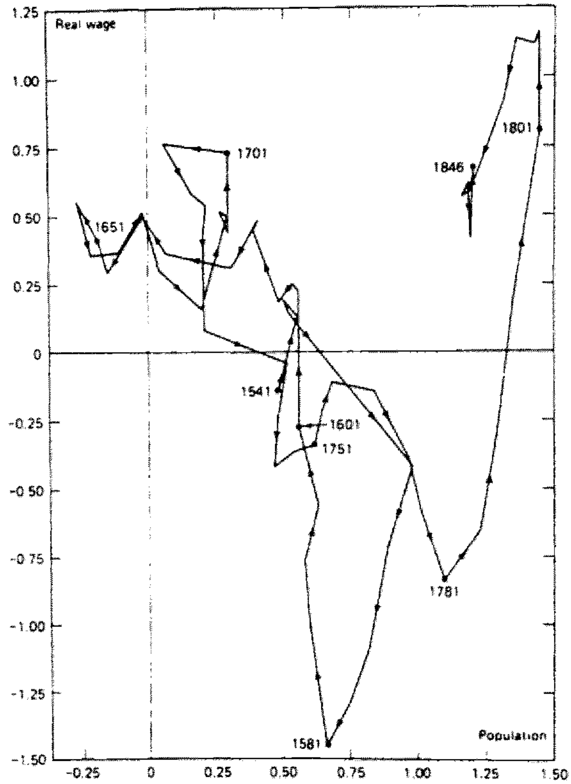

FIGURE 2.1 Great Britain. An End to Malthusian Penalties, 1781 on.
Source: Wrigley and Schofield (1981, p. 410). Reproduction by courtesy of the Cambridge University Press.

King's income figures (1688) — so, two end points 600 years apart and nothing in between — to suggest a rate of growth of national income of 0.49 per cent per year; of income per head, of 0.29 per cent; of productivity per head, of 0.23 per cent. This is high precision to the fourth decimal place on a tenuous base over a very long period, to the point where Knut Borchardt was moved to remark in discussion that he found the paper "wonderful, in the sense that it is full of wondrous things."[6]

[6]Snooks has since published these speculative calculations in his edited collection, *Was the Industrial Revolution Necessary?* (London and New York: Routledge, 1994), pp. 43-78.

This macroeconomic reconstruction and diminution of the Industrial Revolution has been reinforced by new studies of particular sectors. S. D. Chapman (1971), A. E. Musson (1976), Nicholas von Tunzelmann (1978), Dolores Greenberg (1982), and others have pointed out that steam power, for example, long seen as the technological heart of modern industry, was adopted slowly and piecemeal; that water power long accounted for the larger share of the inanimate energy employed in manufacture, to be passed by steam only in the second half of the 19th century; and that indeed use of animal (including human) power remained important (cf. Samuel 1977). Along similar lines, G. R. Hawke (1970), following in the footsteps of Robert Fogel, calculated that the railways, for all their importance, "only contributed about 10 per cent of [British] national income in 1865" (Cannadine 1984, p. 157).[7] And F. T. Evans (1982), denouncing the "iron and steel propaganda of the Industrial Revolution," pointed out that in the mid-19th century timber and wood were not scarce (some prices were even falling) and continued to be used widely for industrial purposes.

The revisionist thesis has been reinforced by comparable quantitative work on the Continental countries, in particular France, the country of choice to cut Britain down to size. More than half a century ago, John U. Nef was warning scholars against a sharp contrast between British progress and Continental retardation in the eighteenth century: "The rate of industrial change from about 1735 to 1785 was no more rapid in Great Britain than in France, a far larger country with nearly three times as many people (1943, p. 5; also pp. 14, 19-23). A quarter-century later, François Crouzet (1966) made a similar argument on the basis of a comparison of British and French trade statistics.[8] And more recently, J. Marczewski, T. J. Markovitch, Maurice Lévy-Leboyer, Crouzet and others have produced data showing that French industry, long seen as slow and technologically laggard, grew quite respectably in the nineteenth, and particularly the first half of the nineteenth, century. Meanwhile, taking the opposite tack, that is, arguing from French slowness and reasoning from the Gerschenkron model (the later, the faster), Richard Roehl (1976) suggested that France, rather than Britain, was the first industrial nation; while Nick Crafts (1977, reprinted in Mokyr, 1985c), picking up

[7]I cite Cannadine because my primary concern here is the impact of this work on the consciousness of the scholarly community. Hawke's estimate of railway social saving in 1865 as a proportion of income in 1865 is 4.1 per cent (Hawke, 1970, p. 196).

[8]Nef, citing "for what they are worth" the data of Levasseur (1911, I, 512 n.2), had already suggested that French trade grew faster than British in the 18th century (1934, p.22). The data in question were the retrospective estimates of French officials assembled toward the end of the Old Regime — principally those of A.-M. Arnould, assistant director of the Bureau de la Balance du Commerce from 1785, and a certain Bruyard, head of the Bureau de Commerce from 1756. For the grievous inaccuracies and lacunae of these returns and their pronounced upward bias of growth, see Landes (1972, pp. 62-65).

a hint from E. A. Wrigley (1972), played with the idea that it was only a matter of chance that Britain industrialized first; that France might easily have taken the lead instead.[9] And Patrick O'Brien and Çağlar Keyder argued in a particularly provocative monograph (1978) that mass production was not the only way to industrialize; that France, with its small craft shops and manufacturing units, grew more or less as fast as Britain; and that when quality of life is taken into account, France probably did better.[10]

All of this has given rise to a reassessment of the nature and significance of the Industrial Revolution. Thus A. E. Musson (1978, p. 61): "The older view of the Industrial Revolution — that it was a sudden cataclysmic transformation, starting around 1760 — clearly is no longer tenable"; and again (p. 149): "British economic historians have generally tended to place too much emphasis on the Industrial Revolution of 1750-1850 by comparison with developments in the second half of

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[9]The article cites approvingly a critical remark by Everett Hagen (1967, p. 37) concerning "retrospective" analysis: "Explanations of Britain's primacy . . . consist mainly of a not very convincing sort of retrospective inference (something must have caused Britain's primacy in time, so presumably the earlier conditions overtly observable did)." And Crafts translates: "In other words, the favourability of certain conditions in England has been inferred from the result with the likelihood of *post hoc, ergo propter hoc* fallacies" (Mokyr 1985c, p. 123). But of course such retrospective analysis is intrinsic to historical method, to say nothing of such other fields as medicine where etiology and causation are the heart of the story. That such analysis *may* give rise to *post hoc* errors is true; that it is *likely* to do so is a function of the quality of the scholarship.

The Crafts article also makes much of a stochastic model in which a "lucky" gain can translate into a string of further advantages; so that in the eighteenth century, one key innovation might have (could have) developed into an industrial revolution and put the British economy far ahead of the French, whose chances *ex ante* were equally good (Mokyr 1985c, p. 127). This theme is further developed in Mokyr's introduction to this volume (Chapter 1). I find such mathematical modeling surreal if amusing: the *deus ex machina* is a convenient tool in drama and fiction, and no one's life is immune to accident, but macrohistory, that is, large and complex institutional change, does not work this way. In any event, the argument does not hold for British priority in industrialization, as contemporaries well understood. On Crafts and the path dependence of a lucky (or unlucky) strike, see Landes, "What Room for Accident in History?" *Ec. Hist. Rev.*, 47, 4 (1994): 637-56.

[10]This divergence of quality of life between England and France is perhaps most marked in food preparation and selection: the French enjoy good, sometimes superb, cuisine; the British often eat mush and paste, bad enough to make palates close down. *Saucisson* and *pommes frites* vs. bangers and chip butty. To be sure, these contrasts vary over time. The Victorian years and industrialization seem to have been especially hard on British taste. British cooking was at its worst right after the war, whereas the French managed to evade constraints in the midst of rationing. On this contrast and a more recent British comeback, see William Grimes, "Talk about a Fork in the Road," *New York Times*, May 9, 1998, p. A15.

the nineteenth century. . . . Truly, much of the England of 1850 was not very strikingly different from that of 1750."[11] Similarly, N. L. Tranter (1981, p. 226):

> The British Industrial Revolution was a very modest affair which emerged slowly from the past as part of a long, evolutionary process, not as a sharp, instantly recognizable break from traditional experience: its technology was small-scale and comparatively primitive; it needed relatively little additional investment capital; its capacity for introducing labour-saving technology was circumscribed; and its pace was gradual and uncoordinated.

And Sylla and Toniolo (1991, p. 9):

> There was no 'kink', no take-off in a Rostovian sense. Nor was there a 'discontinuity' around 1780, where a time-honoured tradition places the beginning of the so-called Industrial Revolution. If anything, the start of the Industrial Revolution has to be pushed three decades back, but even then, the acceleration that took place hardly allows one to speak of a sudden substantial change in the growth of industrial output.[12]

And Harley, dismissing what he feels to be the conventional wisdom (1990, p. 22): ". . . it seems impossible to sustain the view that British growth was revolutionized in a generation by cotton spinning innovation."

The Uncertainties of Numbers

Yet not everyone is persuaded by the new, would-be orthodoxy, and this obstinacy has sorely tried the patience of the more passionate adherents of the new dispensation. Rondo Cameron, once an active contributor to our awareness of the

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[11]My first inclination on reading these lines of Musson was to assume that he was referring to some kind of general state of mind, a sort of popular historical myth; which may be the case. But Crafts, Leybourne, and Mills (1991, p. 125) remind us that Eric Hobsbawm, in his now classic handbook on *The Age of Revolution* (1962, p. 28), spoke of the 1780s as the point where "all the relevant statistical indices took that sudden, sharp, almost vertical turn upwards which marks the take-off." They focus on the suitability of 1780 as turning point; I would express surprise that a good Marxist like Hobsbawm would adopt a term from Walt Rostow's "non-communist manifesto." The point is that metaphor can be misleading as well as illuminating. Still, we shall see that Crafts *et al.* (1991, p. 132), using the latest cliometric estimations, offer charts of British trend growth that support Hobsbawm's image. For some citations of other users of a revolutionary vocabulary, including me, see Mokyr 1991, p. 255.

[12]This statement is part of an introduction to the essays in *Patterns of European Industrialization* and supposedly rests on the contribution by Crafts *et al.* in that volume. I do not think it reads that essay correctly, which is much more cautious on the question of discontinuity (see p. 125) — indeed more cautious than its own data would permit (see Figures 7.1 and 7.2, p. 132). See also below, p. 147.

significance of the new industrial technology and now seized with remorse, has been calling at every opportunity for the abandonment of the term "Industrial Revolution" on the grounds that it is inaccurate, unscholarly, and misleading. The lack of response, moreover, has only made him shriller. For Cameron now, to write Industrial Revolution with capital letters is to "deify" it. And to reject what he calls "recent new knowledge" is to behave like a "fundamentalist ayatollah of economic history" (1991, p. 1165). And yet the name Industrial Revolution is not only consecrated by clarity and convenience; it accords with good English usage of the word "revolution," whose figurative sense of a profound change goes back to the fifteenth century and long antedates the meaning of a sudden political overturn. It will not go away.[13]

Or take Eric Jones,who in *Growth Recurring* believes every revisionist word and gives the back of his hand to what he calls the "technicist" view.[14] Is this disparaging term his invention — a way of deriding all that fuss about new ways of doing things?[15] In any event, he clearly has no patience with those who do not or will not see the light: he describes the "old interpretation" as "a dead horse that is not altogether willing to lie down" (p. 19).

But why should it? It's not dead. And what has it been saying?

One response has been to question the message of the new numbers — to point out that statistical aggregation smooths out discontinuities and drowns innovation and change in a sea of tradition. The Industrial Revolution, after all, was an exercise in selective, unbalanced growth, so that changes in a few branches,

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[13]But what of the suggestion that we speak of evolution rather than revolution? This is the subject of Joel Mokyr's essay, "Was There a British Industrial Evolution?"; also of the final chapter of his book *Lever of Riches* (1990). To be sure, Mokyr's evolutionist model (Gould, Goldschmidt, *et al.*) has room for macroevolutionary mutations and leaps, hence for evolutionary revolutions or revolutionary evolution. Yet Mokyr points out and criticizes the fact that economic historians, in using the evolutionist model or metaphor, have implicitly adopted the purely gradualist version; and it is not unreasonable to suppose that some readers, like reviewers who know a book by its jacket, may never get past his title. In any case, "industrial evolution," however true, is not a substitute label for industrial revolution.

[14]Jones 1988, p. 19. On the tendency to presume that newer is truer, compare Robert Merton's fallacy of the latest word, cited in Gudmund Hernes 1989, which deals with the similar running debate on the merits of the Weber thesis.

[15]He has company. Knick Harley echoes this depreciation of technology in the following terms (1990, p. 40): "The technological breakthrough in industry occurred in Britain in part because of the dynamic character of the economy but Britain probably also benefitted from a lucky draw in the random process of invention." It does seem strange to me that economists (or economic historians trained as economists) should think that major differences in the direction and pattern of invention are or were a random process.

however spectacular, took time to work through to the rest of the economy.[16] A stronger version would note that some of these changes were destructive as well as constructive, that is, they shriveled some branches while swelling others; and that aggregate gains necessarily reflect this process of compensation. One might even argue that it is precisely this demonic aspect, this drastic contrast between new and old, that measures the revolutionary character of the new technology. What matters is not the initially low rate of increase but the fact of a new trend of continuing and accelerating growth. (More on this below.)

One may make a similar point about regional disparities. Pat Hudson (1989, p. 1) points out that aggregate data and averages conceal significant spatial differences in development and miss the discontinuities and the important foci of innovation and transformation. (In effect, this is a reminder of the limits of aggregation: the national income/product approach, for all its claims to understanding and authority, is not good enough [cf. McCloskey 1991, p. 99, citing Gerschenkron 1968, pp. 34-35].) Recent research into real wages would support this regionalist view: thus we have significant differences in wage trends and levels between the manufacturing districts of the North and the agricultural South; the former go up, the latter fall (Hunt 1986, Hunt and Botham 1987, Schwarz 1990), and that is as it should be in a process of uneven growth.

A second argument, advanced by Jeffrey Williamson (1984, 1987), who also agrees with the first (1987, p. 273), is that British government financing, especially in wartime, crowded out investment in industry, which could not take advantage of its technological opportunities. Not everyone would agree with that, in part because the issue is complicated by earlier movements of capital into Britain and by the debt-melting effects of inflation, and obscured by the incompleteness and artificiality of the statistical data (Mokyr 1987). Still, one could make the argument that, other things equal, Britain would have grown faster had it been able to put resources into productive rather than destructive activities. A quarter-century of almost continual war during the period of the French revolution and the reign of Napoleon did not help.

In short, this love affair with numbers entails all the risks of instant passion. Or to cite another metaphor, it is really no more than the make-believe of children: Joel Mokyr compares some of this quantitative casuistry to "a fight between two

[16] Joel Mokyr (1985, p. 5) offers an arithmetical hypothetical on this point: if the modern sector starts with 10 per cent of output and grows at 4 per cent, while the traditional 90 per cent grows at 1 per cent, it will take 75 years for the former to account for half of output. McCloskey (1991, p. 100) suggests that we call this the weighting theorem, or maybe the waiting theorem.

toddlers blowing soap bubbles at each other. Their weapons are too dull to decide the issues at stake" (1987, p. 308).[17] These macro- and microstatistical calculations are all of them bold and ingenious constructs. They build on a variety of theoretical assumptions, often unspecified, that shape (distort) reality to the needs of calculation; make generous use of proxies, interpolations, and extrapolations to fill in the spotty data; combine data from different sources, assembled at different times for different purposes; make drastic assumptions about the changing composition of the work force and draw inferences therefrom about the changing composition of product; assign suppositious and arbitrary growth rates to some branches by way of making the overall increase fit into predetermined limits;[18] and use compromise price and volume indices in the expectation that these will be only half wrong.

To be sure, what we may call the law of abundant error (analogous to the law of large numbers) comforts tenacious arithmeticians in the hope that mistakes will cancel out. In this instance, though, such hope would seem unjustified. There is bias as well as error in these techniques and numbers: bias toward smoothing and bias downward in calculation of rates of change. These indices, for example, do not incorporate new products and improvements in quality over the period of comparison and thus necessarily underestimate the rate of real growth (Mokyr 1990). They also aim at compromise, try to arrive at measures that fall between change *ex ante* and change *ex post*. Such a compromise makes sense when calculating price changes; but where quantities are concerned and one is trying to

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[17]Mokyr's reference is to the statistical measure of agricultural output. But it is a good image and would apply as well to many of the other statistical quarrels that fill the literature.

[18]"One recent exercise found that after adding up British productivity gains in a few major branches — cotton, iron, transport, agriculture--no room was left for further gains in the other branches: other textiles, pottery, paper, hardware, machine building, clocks and watches. What to do? Simple. The author decided that most British industry 'experienced low levels of labor productivity and slow productivity growth--it is possible that there was virtually no advance during 1780-1860.' This is history cart before horse, results before data, imagination before experience. It is also wrong." Landes, *Wealth and Poverty*, pp. 196-97, citing Crafts, "British Industrialization in an International Context," p. 425. Also Crafts, Leybourne and Mills, 1991, p. 116. For a more reliable analysis of growth and gains across the industrial board, see Temin, "Two Views." Also Berg (1985), who does not start her story in 1700 by accident and is especially good on the metal trades; and on the second part of the period, the first volume of Clapham's classic and still useful *Economic History of Modern Britain* (1930). See also Donald Coleman on paper, Peter Mathias on beer, Neil McKendrick (1960) on pottery and porcelain and similar industrial monographs. These branches, described imperfectly by Crafts as "traditional, small-scale and catering for local markets without entering into international trade," were not standing still and did enter into international trade.

reckon the impact of technological progress, it necessarily underestimates the extent of the achievement.[19]

Worst of all, the "cliometricians" generate their numbers in a static context that does not take into account the interactions of change. Every gain is "cut down to size" — a fraction (say the saving of labor yielded by an innovation) of a fraction (that part of a branch affected by the change) of a fraction (the place of that branch in the larger economy). By the time the arithmetic is done, innovations of literally global impact (say, the transformation of cotton spinning) are reduced from earthquake to tremor. D. N. McCloskey, in a new introduction to the second edition of *The Economic History of Britain, 1700-1980* (1992), calls this effect Harberger's Law and recognizes that it truncates reality. It makes it impossible, for example, to account for a twelvefold increase in income per head in Britain since 1780 — not to mention, I would add, even greater gains in other industrial nations.[20] The fault, he says, lies with the economists: "It is in fact something of a scientific scandal that

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[19]The compromise solutions to the classic index number problem, designed originally for the construction of price series, are particularly unsatisfactory in measuring growth due to technological change. So far as I can tell, all calculations of British industrial or national growth have thus far chosen solutions that bias downward the contribution of such rapidly changing branches as cotton and iron, partly because they do not use prices for the year of origin (which are the only ones that convey the productivity effect), partly because they underestimate or do not (cannot) catch the gains in quality and novelty. The usual formulas (A. L. Bowley, Irving Fisher, François Divisia) aim at producing reasonable composite series by using one or another compromise mean, not at measuring the impact of productivity change. I submit that the proper way to gauge productivity gains is by using a Laspeyres volume index, that is, by using zero-year prices throughout: in other words, how much would it have taken to produce that amount of goods using the older technology?

[20]Compare McCloskey 1981, p. 108, who implicitly uses a Laspeyres-type comparison to demonstrate the impact of the Industrial Revolution:

> What was extraordinary about the industrial revolution is that better land, better machines and better people so decisively overcame diminishing returns. Had the machines and men of 1860 embodied the same knowledge of how to spin cotton or move cargo that they had in 1780 the large number of spindles and ships would have barely offset the fixity of land. Income per head would have remained at its level in 1780, about £11, instead of rising to £28 by 1860.

Note that this approach is in some ways analogous to the concept of social saving, which is the economy yielded by a given innovation (or cluster of innovations) by comparison with the next-best alternatives, on the reasonable assumption that improvement in the older technology would have occurred even in the absence of the innovation. Such a fictive comparison demands, of course, much imagination and boldness. (Compare Fogel, 1964, who plays, but only plays, with the question, what if the alternative to the railway were, not canals or not only canals, but precocious automotive transport.)

economists have not explained modern economic growth (1992, p. 33). Coming from a hitherto true believer like McCloskey, that is a serious indictment. In the light of this charge, I submit that the "new economic historians" have been looking in the wrong direction. They would do better to turn toward history.[21]

The Value of Old Scholarship

So the quantifiers build brave structures on shaky foundations (Jackson 1992; Berg and Hudson 1992). Perhaps the best of them, Charles Feinstein, warns in a recent essay that his numbers for the key variables of British economic growth can be little more than "insecure guesses," that most estimates of output and income before the late 19th century are likewise "guesstimates," and that attempts to measure and date changes in the investment ratio or assess the contribution of capital to the growth of output and productivity will continue to be a hazardous undertaking" (cited in Cole 1989). Hazardous indeed. In its short history, cliometrics has already seen considerable revision and re-revision of findings that once seemed authoritative for their numerical character. Why assume that we have heard the last word? But let us assume just that and concede that the "guesstimates" of scholars like Feinstein and Crafts are smart, informed, and reasonably close to what actually happened; that as Crafts put it in a confident moment, "The dimensions of economic change in Britain during the Industrial Revolution are now reliably measured" (Crafts 1989a, p. 416). Some people are better guesstimators than others because they are not merely guessing; they have some data to go on and they possess superior critical faculties. Indeed, *for the*

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[21]While deploring the limitations of static analysis (it cannot explain what happened), McCloskey (1992) does give it credit for demonstrating the "nots" — by which he means the things that are not true, the alleged causes that will not explain enough. Static arithmetic, he argues, shows us that one cannot explain modern industrial growth by foreign trade or transport improvements or literacy or scientific advance or whatever. The difficulty here seems especially to afflict economists: a passionate seeking after The One Cause, the prime mover, and the consequent serial demolition of one good cause after another. Why? Because as every economist knows, one good reason is enough (an axiom), so one looks for the good reason and the inadequate reasons are bad. Unfortunately, since everything is substitutable and nothing is indispensable (another axiom), good reasons are hard to come by. As McCloskey puts it (1992, p.23), "We have not discovered any single factor essential to British industrialization." Surprise. No wonder some have been tempted to see the whole thing as a stochastic phenomenon.

Historians do not have this problem. They do not pursue the will-o'-the-wisp of the single essential factor. On the contrary, they rejoice in and gain honor by multiple causation: one good reason is enough, but two good reasons are even better. Historians know that a given factor may not explain everything, but so what? It combines with other factors to play its role in the actual process. On this level, it is essential. So are others. Change the mix, and you change the result.

purposes of this essay, I am prepared to believe them all, even when they differ. That still leaves the question of interpretation. What does all this mean?

The first thing to note in that regard is that this debate over continuity vs. discontinuity is an old business. Historians never tire of it, because it provides matter for endless retort and rejoinder. It is the stuff of controversy and debate, and controversy and debate are the stuff of Ph.D. theses and professional reputation. The Industrial Revolution is only one of a large number of topics that have generated such arguments: think only of Pirenne's *Mahomet et Charlemagne* (was the fall of the Roman empire a major break?); or the still hot issue of the character and consequences of the French Revolution (Tocqueville's continuity vs. Republican and socialist doctrine of the world transformed); or that favorite Japanese *topos*, how much credit to give to Tokugawa antecedents of Meiji growth.

On this level, there is more noise here than light. In the Industrial Revolution debate, as in most of these others, both sides are right: history, of its nature, is a constant interplay of continuity and change. Everything has its antecedents; but nothing remains the same, and some changes are more drastic and rapid than others.

None of this is new, then. It should be recognized that earlier generations of historians of the Industrial Revolution, for all their emphasis on its revolutionary character and consequences, were explicitly aware of its gradual penetration of the larger economy and its protracted character. I have already cited Clapham in that regard: he did not have national income constructs, but he did have the census, and that told him volumes about the tenacity of older branches of economic activity. Nor were they unaware of the long preparation of these developments: history, like nature and vacuums, abhors leaps and random walks, and generations of scholars worked to understand why England, and why England first. Let me recall William Cunningham, author more than a century ago of what we may call the first textbook in British economic history: ". . . the History of industry does not describe a series of remodellings made from without, but a slow and continuous growth that takes place from within" (1885, p. 2); and then again, on the importance of preparation (1907 [as reprinted in 1922], p. 610):

> It was not an accident that England took the lead in this matter; the circumstances of the day afforded most favourable conditions for the successful introduction of new appliances. Inventions and discoveries often seem to be merely fortuitous; men are apt to regard the new machinery as the outcome of a special and unaccountable burst of inventive genius in the eighteenth century. But we are not forced to be content with such a meagre explanation. To point out that Arkwright and Watt were fortunate in the fact that the times were ripe for them, is not to detract from their merits.

Or take Abbott Payson Usher, who focused on technological aspects of the story and might be expected, more than anyone, to stress the revolutionary character of these innovations:

> The Industrial Revolution was thus a revolution in every sense of the word, except that of suddenness of transition. But the extraordinary character of the transformation must in itself be sufficient to convince one that such changes in the matters of daily life could not take place suddenly. Particular machines can be brought to public attention within a brief space of time; the form of industrial organization can be changed, though that would inevitably require a longer period. But the Industrial Revolution was more than any such formula could possibly imply. The "Great Inventions" were merely a stage in a long development of a new mechanical technique, neither the beginning of the new order nor its culmination. The rise of the modern factory system was only one of the many results of mechanical change, industrial dislocation, and commercial development. The abandonment of the idea that the Industrial Revolution was sudden involves a considerable readjustment of chronology for the entire movement. The study must be carried farther back into the past and continued down nearer to the present time. The establishment of even approximate limits is obviously difficult.

This, in 1920 (p. 271).

I would note in passing that Usher, the product of an earlier, more literate era, understood here that the word "revolution" has more than one meaning.

Reading this and other warnings of the gradualism *cum* rapidity of these developments (I would stress, as Ashton did, this paradoxical combination),[22] one wonders whether the "new economic historians" of today have ever read this literature (it is hard enough to keep up with new material); or if they have read it, whether they remember it. It is as though economic history were like physics: the older works fall into rapid desuetude and well-deserved oblivion because they no longer have story right.

For surely, if the new economic historians had been aware of this literature, they would not have been shocked to "rediscover America"—to find overall industrial growth of 3 per cent per year; and low rates of capital formation in an industrial revolution of low capital requirements; and water power playing an important role throughout; and small enterprise coexisting with large; and agriculture persisting

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[22] "There is a danger of overlooking the essential fact of continuity . . ." (Ashton 1948, p. 2). I would add that Ashton had misgivings about the word *revolution*. He, along with J. H. Clapham, Herbert Heaton, and others of his generation, made it a point to warn the reader of its shortcomings, not only because the Industrial Revolution took time but because they would have preferred a word without, for them, unhappy political connotations.

and improving alongside industry; and railways generating perhaps a tenth of British national income in the mid-19th century.

Instead they would have asked such questions as, what is slow? or what is fast? what is large? what is small? And what matters in assessing significance: level or trend? aggregates? or foci of change?[23] If you were an investor, where would you place your bets?

And so for the British Industrial Revolution. The rates of change were low by 20th-century standards; also clearly lower than these historical income accountants had expected. But were they *low*?

They were certainly not low by comparison with what had gone before. Not that there had not been growth before. There had to be, and that was part of the preparation for industrial revolution. That was one of the reasons Britain came first: thanks to the cost advantages of rural putting-out, its textile manufacture in particular was growing faster than those of other European countries in the decades preceding the invention of the new carding and spinning machinery and the development of new power sources.

But we also know that, from about the 1760s, growth took an upward turn and proceeded at a higher rate. There was in other words a discontinuity, a break in the curve. We know that by extrapolating backwards. It takes some 99 years for income decreasing at 0.7 per cent per year (Crafts's estimate of the rate of growth in the early 18th century) to halve; go back two centuries, and even at this slow pace, one arrives at impossibly low levels of income. Use Crafts's 1.3 per cent rate for the end of the century (after the early innovations of the Industrial Revolution), and it takes only 38 years for income to halve.

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[23] I am reminded of a dinner of the Friends of Business History at Harvard back in the 1960s where I had been asked to comment on the contribution and significance of the so-called New Economic History. At that time, this meant above all Robert Fogel, whose work on the contribution of the railroad to American economic growth was the sensation of the day. (It had everything: lots of numbers, a new technique of argument [counterfactuals], and a surprise ending: the railway had marginally contributed less to U.S. economic growth than anyone would have guessed — maybe 4 per cent of national income in 1890, at most 6 or 7 per cent.) Anyway, I sat down at the head of the table, all prepared to say something measured, safe, and wise, like: The New Economic History is still small and poses serious problems of method and significance, but . . . it does use powerful techniques; it makes more, and more explicit, use of economic theory; and it will become more important with time. But when I looked around, I saw facing me across the way none other than Fogel himself, in Cambridge on a short visit from Chicago. Intimidating. I said my say, but as you can well imagine, my monologue became something of a dialogue with Fogel. And this was the livelier because also in the room was my own teacher, Abbott Payson Usher, long retired and into his 80s, but as sharp as ever. And he asked the big question of the evening, namely, how big is 5 per cent or 6 per cent? (Those were the percentages I recall our playing with that evening.) To that question, no one — not even Fogel — had an answer.

We also have the estimates of aggregate industrial output, including both modern and traditional sectors. They tell a story of industrial revolution. The latest series (Crafts *et al.* 1991, pp. 132-34) of trend growth for Britain show a sharp swing upwards from shortly after the middle of the 18th century and peaking about 1830 —very close to the dates advanced by such scholars as Usher and Ashton half a century and more ago (See Figure 2.2).[24] One can argue about the turning points

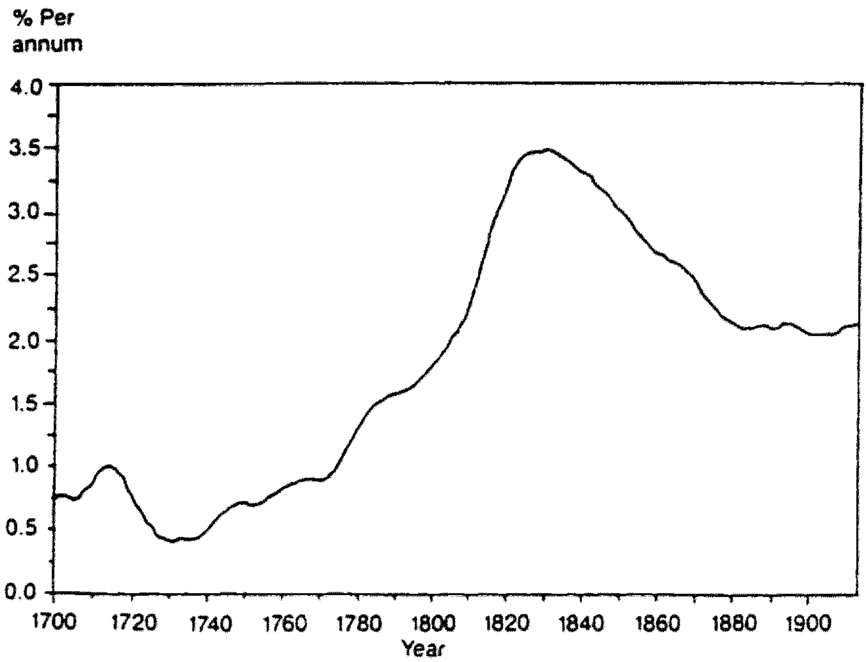

FIGURE 2.2: Great Britain. Trend Growth of Industrial Output, 1700-1900.
Source: Crafts, Leybourne and Mills (1991, p. 132).

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[24]It is interesting to compare the statistical techniques of three quarters of a century ago with today's. They were of course far simpler then: Usher (1920, pp. 310-12) took as his measure of gains in productivity the unadjusted selling price over time of single, homogeneous commodities, in the case of the textile manufacture, of No. 40 and No. 100 cotton yarn. The result in both instances, especially in the latter, is an exponential price curve downward from 1770 and pretty much leveling off after 1830--very much like a learning curve. For this datum (the timing of the Industrial Revolution), I have more confidence in this kind of proxy than in the ingeniously complex aggregations of today's cliometricians.

—push up ten years, push back ten years, mark from trough, mark from the point where trend passes the earlier peak—but there is no mistaking the fact that industrial growth was now faster than before and did not recede again to early 18th-century levels.

So something had changed. That something was essentially technology — the way of doing and making things — with substantial and ramifying effects on productivity, prices, and size of market. In that regard, I am astonished by the assertion of Eric Jones that, "the nexus between technology and economic growth is not particularly strong" (1988, p. 54), for such an assertion is simply wrong in fact and in logic. Although it helps to distinguish between growth (or what Jones prefers to call "intensive growth," that is, growth per head) and technical change, if only because one can conceive of gains in income per head that do not derive from gains in real productivity (for example, windfalls from newly discovered resources, or favorable changes in relative prices and the terms of trade, or increases in trade and profits therefrom, or rents derived from growth itself), it is a mistake to think that such increase can be sustained if not accompanied and supported by technological advances.[25] These may take the form of hardware or software: of new products or new ways of producing; or even of new and more efficient forms of organizing labor (Adam Smith's progressive division of labor would fall in this last category).[26]

Ramifications

These changes in technology, everyone agrees, did not happen overnight. Old ways and forms, persisted alongside new. But however gradual, these changes were deep and unprecedented, with comparably serious consequences, both positive and negative, for the condition of the population. There is no room here to do justice to the tenacious and probably everlasting debate (which numbers will not settle)

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[25]That is the soft form of the proposition. I would argue the hard form: that although such technology may be imported, as is often the case with multinationals or joint-ventures, unless an economy possesses technological autonomy, that is, the ability to generate its own innovations, technical advances will not ramify and the modern sector will remain encapsulated, a kind of industrial plantation. Cf. Krikkiat and Yoshihara 1989.

[26]On the implications of division of labor for technological innovation, one has only to consider the history of clock and watchmaking and the invention of special-purpose tools that later found application in the manufacture of machines. Mokyr 1990, 323, nn. 7-8, would cast doubt on this connection and asserts, "Before standardization and interchangeable parts, . . . the simplification of work brought about by the division of labor as such was not significant." But it was precisely this simplification, which grew out of specialization and made possible batch production, that suggested the utility and method of interchangeable parts (cf. Landes 1983, chs. 16 and 18). Mokyr cites Brenner 1987, who cites Smith's own intellectual versatility as a kind of argument against the alleged advantages of work specialization. I don't get it.

between the optimistic and pessimistic views of the social impact of the Industrial Revolution. There is truth on both sides, and the bottom line depends greatly on the dates chosen for comparison.

What needs stressing, however, is the rapidity with which technological change impinged on the livelihood of old workers and translated into protest, much of it violent. Changes may have been making their way in some regions more than others, in some industrial branches more than others, and slower than some enthusiastic scholars may have thought. But do not tell that to the people affected: the pauper apprentices; the women who were sent to work in the mills where their husbands or fathers would not go; the displaced craftsmen; the residents of once-

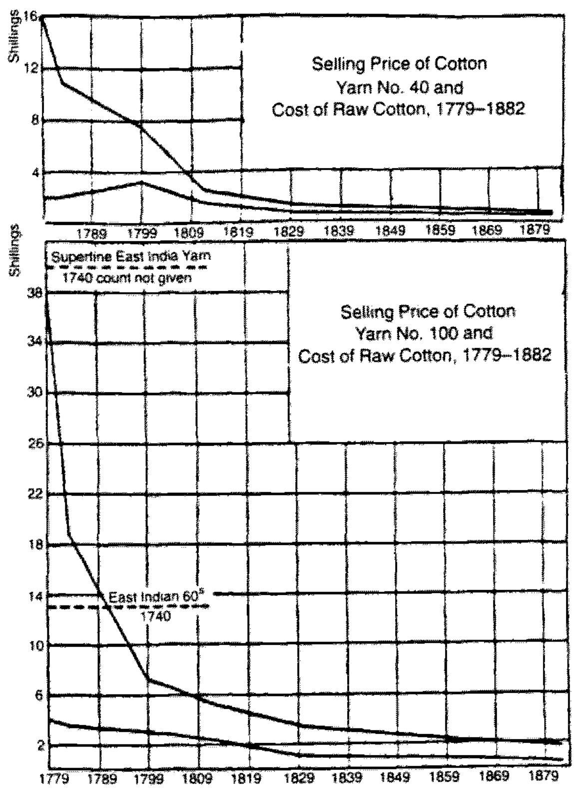

FIGURE 2.3: Great Britain. The Learning Curve in Textile Manufacture—The Selling Price of Cotton Yarn and the Cost of Raw Cotton, 1779-1882.
Source: Usher (1921, p. 311).

green valleys now renamed the Black Country; the Irish immigrants who did the dirty work. Or for that matter, to the winners of the new industrializing world: the managers, merchants, and shopkeepers, the newly skilled and the "labor aristocracy," the consumers of the new commodities and of older ones now within reach, the multiplying professionals in growing towns and cities. The machine breakers did not need to wait 75 years for the new technology to work through its potential to know they were hurting. The doctors who had to deal with new health problems in mining villages and urban slums and wynds in the 1790s quickly understood that industry was growing and changing and injuring people. Meanwhile conservative moralists in distant lands were, already in the 1760s and 1770s, lamenting the effects of material seduction and stimulation on once-simple rural populations (cf. Muller 1990, pp. 170-172). For them, personal experience was a good proxy measure of revolution; and for us, with our subtle number play and 20/20 hindsight, it is a fair reminder that there is more to life, work, and death than macrostatistics can tell.[27]

The Contemporaries Understood

When the British began to move ahead of their neighbors and inaugurated a new, more productive mode of production, they did so because, building on earlier gains, they found technological solutions to the stresses and opportunities of widening and deepening markets. They substituted machines for men; they used more and more inanimate power; they found new materials or made old materials and products better, bigger, and faster; and they organized all of this in larger units that brought labor together under supervision.

This did not mean that they had a monopoly of discovery and invention. On the contrary, their neighbors and rivals on the Continent were as advanced as they in science and created their own innovations to meet the needs and opportunities of their economies: one thinks for example of the French improvements in silk manufacture, or their production of sugar from beets once colonial supplies were cut off, or their manufacture of alkalis by the Leblanc process in response to a similar problem. But the British innovations had wider economic consequences because the demand for these products was potentially larger and supply more elastic (compare cotton and silk for supply and cheapness); and because they had

[27] I would add to that the silent effects, the ones that contemporaries could not begin to appreciate. My favorite is the consequences for health of the introduction of cheap cotton underclothing, replacing the body linen used by the wealthy. In a world of primitive toilet and washing facilities, the greatest endemic threat to health was gastro-intestinal infection, easily passed by unwashed hands that had come into contact with body wastes. The lack of easily cleaned undergarments was an invitation to skin irritation, scratching, and thus transfer of pathogens from body to hands to food to digestive tract. The new underclothing, in combination with cheaper soaps, probably saved more lives than all the medical advances of the century.

wider ramifications within the larger economy (thus multiple uses of iron and the general applicability of advances in power technology). They were the stuff of an industrial revolution. *Pace* Nick Crafts (1977), the French changes were not.[28]

The nations of Continental Europe, of course, understood that. They also understood that such innovations enhanced enormously Britain's wealth and political strength while threatening industries and crafts everywhere else, to say nothing of their deleterious consequences for social stability and for what some would now call "family values" (Muller, 1990). In short, the Industrial Revolution was upsetting the European balance of power; and the other nations understood that if they did not follow Britain's suit, for all the risk and discomfort that that entailed, they were condemned to secondary, dependent status.[29] (This was the same judgment made by Japan almost a century later: modernize or become another China.)

Fortunately for these Continental follower countries, they were not able to read the "New Economic History." So they did not think they were doing just fine, maybe even better than Britain, and that cheap imports, *haute cuisine*, and picturesque landscapes are an adequate compensation for lower wages and incomes. Nor for that matter did they listen to British injunctions about the advantages of an international division of labor in which Britain would be workshop of the world and they would supply food and raw materials.[30] Instead they read Alexander Hamilton,

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[28]There is also good reason to believe that the level and diffusion of mechanical skills were more favorable in Britain. One may reasonably infer that from the difficulties the Continental countries had copying the British machines. Whence this superiority? I would lay heavy emphasis on the British advance in clock and watch manufacture (clockmakers constituted the preferred pool of skilled workers for the making and maintenance of textile machinery, and the wheelwork was commonly known as clockwork) and on the precocious recourse to water and steam power in mining and industry. (Landes 1969, 61-63; 1983, 219-27; also Mokyr 1990, 235-39.)

[29]In a strange, even bizarre, excursion, D. N. McCloskey has tried to decouple Britain's economic lead and the strategic interests of other countries, and by implication to devalue its significance, by arguing that the nations of Continental Europe should not have been concerned about British industrial gains for political reasons, that industrial power was (is?) not a vital ingredient of political and military power: "In economics there are substitutes, even if there are not in chemistry" (1990a, p. 42; also 1988, p. 647; 1990b, p. 295). That inference from theory strikes me as dead wrong, but even if it were right, it would not be relevant to the decisions of contemporaries of the Industrial Revolution, who thought otherwise. But then they had not had the benefit of courses in neoclassical economics. A little theory is a dangerous thing.

[30]Cf. Kiesewetter (1991). For a similar siren song regarding the consolation for the United States of being able to buy good, cheap foreign goods at the expense of American wages and employment, see Baumol *et al.* (1989) and Williamson (1991).

J. A. Chaptal, Friedrich List, and the other advocates of strong and deliberate measures to promote industrial change. And they caught up with Britain, in the case of Germany even passed it, much to Britain's surprise.[31]

In sum, the basis of wealth, hence power, had been transformed. Those nations that were able to emulate these new technologies became rich, richer than anyone could have dreamed. By comparison the rest of the world was poor; and with the spread of European dominion, the widening European presence, the ever more visible contrast of the industrial artifacts and material exigencies of the white man and the limited resources of people of color, the poor came to know they were poor. As a result of these gains in productivity, the gap between Europe and its overseas offshoots (the "West") on the one hand, and the preindustrial Rest on the other, already significant in the sixteenth century but still quantitatively modest, now became a gulf. If we accept the bold estimates of Paul Bairoch (1979), income-per-head ratios between Europe and the great Asian empires went from 1:1 or 1.5:1 in the 18th century to 50:1 or even 150:1 in the 20th. For the growing spread between the developed and the underdeveloped countries, see Table 2.3, which also rests on Bairoch's estimates. These figures are composite averages, which soften the contrast. At the extremes (Switzerland vs. Mozambique), the income gap in 1990 was 300 or 400 to 1.

Such a chasm is not impassable, but is large and difficult enough to be a source of resentment, discouragement, humiliation, and hostility.

This gap between industrial and nonindustrial, rich and poor, is probably the most serious political, social, and moral challenge of our time. How to close it? By helping poor countries to do what their predecessors have done: they have to effect their own industrial revolution. This will not be the same as the old; it cannot be. D. N. McCloskey warns that the Industrial Revolution as accomplished in Britain

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[31] As in France and Prussia, so in the British colonies of North America. Already in the 1760s, the growing resentment of the colonists against British protectionist trade policies and fiscal initiatives gave rise to an interest in promoting import substitution. And since the subservient colonial governments could not be expected to pursue their own protectionist policies, the leaders of this movement called for a voluntary boycott of British manufactures. Among the more active of these visionaries: Benjamin Rush, newly graduated in 1768 from Princeton and beginning his medical education at the University of Edinburgh. Cf. his letter of April 1768 to Thomas Bradford, publisher of the *Pennsylvania Journal and The Weekly Advertiser*: "Go on in encouraging American manufactures. I have many schemes in view with regard to these things. I have made those mechanical arts which are connected with chemistry the particular objects of my study . . . .Yes, we will be revenged of the mother country." Quoted in Brown 1989, p. 557.

TABLE 2.3 Relative Backwardness of Groups of Countries, 1800-1970 (GDP per capita in 1960 US dollars)

	1800	*1860*	*1913*	*1950*	*1970*
Developed Countries					
(A) Average	198	324	662	1054	2229
(B) Most Developed	240	580	1350	2420	3600
Underdeveloped Regions					
(C) Average	188	174	192	203	308
(D) Less Developed	130	130	130	135	140
Relative Backwardness					
B / A	1.2	1.8	2.0	2.3	1.6
A / C	1.1	1.9	3.4	5.2	7.2

Source: Hikino and Amsden (1993, pp 6-7).

is a poor model for would-be industrializers.[32] That it is, for it is an obsolete model. The technological content of modernity keeps changing, and that very change of content is another process that has been accelerated by the Industrial Revolution.

The details pass, but the substance remains; and this revolution (I use the word advisedly), for all that some historians would depict it as a small, gentle bump on a pre-existing trend, was in Britain and has been elsewhere a wrenching, compelling force for change. In all the annals of human history, no innovation has been so universal in its appeal, so ecumenical in impact.

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[32]Cf. McCloskey 1981, p. 104: "The fascination in poor countries now with industrialisation on the British pattern, complete with exports of manufactures (in an age of ubiquitous skill in making them), puffing railways (in an age of cheap road transport), and centralised factories (in an age of electric power) would seem odd without the historical example in mind."

My own sense is that the "fascination" sketched out above has been shaped more by mid-nineteenth-century national economics and Marxian doctrine than by recollections of British industrialization. I would also observe that the ambition to export is a useful incentive to come up to standard; that poor countries no longer think much about building railways; and that the scale of factories is in large part a reflection of the production function. Some things call for large scale, while the multiplication of smaller units calls for entrepreneurial initiatives that are often harder to come by than the conventional factors of production.

The Resilience of Old Ways

But if such is the power of technology, why do we see these major, revolutionary innovations take so long to drive out older methods? Why do we see small units persist and even flourish alongside the factories of the new industrial order? Why do such older techniques as water power persist and even grow in efficiency and application?

These questions are not so difficult as they may seem, especially if one does not subscribe to simplistic views about the nature of technological change. Few innovations ever sweep the field. The electric lamp, for all its intrinsic superiority, did not put an end to gas lighting or, for that matter, to kerosene lamps and candles. And in spite of desktop and laptop computers, some people still type their manuscripts or even write them out by hand and then have secretaries, spouses, or friends transcribe.

For one thing, the early versions of innovations are always less than satisfactory, full of problems that have to be worked out, but also full of opportunity. As result, they may begin only marginally better than the older techniques, and they need a lot of work and attention. This was true, for example, of the new spinning machinery, perhaps the most immediately advantageous of the new equipment of the Industrial Revolution. It worked well at first only for coarser yarns, for only they had the strength to withstand the still irregular motions of the working parts. It took two generations to devise machines smooth enough in their motions to make the higher counts, higher even than could be made by human hand, and it was not until after 1815, for example, that British yarn was able to penetrate the Indian market and kill off the fine hand-spun yarn of the Indian peasant.

Secondly, older equipment does not ordinarily die and just abandon the field to its newer rivals. On the contrary, the users of old equipment are moved by competition to imagine their own improvements, so that the greatest technological gains often take place in obsolescence. Sailing vessels, for example, reached their peak only after the introduction of steam. Water power was enormously improved in the late 18th and 19th centuries, the biggest advances perhaps being the adjustable breast wheel (cf. Mokyr, 1990a) and the use of the turbine in place of the wheel. And today mechanical watches are better than they ever were, even though the quartz watch is simply, flat out, a superior timekeeper.

Thirdly, older technologies often have special, local advantages that ensure continued application. Water power, for example, was not available everywhere, but where it was abundant, it offered a cheaper alternative to steam; capital requirements were considerably lower. The same for wood fuel as against coal: in a timber-rich country like the United States, it paid to throw logs into the locomotive firebox. The same for the putting-out system and domestic manufacture, which offered real advantages over the factory in circumstances that made possible dependable performance. In the mid-19th century, for example, a number of the new power-loom enterprises worked along with domestic manufacturers, because this enabled them to handle the variance in demand without sinking unnecessarily large sums into fixed capital. There was, and is, a symbiosis between newer, larger-scale modes of manufacture and older, smaller units. Why should we be surprised that the old did not disappear overnight?

Accounting for Misunderstanding

The question has been raised, why, if the written record and (I would say) the numbers are so clearly on the side of a gradual but profound revolution, is this new orthodoxy so dismissively triumphant? Why are people so ready to argue that the new data constitute a revelation, that the term *Industrial Revolution* is a misnomer, that nothing of the kind happened, or that if it did, it had little effect?

I shall hazard a number of reasons:

(1) This is one more example of the kind of cyclical revisionism that characterizes all the social sciences. The best way to attract attention, get a Ph.D., get a good job, get promoted, is to stand things on their head. As a cynic once put it, we climb on the backs of our predecessors.

(2) David Cannadine, in a provocative historiographical article of 1984, argues on Crocean grounds ("all history is contemporary history") that this new turn in opinion reflects a larger change in public and political mood; that the slowing of economic growth in the 1970s (oil shock) and the growing doubts about its inevitability and even desirability led to a more negative assessment of the Industrial Revolution and turned the "dissenting views of the 1960s and even some of Clapham's dissenting views of the 1920s" into a new orthodoxy (1984, p. 162). Joel Mokyr strongly disagrees and feels that the moods, modes, and substance of economic history can be explained by endogenous considerations. I agree with Mokyr. Cannadine's Crocean interpretation might better apply to the views of J. H. Clapham, T. S. Ashton, Herbert Heaton, *et al.* in the interwar years.

(3) The fallacy of misplaced concreteness. Constructs and figments become reality. This is largely because numbers have power to lull the skeptical and intimidate the uncomprehending mind. They seem somehow more authoritative, and what's more, today's numbers are by definition better than yesterday's.

(4) The move toward quantification has resulted in a skewed recruitment into economic history. We do not get many historians any more, and that brings a loss — of sense of proportion and knowledge of context. We are stronger in some respects, weaker in others. (In a way, I am reminded of the Industrial Revolution: some branches grow; others shrink.)

(5) The cliometricians, thrilled by technical mastery, are too quick to scorn the quantitatively innocent; and these, *mutatis mutandis*, return the compliment. Here is Roy Porter (1992, p. 35) on E. P. Thompson's sense of intellectual and moral outrage: "How could an industrializing movement that shattered the lives of millions of workers be reduced to percentages and graphs? How dare number-crunching econometricians continue to ignore those workers who once had been exploited by the profit system?" In short, we are talking past one another.

(6) Economics as generally practiced is incapable of dealing with an industrial revolution. It deals with questions of efficiency and distribution and takes as its fundamental premise a version of the law of conservation of mass and energy: nothing for nothing, and there is no room for transformation. And since most revisionist "new economic historians" are by training, temperament, and self-esteem devotees of (neo)classical economics, they are similarly blinkered. D. N. McCloskey, a "new economic historian" of many parts, pinpoints the trouble: "The kind of growth contemplated in the classical models, embedded now deep within modern economics as a system of thought, was not the kind of growth that overtook Britain and the world in the late eighteenth and nineteenth centuries" (1992, p. 28).

(7) Anachronism is the enemy of understanding. The high rates of growth of the latter half of the 20th century make those of the 18th century look trivial. Similarly, the costly technologies and spectacular product innovations of today devalue the primarily process innovations of the Industrial Revolution. Else what meaning to give such statements as that of Tranter (1981): ". . . its technology was small-scale and comparatively primitive . . ."? Compared to what?

(8) Rhetoric and loose imagery are the enemy of understanding. The best of the definers of the traditional position were cautious and moderate in their propositions, as are the best of the cliometricians. Much of this debate, as always, is at second and third hand — epigoni vs. popularizers.[33]

The Industrial Revolution as Mega-History

When all is said and done, then, the supposedly new and revisionist picture of industrialization is not that different from the old. It is richer, more detailed, sharper in its analysis of the evidence. But talk of drastic revision strikes me as misleading and contrary to fact. To be sure, it is not easy to find a straightforward statement of the new and corrected past. Most revisionist generalizations take the form of broad criticisms of alleged convention, if not easy demolitions of straw men (and straw horses). But I would refer the reader to Knick Harley's reconstruction in the present volume — what he calls "a coherent new view of British growth" (1992 and ch. 3 in this book). Without repeating his view in all its details, the sense may be inferred from a few main points:

> The main growth occurred in cotton textiles. Cheaper cottons displaced competing textiles . . . . Large urban concentrations of industry occurred because the steam engine freed textile mills from water power and because the British economy redistributed labor and capital from rural agriculture to urban industry with considerable facility. . . . By 1840 Britain had achieved a notable economic leadership. Growth was clearly different after 1840 than it had been in previous centuries. . . . The economic change

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[33]It was Jacob Metzer who first put this suggestion to me, at a seminar in Jerusalem. I agree.

in Britain in the late eighteenth century and early nineteenth century marked the beginnings of modern economic growth.

We also have Crafts and Harley's verbal translation (1992) of the estimates of British industrial trend growth for the eighteenth and early nineteenth centuries (see Figure 2.2): "The distinguishing characteristic of the British case is a long period of steady acceleration of industrial growth from the mid-eighteenth century through into the second quarter of the nineteenth century." In the context of the technological changes that generated that growth, I would call that tacit (unwitting) recognition of an industrial revolution.

In the end, then, I come down on the side of Friedrich Engels. Steam and even more the clock, used as metaphorical symbols for a much larger complex of technological changes, transformed first Europe and then the world. The Revolution was a revolution. If it was slower than some people would like, it was fast by comparison with the traditional pace of economic change. Different aspects of life operate on different calendars (cf. Braudel's geological-geographic, socio-economic, and political times), and one must not expect to change an economy as one would a regime — as the nations of eastern Europe are finding out. Now as before, no serious history of Europe or the world will be able to make sense of our times without taking the Industrial Revolution and its sequels as the progenitors of a new kind of modernity.

We are its children, and children often try to diminish or kill their parents; but that does not change the fact of paternity or its importance.

I never saw a dead horse stand,
I never hope to see one;
But I can tell you, out of hand,
I'd rather see than be one.[34]

[34]With apologies and respects to Gelett Burgess.

3

Reassessing the Industrial Revolution: a Macro View

C. Knick Harley

Since the mid-nineteenth century, the standard of living in Western Europe and its offshoots has increased steadily. The relationship between the human population and the environment changed, apparently as a result of the Industrial Revolution in Britain between 1750 and 1850. The change was dramatic, perhaps comparable to the Neolithic development of settled agriculture, and needs to be explained if we are to understand modern economies. The Industrial Revolution led to factory industry, the modern industrial city, and an urban industrial proletariat, but recent reassessment suggests that the sudden Industrial Revolution was not the only engine of modern growth. The eighteenth and early nineteenth centuries need to be examined anew for other sources of growth.

Recent demographic history provides a long perspective on European growth (Lee, 1973, 1988; Wrigley and Schofield, 1981). Juxtaposing English population and the real wage of workers for the last seven centuries (Figure 3.1) reveals dramatic change about 1800. In earlier centuries over long periods, real wages rose and fell in inverse relationship to population, but real wages were without secular trend. The Black Death in the fourteenth century killed about a third of England's population, and population remained low until the early sixteenth century. Workers in the smaller population enjoyed nearly twice the real wages of their pre-plague ancestors. Population then grew during the sixteenth and first half of the seventeenth century, and wages fell to pre-plague levels. History conformed to economists' theoretical expectations, first developed by David Ricardo about 1800, that wages in an economy constrained by limited resources vary inversely with population.

Since Ricardo's time, wages' inverse relationship to population has disappeared. Between 1820 and 1980 English population grew from 11.5 million to more than 45 million (a rate of 260 percent per century). In the previous five centuries, population grew about 14 percent per century and, roughly, technology and capital stock improved enough to maintain the standard of living. The statistics are imprecise, but the broad picture is clear: The relationship of population to environment changed radically. The transformation of the European economy is

FIGURE 3.1 Population and Real Wage, England and Wales, 1250-1980 (Logarithmic Scale)
Source: Crafts (1989a); Phelps Brown and Hopkins (1956), Wrigley and Schofield (1981, pp. 563-595).

indisputable; but its nature remains unclear. Was it sudden or protracted? Was change pervasive or localized? Did new manufacturing technology change the economy? What roles did agriculture and foreign trade play? Recent research provides a new perspective on these persistent questions.

Conceptions of the Industrial Revolution

Most observers since the nineteenth century have thought that key industrial innovations in the late eighteenth century transformed the economy and altered society rapidly and fundamentally. Friedrich Engels begins his 1845 *The Condition of the Working Class in England* with the following sentences: "The history of the English working classes begins in the second half of the eighteenth century with the invention of the steam engine and of machines for spinning and weaving cotton. It is well known that these inventions gave the impetus to the genesis of an industrial revolution. This revolution had a social as well as an economic aspect since it changed the entire structure of middle-class society" (Engels, [1845] 1958, p. 9). In the paragraphs that follow, Engels compares an idyllic life of quasi-artisan pre-factory textile workers who controlled their work with the life of proletarian workers in Manchester in the 1840s. This view quickly became a part of the Marxist historical dialectic. Near the other end of the political spectrum, Benjamin Disraeli, in his novel *Sibyl*, similarly describes the displacement of a humane, well-ordered world by a disjointed capitalist society.

Academic historians have expressed similar views. Arnold Toynbee, in his famous 1884 *Lectures on the Industrial Revolution in England*, pictures society "suddenly broken in pieces by the mighty blows of the steam engine and the power loom" ([1884] 1969, p.226). The succeeding generations of historians, particularly those like the Hammonds and the Webbs, associated with the Fabians and concerned with social issues, shared this view. In the inter-war years, Sir John Clapham presented a gradualist view in his massive economic history of Britain without displacing the prevailing class-oriented view of the Industrial Revolution.

After World War II, historians shifted their interest to economic development. They shared a prevailing belief, or at least hope, that industrialization would quickly eliminate the poverty prevalent in most of the world and sought a model of growth in European industrialization. Walt Rostow, in his *Stages of Economic Growth* (1960), developed an emphatic and popular model in which a dynamic leading sector and markedly increased investment led to "take-off into self-sustained growth" over a couple of decades. Britain "took-off" between 1783 and 1802. Such precise dating inevitably drew challenge. Nonetheless, much of the historical literature looked for a brief period with lessons for development planning in contemporary low-income countries.[1]

In the last forty years, economic historians have increasingly placed their research within the context of economic growth and employed a framework of national income accounts. They relied on quantitative evidence and estimates of key economic aggregates. Pioneering aggregate studies — Walther Hoffmann's (1955) index of industrial production and Phyllis Deane and W. A. Cole's (1962) indices of national income — have had enormous influence. In the 1950s historians trained in formal economics (the "New Economic Historians") began to influence the writing of economic history. They attempted to unite formal models of the entire economy with quantification. Their search for data led them to Hoffmann and Deane and Cole.

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[1] David Cannadine (1984) presents an interesting analysis of views of the Industrial Revolution over the last century. He links interpretation to the concerns of the societies in which the historians wrote.

Hoffmann's index appeared in German in the 1930s and in English in 1955. Although the index received considerable criticism, it became widely quoted. Deane and Cole (after rejecting Hoffmann's index for the eighteenth century as "too narrowly based to be conclusive" (1967, p.41)) produced an independent estimate of industrial growth as part of estimates of national income. Hoffmann's and Deane and Cole's different procedures yielded similar results that confirmed the long-held view of a major structural change in British industry in the fifty years before 1830. Both indices showed that industrial output grew less than 1 percent per year from 1700 to about 1770 and then jumped to a growth rate of 2.5 percent per year over the next half century and accelerated a bit more in the following decades.

Deane and Cole's national income estimates remained the unquestioned backdrop of research until recently. Quantitative research into individual industries showed that Deane and Cole's aggregate growth could not have resulted only from the famous technological change in textiles, iron, and steam, even with very free assessment of linkages to the rest of economy. A synthesis emerged that married Clapham's appreciation of an economy that extended beyond the famous sectors with Deane and Cole's quantitative estimates.[2] In the 1960s Max Hartwell articulated the view that change occurred in a wide range of sectors (Hartwell, 1971a). A generation later, McCloskey summarized the view of growth emerging from widespread, but uneven, technological advance with a meteorological metaphor (1981, p. 106): "The gadgets came more like a gentle (though unprecedented) rain, gathering here and there in puddles. By 1860 the ground was wet, but by no means soaked, even at the wetter spots." Research and synthesis in the Hartwell-McCloskey spirit had changed the general impression of the Industrial Revolution by the early 1980s. The study of individual industries had revealed gradual, often incremental change. Innovations in textiles, iron, and power could have had only modest impact on the standard of living. The idea of a heroic industrial revolution caused by the initiative of a few great entrepreneurs had given way to a view in which change was broadly based within the fabric of British society.

In the last decade, reassessment of the aggregate growth has again changed the idea of the Industrial Revolution. The sharp increases in the growth rate of industrial production and income during the last quarter of the eighteenth century now appear to have been an artifact of inappropriate index construction by Hoffmann and Deane and Cole. It now seems that change in manufacturing was largely concentrated in the famous industries, that agriculture contributed much, and that growth accelerated gradually over many decades.

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[2] Deane and Cole, themselves, undertook the early work (see 1962, chap. 6).

New Aggregate Estimates

To assess Britain's growth, we need to account for the entire range of economic activities. Particular industries can expand at the expense of other activities, so to understand growth we need estimates of aggregate economic performance. Prior to the mid-nineteenth century, statistical information is extremely spotty. Even in modern industrial societies, construction of national income statistics presents theoretical and data problems; for eighteenth-century Britain the problems are much greater, and national income estimates can only be controlled conjectures. While the aggregates can never be more than indications, growth cannot be understood without them. Factors of production moved between alternate uses, and some sectors could grow even in a static economy. Aggregation is necessary to strike the balance between growing and contracting sectors.

Ideally, national income estimates summarize complete enumerations of economic life. Factor incomes, values added in various sectors and the value of final sales each sum to national income. Modern statistical bureaucracies collect all these data to construct national income statistics. But estimating national income prior to the beginnings of modern national income accounting in the mid-twentieth century requires creative use of population censuses, tax returns, and other available quantitative data. In the early 1960s, Phyllis Deane and W. A. Cole completed a massive research project that provided estimates of historical national income for Britain. These estimates remain the foundation on which all others have built. Beginning in the mid 1970s though, N.F.R. Crafts (1976, 1985a) effectively criticized aspects of Deane and Cole's estimates and provided substantially different national income estimates. Many details of Crafts' work are speculative, and controversy surrounds several of its aspects, but in general outline his conclusions have largely displaced those of Deane and Cole.[3]

Estimates of British national income prior to the mid-nineteenth century involve projection backward into periods of less and less adequate data. Comprehensive enumeration of British life began with the first decennial censuses of population in 1801. The early censuses were pioneering exercises and of poor quality by modern standards, but gradually the enumeration became more reliable. By mid-century the census contained useful occupational information. The census of 1841, although judged to be somewhat incomplete, contains the earliest reliable labor force data from which to construct labor income estimates (Deane and Cole, 1967, pp. 139-140). Income tax during the Napoleonic War and after its 1842 reimposition by Sir Robert Peel provide information on property income (Deane and Cole, 1967, p. 164ff.). Deane and Cole use these sources to estimate factor incomes and

[3] Inevitably, Crafts' new work has attracted criticism. See Berg and Hudson (1992); Hoppit (1990); Jackson (1990, 1992); Mokyr (1987); Williamson (1987a); Cuenca Estaban (1994). For a discussion of these criticisms see Crafts and Harley (1992), Harley and Crafts (1995).

national income from 1801 on. The evidential basis was weak before 1841 but improved thereafter. Officials began collecting comprehensive agricultural output data in the 1880s, and the first census of industrial production occurred in 1907.

Some political commentators before the nineteenth century attempted to estimate national income from data available to them,[4] but modern estimates of national income prior to the 1840s consist primarily of projections backward. Population (from censuses and earlier estimates), incomplete output series, and inferences of various sorts have been used in attempting to project from the relative certainty of the mid-nineteenth century to earlier dates.

The best pre-industrial estimate of the extent of the British economy was made by Gregory King in the late seventeenth century. King was a member of the inner circle of government and had access to such data as the government had available to calculate aggregate activity. His journals have survived and show his use of tax records. As Peter Lindert (1980) has shown, King almost certainly underestimated the extent of non-agricultural activity in the country outside London. Lindert revised King's estimate using more careful assessments of occupations from local censuses and burial records. The resulting social table provides valuable information on the industrial structure of late-seventeenth-century Britain and can be used to construct an estimate of income that provides an important independent check on estimates based on projections back from more reliable nineteenth-century benchmarks. The revised estimate of national income in 1688 comes to about £55 million at 1688 prices. Inflation after 1750, and particularly in the final years of the eighteenth century, complicates comparison of this estimate with nineteenth-century calculations but a good guess is that prices doubled between King's day and the first census in 1801[5]. Cole (1981, p. 65) estimates the value of income in England and Wales in 1801 to be £200 million. Over the same period English population increased by three-quarters. In very round numbers, which is the best that can be done with this kind of calculation, these figures suggest only a small increase— less than 5 percent — in real per capita income (200/(55x2)/1.75=1.04). The calculations here are much too speculative to stand alone, but they may offer some rough check on other procedures.

Until recently, even British population prior to 1801—a prime input to any early national income estimate—had been poorly understood. Fortunately, extensive research under the direction of E. A. Wrigley and R. Schofield (1981) over two decades has greatly improved matters in this regard. Even here historians have had

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[4]These estimates are discussed in section 6 below. See Deane (1955) and Lindert and Williamson (1982, 1983a) for a discussion and assessment of these estimates.

[5]This price change is the average of O'Brien's (1985) agricultural (with rough allowance for the famine prices in 1800) and industrial prices.

to rely on estimates constructed from partial evidence, but most now feel confident that the estimates accurately convey the course of eighteenth-century population.

Industrial Production

Traditional interpretations see a transformation of industrial technology in late eighteenth century initiating modern growth. Machines revolutionized the production of cotton and then other textiles, Watt radically improved the steam engine, and various advances led to the smelting of iron with coke. How much did these improvements lead to growth in industrial output as a whole and in national income?

Data. Underlying data for industrial production come from various sources and suffer various problems of reliability. The British state was remote from most economic activity and lacked the statistical apparatus of a modern state or even, for that matter, of more centralized and interventionist France. Most of the reasonably comprehensive data that do exist arose from tax collection. Customs duties on internationally traded goods and excise taxes on domestic consumption provided the bulk of the state's revenue. Records necessitated by the administration of these taxes provide the most reliable data. But large areas of manufacturing avoided the state's fiscal attention, and here tax records provide little information. Fortunately, historians have studied the most important of these industries and have provided estimates of growth. Nonetheless, we have little information for a considerable portion of manufacturing.

The underlying data are clearly imperfect and must be used with care. Individuals certainly had good reason to avoid the state's revenue officers and to understate the values on which taxes were collected (Hoppit, 1990). Certainly evasion occurred, but Britain was an island with limited ports, and domestic excises were collected primarily on goods produced in large-scale enterprises that the excise officers could monitor (Mitchell and Deane, 1962, pp. 242-244). Fortunately, the revenue figures will correctly indicate trends in growth even if there was widespread evasion if the extent of evasion was constant over time.[6]

Textiles and clothing together made up nearly half of manufacturing in mid-eighteenth-century Britain. We can trace the growth of the new cotton textile industry with some confidence since all Britain's raw cotton was imported. The customs data, although alternative sources differ slightly and some cotton was used for non-textile purposes, provide good information on the general trend. Unfortunately, we have much less precise records for the initially more important older textiles that used domestic raw materials — wool and linen. Some records exist of the sale of woolen cloth in the West Riding of Yorkshire. But the West

[6]Crafts and Harley (1992) considers implications of problems in the data at some length.

Riding contained only a portion of the industry, and we know that its importance increased from the eighteenth to the nineteenth century, so this data cannot be used as an index of the industry's total output. The best indications come from estimates of the amount of wool produced in Britain—provided by contemporary estimates and other indicators—plus imports of wool. Phyllis Deane (1957; Holderness, 1989, pp. 171-174) provides a detailed assessment of these sources and her conclusions have been accepted as providing an indication of the industry's broad trends, although considerable uncertainty exists. The linen data are similar to those for wool (Deane and Cole, 1967, pp. 202-205) in their sources and accuracy. Silk, a relatively small industry in Britain, depended on imported raw materials whose quantities were recorded by customs, but there is only limited information with which to calculate value added (Deane and Cole, 1967, pp. 207-211). Clothing trends can be estimated from the estimates of textiles retained for domestic use. Metal production and mining have also required careful historical assessment. Fortunately, the scale of mining and smelting operations makes them easier to trace in the historical sources than more dispersed smaller-scale activities (such as many parts of textile production and food processing). Estimates of primary iron production and coal output can be made from these sources (Hyde, 1977, pp. 204 -206, Pollard, 1980). The estimates of primary iron production plus iron imports can be used to provide an indication of the trend of output in the highly dispersed metalworking industries (Harley, 1982, pp. 273-275).

Excise tax records reveal the histories of some other industries. Leather, a large pre-industrial manufacturing sector, was taxed. So too were beer production and paper and printing (Deane and Cole, 1967, pp. 50-62; Hoffmann, 1955, pp. 291-330; Mitchell and Deane, 1962, pp. 247-67). The output of food processing industries can be inferred from agricultural output. Estimates of capital formation have provided the basis for estimating the level of activity in the construction industry (Feinstein, 1978, p. 40; Feinstein, 1988a, p. 446). But for about 10 percent of industrial activity there is almost no indication of trends of growth; here output probably more or less kept pace with population growth.

Table 3.1 presents the rather uncertain indices of output (with 1841 outputs set to 100) for various industries in 1770 and 1815. The very rapid growth of cotton textiles stands out; output in 1770 was just 0.8 percent of its 1841 level so it grew 125 fold in 71 years. By contrast, other industries grew slowly. Metal production, the second fastest growing industry, stood at nearly 7 percent of its 1841 level in 1770; other large industrial sectors—the other textiles, leather, and food and drink—were already nearly half as large in 1770 as they became by 1841. Aggregate industrial output is the sum of the output of all industries aggregated at appropriate prices and its growth is a weighted average of the very different histories of different activities. In particular, an estimate of aggregate industrial production for the industrial revolution will grow much faster if fast-growing cotton textiles have a large weight than if they have a small weight.

TABLE 3.1 Indices of Output, Various Industries (1841 = 100)

Industry	*1770*	*1815*
Cotton	0.8	19
Wool	46	65
Linen	47	75
Silk	28	40
Clothing	20	43
Leather	41	61
Metal	7	29
Food and drink	47	69
Paper and printing	17	47
Mining	15	46
Building	26	50
Other	15-50	40-60

Source: Harley (1982, p. 273) with building modified to reflect new estimates of "Total buildings and works" (Feinstein, 1988a, p. 446).

Weighting. Because various parts of manufacturing grew at very different rates, indices of aggregate output will vary if different weights are used. Fortunately, there is agreement that appropriate aggregation involves summing the quantities of various commodities valued at their prices at some base date. A key step in constructing the index is the identification of appropriate prices and quantities for various base dates. During the Industrial Revolution, relative prices changed rapidly, primarily because technological advances drove down the prices of cotton textiles. Consequently, different base years will produce different, but equally legitimate, indices.[7]

[7] In 1841 cottons were less than a third as expensive relative to other manufactured goods as they had been in 1770 and only half as expensive as in 1815. Aggregation using 1770 prices (a Laspeyres index) will value the large 1841 cotton textile sector more than will aggregation using 1841 prices (a Paasche index) and will lead to an estimate of more rapid growth. This discrepancy is an unavoidable index number problem. Some compromise between initial and terminal weights, which has intuitive appeal and support in formal consumption theory, leads to Fisher's Ideal and the Divisia indices (presented below). Nonetheless, an inherent problem exists because we are attempting to aggregate when strict conditions allowing aggregation are absent.

Laspeyres and Paasche index numbers are usually calculated by constructing a weighted average of quantity relatives of components. The appropriate weights consist of the shares of each component in the value of total output in the base period (on which the quantity relatives are also based). If initial shares are employed, the index is Laspeyres; if terminal shares, Paasche. Fisher Ideal index is the geometric mean of the corresponding Laspeyres and Paasche indices. The Divisia index differs in its construction. For very small

In practice, output indices are usually constructed as a weighted average of industry output relatives — a procedure equivalent to aggregating with fixed base year prices. The appropriate weights are the various industries' shares in output, or value added, in the base year. Quantifying the base year structure of the industrial sector to provide appropriate weights for aggregation presents the greatest challenge to constructing an index of industrial production for Britain prior to the 1840s. An ideal base would come from a comprehensive enumeration of outputs and inputs of all industries in a census of industrial production. But the first such census occurred only in 1907. Without an industrial census, compromises have to be made.

Occupational classifications in the population census of 1841 provide the earliest reasonably comprehensive substitute for an industrial production census. I chose to use these data as a proxy for ideal but unavailable information on value added by specific industries (Harley, 1982). This procedure resulted in a much lower weight than Walther Hoffmann had used for cotton in his pioneering index. As a result, my index grew much more slowly.

I assigned weights for 1841 in proportion to 1841 labor force by industry (with women, children, and handloom weavers given half the weight of adult males). This approximates value-added shares. I estimated value-added shares for earlier benchmark dates by projecting the 1841 employment shares backward using industry output indices and adjusting for the change in relative prices of cotton textiles and iron. This provided logically consistent shares for 1841, 1815, and 1770.

Unfortunately, although it is clear that the prices of cotton textiles fell rapidly during the industrial revolution, precise price data have been hard to come by. In my calculations I adjusted cotton value added using relative prices 1.8 times as high in 1815 as in 1841 and 3 times as high in 1770 as in 1841. The evidence for this adjustment was meager and, because cotton grew exceptionally fast, the weight given to cotton has a large influence on my results. The adjustments of weighting of iron I used to allow for the declining price of iron used an 1815 relative price 1.2 times its 1841 level and an 1770 price 1.8 times the 1841 level.

Recently, Javier Cuenca Esteban (1994) argued that I had seriously underestimated the decline in cotton textile prices. He estimated that cotton cloth cost nearly 10 times as much in 1770 as in 1841rather than the value of three times as much that I had used. The higher cotton prices for 1770 implied that the cotton textile industry should have a significantly higher weight in the index of industrial production for the industrial revolution. The higher weight for cotton textiles implies a faster growth of aggregate industrial production. In his conclusion he

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changes an aggregate's rate of growth equals the weighted sum of the growth rates of its components, each weighted by its share in the aggregate. For large changes, of the sort we are considering, an appropriate weighting procedure is to use the geometric mean of initial and terminal shares as weights.

argues that estimates of industrial growth should "be revised in the direction of Hoffmann's and of Deane and Cole's classic, much higher estimates (1994, p. 89). Cuenca's attention to the problem of cotton prices is certainly welcome. New archival research has revealed that I somewhat underestimate the decline in cotton textile prices during the late eighteenth and early nineteenth centuries, but not to anything like the extent Cuenca suggested. I now believe that 1770 cotton textile prices were some 4 times their level in 1841 (Harley and Crafts, 1995 and Harley, 1998). Revisions incorporating a higher 1770 weight for cotton textiles appear in Tables 3.1, 3.2 and 3.3 and Figure 3.2[8]. The revisions hardly change the growth rate of aggregate industrial output. The mean estimate of industrial growth between 1770 and 1815 was 1.64 percent annually with the old cotton price estimate and 1.69 percent with the improved price data.

The industrial structures implied by these calculations are presented in Table 3.2. Inevitably, my procedures to substitute for non-existent manufacturing census data introduced possibilities of error. Employment and value added did not correspond exactly. In addition, I made no attempt to adjust for relative price changes except in cotton and iron, primarily because reliable data do not exist. I felt, however, that the gains from using the (fairly) complete enumeration of the census and maintaining clear consistency among bases outweighed shortcomings.

Shortly after my index appeared, N.F.R. Crafts (1985a, pp. 17-34) independently reestimated industrial production. His data on sectoral growth were mostly the same as mine (although there were minor differences), but he approached the crucial issue of weighting somewhat differently. Whereas I attempted to maintain consistency by projecting back from a comprehensive 1841 labor enumeration, making explicit adjustments for relative price changes, Crafts employed separate estimates of industrial output at current prices for 1770, 1801, and 1831. His shares differ somewhat from those derived from the census employment data. Most importantly, his weight for cotton, although below Hoffmann's, was nearly twice mine, and so his aggregate growth rate was higher than mine but still much below Hoffmann's. Recently, Crafts has recognized that he over-weighted cotton, at least in the early nineteenth century, because he failed to deduct inputs other than raw cotton that the industry purchased in calculating value-added. He has revised his index downward, bringing it close to my own (Crafts and Harley, 1992). Crafts' new figures are incorporated in Table 3.3 and Figure 3.2.

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[8] I have also revised the weights for 1815 and 1770 to make them consistent with the revised Feinstein data that Crafts and I used as the basis of our estimates of construction output.

TABLE 3.2 Industrial Structure, 1841, 1815, and 1770

Industry	*1841*	*1815*	*1770*
Textiles			
Cotton	0.10	0.07	0.01
Wool	0.08	0.10	0.14
Linen	0.04	0.06	0.07
Silk	0.03	0.02	0.03
Clothing	0.13	0.11	0.10
Leather	0.11	0.14	0.17
Metal	0.11	0.08	0.05
Food and drink	0.04	0.06	0.07
Paper and printing	0.02	0.02	0.01
Mining	0.08	0.07	0.05
Building	0.18	0.19	0.16
Other	0.09	0.09	0.11

Source: Harley (1982, p. 269).

Comparison of New and Old Estimates. Hoffmann and Deane and Cole overestimated the growth of industrial output during the industrial revolution. This created an inappropriate sense of discontinuity in growth around 1770 and also understates the level of eighteenth-century industrial output. Hoffmann's overstatement of growth arose from the industry weights he used for the late eighteenth century. For that period he weighted sectors using a 1783 base he constructed. He estimated that cotton textiles constituted 6.7 percent of industrial output—just about Crafts' weight but larger than mine. He also estimated that the industrial output series he had available covered 56.4 percent of total industrial output. To construct an index, he had to estimate the growth of the remaining 43.6 percent, either explicitly or implicitly. He proceeded by raising the weight of each included industry in proportion (by a factor of 1.79 = 1/0.564). This raised the weight of cotton textiles to 12 percent of the index. Hoffmann's procedure implicitly, but incorrectly, assumed that some other industries, 79 percent the size of cotton, grew as fast as cotton. Deane and Cole used distinct procedures for the eighteenth and nineteenth centuries. For the nineteenth century, they constructed estimates of current incomes by sectors. These calculations combined estimates of labor income based on the census and property income estimates based on the income tax assessments.[9] They then deflated these current income estimates with

[9] See Deane and Cole (1962, chaps. 4 and 5). They point out that these data were suspect before 1840, since the early censuses did not contain reliable occupational informa-

TABLE 3.3 Indices of Aggregate Industrial Production, 1700-1841

	Harley	*Crafts*	*Hoffmann*	*Deane and Cole*
1700	-	13	8	9
1730	-	-	10	10
1760	-	19	12	14
1770	22	-	14	13
1780	-	25	16	15
1790	-	-	23	18
1801	-	37	32	23
1811	-	-	40	24
1815	46	-	-	-
1821	-	-	51	57
1831	-	85	72	85
1841	100	100	100	100

Note: These Data are also plotted in Figure 3.2

Source: Crafts and Harley (1992, table 2) (revised from Harley [1982, p. 276], calculated from mean of Divisia range; Crafts [1985a, p. 26], calculated using series with weights based on geometric average of adjacent years [Divisia]). Hoffmann [1955, appendix]. Deane and Cole (1967), calculated from data pp. 78, 166; Deane and Cole's current price data has been deflated by Rousseaux's industrial price index.

Rousseaux's index of industrial product prices to estimate output volumes. Unfortunately, Rousseaux's index inadequately represented industrial prices and exaggerated industrial price decline in the early nineteenth century (Crafts, 1985a, pp. 30-31).

For the eighteenth century, Deane and Cole divided the industrial sector into two parts: a domestic portion and an export portion. The output of domestic industry (one third of the whole in their1700 base) was estimated from excise series (Deane and Cole, 1967, p. 76). They felt that the direct statistical base for the export industries was inadequate. They decided, after an extensive discussion (pp. 50-61), that "it seems fair to assume that the volume of imports and exports may provide us with a reasonably accurate index of the growth of those industries which entered largely into overseas trade." Eighteenth-century growth of trade provided their estimated growth of export industrial output, but the procedure has no sound theoretical basis. In particular, because much of the late-century growth of trade occurred with the Americas where population grew more rapidly than in Britain and

tion and the income tax was repealed at the end of the Napoleonic War.

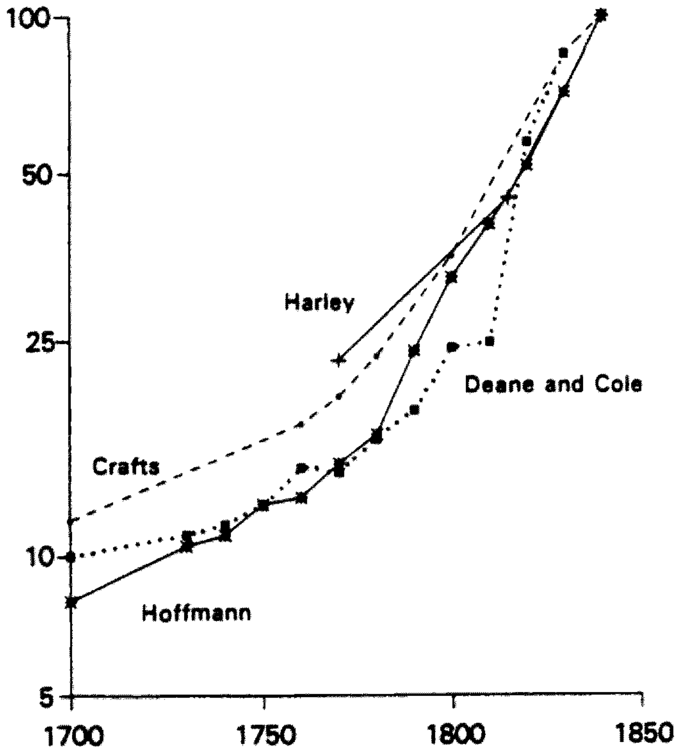

FIGURE 3.2 Estimates of Industrial Production (Logarithmic scale, 1841 = 100)

where the war temporarily closed markets to rival non-British exporters, trade probably grew faster than the output of the exporting industries.

The data do not permit precise conclusions, but my and Crafts' critical evaluations of industrial production, although differing somewhat, pointed to a common conclusion: Industrial growth, particularly growth per capita, in the decades after 1770 was much slower than had generally been assumed. I estimate industrial growth from 1770 to 1815 at 1.6 percent per year or 0.6 percent per year per capita. Crafts estimates faster growth: about 2 percent per year in aggregate and 1 percent per capita. Both these estimates are well below Hoffmann's 2.6 total and 1.6 per capita. The extent of the differences can best be appreciated by comparing the levels of industrial output per capita in 1770 to levels in 1815. My calculation implies per capita output of 79 percent of the 1815 level, Crafts' of 65 percent, and Hoffmann's 49 percent.

Crafts and I have recently reassessed our industrial production indices in light of a decade's research and criticism (Crafts and Harley, 1992; Harley and Crafts, 1995). The estimates, although inevitably imprecise because of problems in the underlying data, seem to have generally withstood criticism. Industrial growth during the industrial revolution was much slower and accelerated much less than had previously been assumed. Industry's share of national income was just under a third from the 1780s to the 1830s (Crafts, 1985a, p. 45; Deane and Cole, 1967, p. 166), so industrial growth generated per capita income growth of 0.2 or 0.3 percent per year. At these rates, income would double only in two hundred to three hundred and fifty years — not the stuff of sudden transformation.

Incomplete data make it impossible to construct anything more precise than controlled conjectures about industrial growth during the Industrial Revolution. Crafts' and my indices probably define the bounds of the acceptable conjectures. The conclusion that industrial growth was much lower and eighteenth century industrial output considerably higher than economic historians for a generation had assumed on the basis of Hoffmann's and Deane and Cole's estimates has been established. The discontinuous acceleration of industrial growth seems to have been an artifact of inappropriate aggregate estimates. Uncertainty, of course, remains; its most important source is the weight of cotton textile production in the aggregation. My weight may still be a bit low as a result of failure to account adequately for the value added in chemical and other industries involved in the finishing of cotton cloth. I think I have now adequately estimated the decline in cotton cloth prices in the industry's early years. Crafts, on the other hand, may overweigh cotton. He has now reduced his 1831 weight for cotton to remove the industry's purchase of inputs other than raw cotton but, because of uncertainty in the underlying estimates of earlier cotton output, has made no such adjustment to earlier weights. Ongoing detailed research into the late eighteenth century cotton industry may resolve this issue. Although probably less important than appropriate weighting, many indices of sectoral output growth are crude approximations. The errors in individual series are unlikely to be strongly correlated, so we may hope that the error in the aggregate is less than the error in individual series. Nonetheless, estimates of industrial production are approximate.

Agriculture

Agricultural output must also be estimated from imperfect primary data. B. A. Holderness, in his recent assessment, summarizes the general view of those of us who have bravely or foolishly attempted to estimate aggregate output for periods before official statistics existed (1989, p. 174):

> The section on production and productivity is so replete with expressions of doubt, uncertainty, and disbelief that it reads like a litany for skeptics. It is obviously necessary to keep in view the doubtful character of all estimates of production not founded upon the bedrock of agricultural census returns. Nevertheless, precision in

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For a somewhat different view see Gregory Clark's article in the present volume.

detail is not essential to the assessment of probable magnitudes or the direction of trends.

Agricultural estimates have various sources of support. Primary among them, roughly in declining order of reliability, are data on prices, estimates of population, and estimates of areas under cultivation, crop yields, animal stocks, and marketed weight.

Deane and Cole estimated eighteenth-century agricultural growth by assuming that per capita consumption remained unchanged (1967, pp. 65, 74). Their index of output was population adjusted for net imports of grain. Crafts points out that this procedure was inadequate because demand for food in low-income societies has considerable price and income elasticity that Deane and Cole ignored (1976; 1985a, pp. 38-44). Since relative agricultural prices were the same in 1760 as in 1700, only income effects needed to be considered in comparing these dates. Crafts allowed an income elasticity of demand from food of 0.7 and estimated agricultural growth of 0.6 percent per year, about 0.2 percent above the growth rate of population. After 1760 agricultural prices rose relative to other prices, complicating analysis. Crafts used two independent procedures for this period. In the first, he deflated estimates of current values of output by an agricultural price index (O'Brien, 1985). For 1760 he used Peter Lindert and Jeffrey Williamson's (1982; 1983a) estimate of the value of agricultural output based on Joseph Mashie's contemporary estimate. Deane and Cole provided estimates of agricultural output for nineteenth-century census years. In his second procedure, Crafts assumed a price elasticity of -0.8 and the income elasticity of 0.7 and solved simultaneously for national income and agricultural output. The two procedures generated similar estimates for 1760 to 1800: growth rates of 0.44 and 0.50 percent per year, respectively. Both these estimates are slightly below Deane and Cole's estimate of 0.56. A greater discrepancy arose from the two approaches between 1801 and 1831. Deflation yielded 1.18 percent annual growth, while demand estimates produced a 1.88 percent. Crafts has used the lower estimate in subsequent work. Deane and Cole's estimate for this period was 1.64 percent.

Crafts' estimates of agricultural output and productivity growth have been criticized for slimness of the evidential base and apparent inconsistency with general views of modern growth. As Crafts himself acknowledges and Joel Mokyr (1987, pp. 305-312) explored in greater detail, the estimates of agricultural growth are undeniably insecure. Jeffrey Williamson, who has put forward a different overall view of Britain's growth, rejects the view that agricultural advance was of similar magnitude to industrial advance. He draws on analogies to industrialization elsewhere: "Central to all industrialization accounts past and present has been the view that modern sectors exhibit much faster rates of productivity advance while traditional sectors lag behind." He also suggests that Crafts' productivity estimates cannot fit into a consistent macroeconomics of the Industrial Revolution (1987a, p. 273-274).[10]

Historians of British agriculture have recently provided independent estimates of aggregate agricultural output based on the history of production (Allen, 1994, cf. table 5.1, p. 102; Chartres, 1985; Holderness, 1989; Overton, 1996) that generally support Crafts' calculations. The estimates combine acreage and yield estimates for grain, and estimates of herd size and animal size for animal production, at fifty-year intervals from 1700 to 1850. Over the century and a half these production estimates grow at about the same rate as Crafts' estimate: Crafts' estimate projected a 1700 output that is about 10 percent lower than the independent output estimates. Put slightly differently, Crafts estimates output growth at 8.7 percent per decade, whereas the Holderness-Allen series estimates 8.1 percent.

The Holderness-Allen estimates do not attempt to estimate short-term movements, but they raise some doubts about the timing of agricultural growth that Crafts proposes. Crafts' inferences from price data and income suggest relatively rapid initial growth, near stagnation for a generation or so after mid-century and finally very rapid growth in the early nineteenth century (although considerably slower than the growth that Deane and Cole proposed for this period). The Holderness-Allen series indicates nearly steady growth with only small acceleration (the index grew at 0.77 percent annually from 1700 to 1750, 0.80 percent from 1750 to 1800, and 0.85 percent from 1800 to 1850). Estimates of grain yield vary but suggest a still different pattern: slow yield increases during the eighteenth century and little acceleration in the nineteenth (G. Clark, 1991d and Chapter 4 below). Animal products, however, were about half of final output in agriculture by the mid-eighteenth century.

Greg Clark—who presents a version of his view elsewhere in this volume—has recently provided assessments of British agriculture that suggest less rapid output growth than most other experts suggest. In addition, he has concluded that much of the increased output normally attributed to technological change should properly be seen as the result of costly investment in soil fertility. In this view technological change played a smaller role and capital formation a larger role in British growth than most narratives have allowed, although some will argue that Clark has slighted the interconnection between knowledge and investment (Clark, 1992a). In Chapter 4, Clark presents a much more pessimistic assessment of agricultural growth than is general among specialist agricultural historians. His observation that Crafts' calculations probably pay too little attention to non-food agricultural output seems well taken. The aggregate impact of these considerations, however, seems too small to establish his position. His discussion also may pay too little attention to the regional nature of British agricultural change. Qualitative studies of the

[10] Also see the discussion of Williamson's modelling of the industrial revolution below.

organizational and technological change in British agriculture in the late eighteenth and early nineteenth centuries emphasize differing regional patterns and the introduction of mixed agriculture in which animal husbandry played a key role (Jones, 1981a; Thirsk, 1987). It may be that Clark's data are concentrated in the clay Midlands where change was slow and have failed to capture productivity growth that affected other farming environments.

Clearly, agricultural change will repay more detailed analysis. In assessing the agriculture estimates, however, it is important to remember that we are projecting backward from firm knowledge about the end of the period. In the middle of the nineteenth century, British agriculture had the highest productivity in Europe. Agriculture employed only a small proportion of British resources but still fed most of her people after decades of rapid population growth. Britain's agricultural superiority had emerged in the previous two centuries from myriad improvements in different agricultural regions that occurred at different times. It is unlikely that precise dating of aggregate productivity advance is possible.

Although uncertainty seems inevitable, certain conclusions are inescapable. In particular, if agricultural growth was as slow as some of Crafts' critics suggest, British agriculture was extraordinarily productive in the early eighteenth century, and Britain must have attained agricultural superiority over most of its European neighbors before that. Anthony Wrigley's work on the ratio of urban consumers to agricultural producers indicates this is improbable. The proportion of population in towns in Britain only began to diverge from that of the rest of Western Europe in the eighteenth century (1986, p. 147).

Agriculture made up a large portion of the eighteenth-century British economy. Consequently, estimates of agricultural growth make up an important part of estimates of British aggregate growth prior to the mid-nineteenth century. If agricultural growth was slower in the century before 1850 than Crafts has estimated, then aggregate growth was also slower. Overall, Crafts' reassessment has already led economic historians to conclude that growth was slower than they had previously thought. Slower agricultural growth implies even higher British standards of living in the middle of the eighteenth century and an earlier date for the beginning of Britain's economic lead. If this is the case, historians will have to devote their attention to earlier periods of change.

Services

Measuring the service sector, difficult even in modern economies, cannot be done with any accuracy for the late eighteenth century. Deane and Cole divided eighteenth-century services into "government and defence" and "rents and services," and Crafts relied on these estimates. Reported government expenditures were deflated by the Schumpeter-Gilboy price index.[11] Rents and services were

[11]Jackson (1990) criticizes some of Crafts' procedures but overstates the significance of his findings. There are no demonstrably "correct" procedures, and the

assumed to grow with population growth. Crafts also considered a trade and commerce sector — which Deane and Cole had subsumed in industry for their eighteenth-century calculations — and assumed that it grew with national income (Crafts, 1985a, p. 28). For the early nineteenth century, Deane and Cole estimated current value of output primarily from census employment. They obtained quantity estimates by deflating current value by Rousseaux's price index. Crafts rejected Deane and Cole's deflation; the deflator was inappropriate, and the results were highly implausible. Instead, he constructed alternate estimates based primarily on employment estimates (1985a, pp. 34-37).

National Income

Re-evaluation fundamentally altered the picture of aggregate growth. Crafts' and Deane and Cole's indices of national income are compared in both aggregate and per capita terms in Table 3.4 and Figure 3.3. Deane and Cole show a shift to high growth of per capita income coinciding with the textile innovations of the late eighteenth century. Crafts' data show no such shift. Per capita growth increased slightly about 1780 or 1800, but if there was a break in the trend instead of acceleration over perhaps as much as two centuries, it occurred after the Napoleonic

TABLE 3.4 National Income, 1700-1870 (U.S. 1970 $)

	Crafts		*Deane and Cole*	
	Total (mn.)	*Per capita*	*Total (mn.)*	*Per capita*
1700	2	330	1.3	190
1760	3	400	1.9	250
1780	3.4	400	2.1	250
1800	4.5	430	3.2	310
1830	8.1	500	8.1	500
1870	23.6	900	23.6	900

Note: These data are plotted in Figure 3.3

Source: Crafts and Harley (1992, table 2) (revised from Harley [1982, p. 276], calculated from mean of Divisia range; Crafts [1985a, p. 26], calculated using series with weights based on geometric average of adjacent years [Divisia]). Hoffmann [1955, appendix]. Deane and Cole (1967), calculated from data pp. 78, 166; Deane and Cole's current price data has been deflated by Rousseaux's industrial price index.

maximum difference he produces is under 0.2 percent per year for the period 1760 to 1800 —a cumulative difference of 8 percent, which is swamped by the various uncertainties within the calculations.

Wars (Crafts, Leybourne, and Mills, 1989). The main criticism of Crafts' calculations has been that he exaggerated agricultural growth. However, lower agricultural growth would reinforce his conclusion. It would imply slower income growth and a still more protracted and gradual acceleration of national income, further reducing the significance of the traditional Industrial Revolution era.

A Coherent New View of British Growth

The new indicators of aggregate income suggest a coherent picture of growth in Britain that contrasts with the previously accepted view. Industrial change now appears largely confined to the famous sectors of the Industrial Revolution. The main growth occurred in cotton textiles. Cheaper cottons displaced competing textiles that had not shared its rapid technological change. Part of the industry's growth came from British consumers buying cotton textiles, but even more came from the British industry's capture of foreign textile markets. The British economy became increasingly industrial and urban as the "modern" textile sector grew. The new cotton technology caused factory production to displace cottage industry. The steam engine allowed textile mills to abandon rural water power for urban sites. Labor and capital moved from rural agriculture to urban industry. Urbanization was not without friction but was much more rapid in Britain than it has been in most societies that have made such transitions. The income gains from the growth of urban industry were modest, however. Much of the growth of urban industry was simply a concentration of activity. Furthermore, the export of two-thirds of cotton output transferred benefits of British technological change to foreign customers.

Agricultural change appears to have played a large role in British growth, although the complexity of the rural economy hides its exact extent and timing. Agricultural technology advanced much less, to be sure, than technology in the leading industrial sectors but probably more than in other industrial and service sectors. Also, British agriculture, most likely because of its class structure, released labor and capital to growing sectors quickly by comparison to the history of industrialization elsewhere.[12] The labor force in the primary sector of the economy, although it increased from 1801 to 1851, fell dramatically as a proportion of the total. Primary production employed 40 percent of the workforce in 1801 but only 25 percent in the 1840s (Crafts, 1980, 1985c and 1987, p. 257). Other European economies did not reach this low a share of primary sector employment for another century. During the early stages of industrialization in most countries, labor left the primary sector very slowly, and a large gap opened between labor productivity in agriculture and industry. No such gap appeared in Britain. Deane and Cole's estimate for 1840 (1967, p.152, 166) shows 25 percent of the labor force engaged

[12] This hypothesis and the origins of the class relationship in British agriculture have been explored at some length by Robert Brenner (1976).

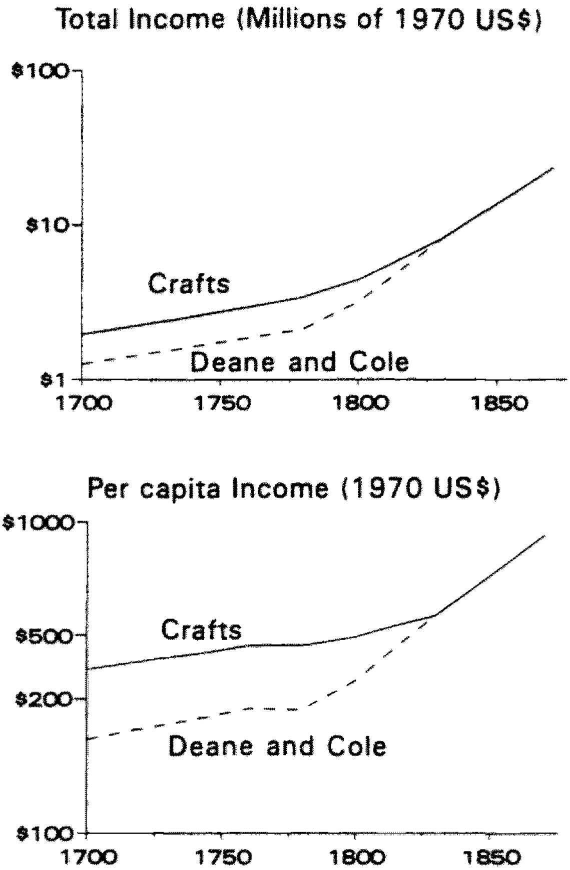

FIGURE 3.3 British National Income, 1700-1870

in the primary sector and an essentially equal share of income produced by the sector (24.9 percent). The average European economy ("European norm") at that level of income had a labor share in the primary sector that exceeded the sector's income share by some 40 percent. Later in the nineteenth century, cheap imported American food became available, and the share of income in the British primary sector fell more rapidly than the share of labor. By the eve of World War I, 15 percent of the labor force remained in the primary sectors, while only 10 percent of the income originated in these activities. Even so, Britain remained unlike the European norm, where at a similar level of income, primary production employed 29 percent of labor and produced 15 percent of income (Crafts, 1985a, chap. 3).

From 1770 to 1830, the years of the classical Industrial Revolution, real income grew only modestly, and the standard of living improved only slowly. Relatively rapid change in the large agricultural sector (about half of the labor force, but somewhat less of income, in the mid-eighteenth century but declining rapidly in the early nineteenth) proved about as important to growth as the more famous new industrial technology—which was limited to a relatively small part of the economy (not more than 40 percent of industry, or 12 percent of national income, even in 1841). Not all scholars share this view of agriculture's contribution. The evidence is shaky, and some believe that Crafts has exaggerated agriculture's achievements.[13] But to the extent that agricultural growth has been exaggerated, so too has the growth of income. If agricultural grew more slowly, British income in the early eighteenth century has been underestimated.

Assessment of early British growth must appreciate that our view is inevitably projected backward from the relatively reliable data that became available in the mid-nineteenth century. Britain's economic position in 1840 is well understood. Britain had achieved a notable economic leadership, and continuing economic growth had become established. From 1840, when per capita income was still low, to 1910 British income per capita grew at 1.2 percent per year. Simple back projection shows that the growth rate must have accelerated in the century before 1840: Income growing at 1.2 percent doubles every 58 years, and eighteenth-century growth at that rate implies impossibly low per capita income in 1700. Contemporary observers and historians broadly agree on Britain's economic lead at the middle of the nineteenth century. During the previous century, British textile firms had achieved international predominance by revolutionizing the technology of production. British iron masters had become low-cost producers by pioneering technological change (Allen, 1979). British agriculture also led the world in productivity.

Measurement of Britain's leadership is difficult. Quantitative estimates of nineteenth-century production elsewhere are even more uncertain than those for Britain. Certainly, Britain had a large lead in the "new" industries. British mills consumed over half of all the world's raw cotton in the 1840s; British furnaces produced about a third more pig iron than all the rest of Europe (Mitchell, 1975, pp. 391-392)—and a much larger proportion of the iron produced using the new coke-smelting technology; and Britain contained the largest modern woolen industry. Paul Bairoch (1982; 1989, p. 37) probably over emphasized these "new industries" when he showed that Britain's industrial sector, in per capita terms, produced some four times as much as its French equivalent, five times as much as Germany and nearly three times as much as Belgium and Switzerland, the most industrialized Continental economies. Calculations from more comprehensive national income

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[13]Thus, *if* Clark's (chapter 4, below) estimates of agricultural growth are accepted, the overall growth of national income was much slower and technological change in agriculture contributed much less. However, in that case the aggregate technological change was much smaller and the 'famous sectors' of the Industrial Revolution contributed an even larger proportion than the estimates in Table 3.6 indicate.

figures show that British industrial output per capita was 60 or 70 percent higher than Belgium's and two and a half times Germany's.[14]

Industrialization must not be confused with output per capita, tempting though the equation seems. Britain's per capita output also exceeded that of her neighbors — a quarter over Belgium and two-thirds over Germany, with France occupying an intermediate position (Crafts, 1983b; Maddison, 1982). The British lead was based only in part on the manufacturing industry, and the British lead should not be overdrawn. In many industries the British possessed little superiority and undoubtedly lagged behind established Continental producers in many areas of production. British agriculture contributed to high incomes. Bairoch's (1989, p. 37) calculation of caloric net output per male worker in European agriculture for 1860 may again have exaggerated Britain's leadership, particularly over the Low Countries where non food production was important. His figures show the Danes closest at 87 percent of British productivity. French and German output per worker were about half the British level, with Belgium and the Netherlands slightly farther behind. Recent estimates for 1870 show a more modest British advantage but still reveal a sizeable gap. British productivity in these calculations approximately equaled that of Denmark, Holland, and Belgium — which had recently undergone rapid technological change — and exceeded that of France by about 15 percent and that of Germany by nearly 50 percent (Van Zanden, 1991, p, 226).

The economic change in Britain in the late eighteenth and early nineteenth centuries marked the beginnings of modern economic growth. The basic character of the economy changed from one governed by the balance of land and population to one dominated by technological change and capital accumulation.

Robert Solow's (1957) procedure of estimating the contributions of factor inputs to output growth and identifying a "residual" growth due to "technological change" constitutes the first step in "explaining growth" within an aggregate neo-classical framework. The procedure assumes that national output can be adequately represented as an aggregate produced by a well-specified production function. Also, competition is assumed to result in factor prices proportional to marginal products. In these circumstances, the growth rate of output due to a factor's growth equals the growth rate of the factor times its share of total income. The "residual," or "total factor productivity growth," is the difference between the measured output growth rate and the growth predicted by the growth of inputs.[15]

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[14]Calculated from national income estimates in Crafts (1985a, chap. 3) and industrial shares in Mitchell (1975, pp. 799-800).

[15]The "residual" equals technological change under somewhat restrictive assumptions. This has led many to question the relevance of the exercise (Berg and Hudson, 1992). Despite the undoubted room for error, the calculations seem quite robust (Crafts and Harley, 1992).

Total factor productivity calculations are presented in Table 3.5. Some two-thirds of the acceleration in output growth between the early eighteenth century and the mid-nineteenth century was due to increased rates of factor growth. Historians have long known that population growth accelerated in the final decades of the eighteenth century. Savings and investment maintained the capital stock per capita at approximately the 1760 level. Productivity growth occurred in both industry and agriculture. If Crafts' somewhat speculative calculations can be believed, productivity advanced somewhat faster in agriculture than in the economy as a whole.

Some time ago, D.N. McCloskey brought together information pertaining to various industries and sectors in an interesting attempt to find "the location ofingenuity." The aggregate growth of total factor productivity—calculated by subtracting aggregate input growth from estimated aggregate output growth—conceptually equals a weighted average of the total factor productivity growths of individual industries. McCloskey produced "crude approximations to annual productivity change by sectors" for various modernizing industries and for agriculture (1981, pp. 108-117, 124-127). The estimates for these sectors, appropriately weighted, implied a growth of aggregate total factor productivity only slightly over half of the total factor productivity implied by aggregate calculations using Deane and Cole's national income estimate. McCloskey attributed the remaining unaccounted aggregate total factor productivity to "all other sectors" and concluded that "ordinary inventiveness was widespread in the British economy 1780 to 1860"(1981, p. 117). Revised national income estimates change the conclusion. Deane and Cole's aggregate implied a rate of technological change of 1.19 percent

TABLE 3.5 Sources of Growth, 1700-1860, Crafts' Estimates (percentage per year)

	Growth Rate				*Contribution to Growth*			
	Income	*K*	*L*	*T*	*K*	*L*	*T*	*Residual*
1700-1760	0.7	0.7	0.3	0.05	0.24	0.15	0.01	0.3
1760-1800	1	1	0.8	0.2	0.35	0.4	0.03	0.2
1801-1831	1.9	1.7	1.4	0.4	0.6	0.7	0.06	0.5
1831-1860	2.5	2	1.4	0.6	0.7	0.7	0.09	1

Notes: K = capital; L = labour; T = land. Factor shares for the calculation are capital, 0.35; labour, 0.5; land, 0.15.

Source: Crafts and Harley (1992, Table 5), with allowance for land.

TABLE 3.6 Sectoral Contributions to Productivity: Annual Percentage Growth, 1780 -1860

		New Estimates		McCloskey's Estimate	
	Share	*Productivity*	*Contribution*	*Productivity*	*Contribution*
Cotton	0.07	1.9	0.13	2.6	0.18
Worsteds	0.035	1.3	0.05	1.8	0.06
Woollens	0.035	0.6	0.02	0.9	0.03
Iron	0.02	0.9	0.02	0.9	0.02
Canals and Railways	0.07	1.3	0.09	1.3	0.09
Shipping	0.06	0.5	0.03	2.3	0.14
Sum of modernized	0.29	1.2	0.34	1.8	0.52
Agriculture	0.27	0.7	0.19	0.4	0.12
All others	0.85	0.02	0.02	0.6	0.55
Total	1.41		0.55		1.19

Source: McCloskey (1981, p. 114), with revisions discussed in text.

annually, but Crafts' revision implied total factor productivity growth of only 0.55 percent annually. The productivity growth McCloskey estimated for the modern sectors and agriculture completely exhausts Crafts' aggregate productivity growth (Crafts, 1985a, p. 86; 1987, p. 250).

McCloskey's exercise, although a precarious and uncertain process of identifying residuals of residuals, is extremely interesting and warrants reconsideration. Not only did McCloskey's original calculation depend on Deane and Cole's income estimates, he exaggerated total factor productivity growth in several sectors (cotton,wool, and shipping).[16] In addition, McCloskey's estimate of agricultural productivity growth lies well below Crafts'. Table 3.6 presents revised sectoral growth rates (with McCloskey's original calculations for comparison). Productivity

[16] McCloskey exaggerated productivity change in cotton textiles by overstating the decline in cotton cloth prices (he compared the price of a fancy raised-pile fabric—a velveret—in the 1780s with an ordinary grey printing calico in 1860). Grey calico sold in the 1760s and 1770s for about three (not fifteen) times its price in the mid-nineteenth century (Harley, 1982, pp. 271, 286-291). For worsteds and woollens, McCloskey attributed the rate of productivity growth between 1805 and 1860 to the entire period. History of the industry indicates little technological advance before the early nineteenth century, so the appropriate rate of change for the entire period needs to be lowered. Finally, McCloskey used North's (1968) estimate of productivity change in North Atlantic shipping as an estimate of technological change in coastal and ocean shipping. Recent work (Harley, 1988) has shown much slower technological change in shipping.

growth in the modernized sectors was only two-thirds the rate McCloskey calculated. Nonetheless, the contributions of these sectors and a dynamic agriculture practically exhaust estimated aggregate total factor productivity change.[17]

Aggregate calculations reveal only slow per capita growth during the Industrial Revolution. Radical technological change transformed cotton textiles and iron production, but these sectors were too small to do much to accelerate aggregate growth. Other industries remained largely unchanged. But aggregate growth was only part of the change occurring in Britain. A visitor approaching Manchester in the 1840s might be excused for disagreeing with the view that change had been slow and localized. Before him, beneath a pall of factory smoke, lay a phenomenon —threatening or promising depending on his beliefs—that had not existed when he was a boy: the great industrial city, much smaller, to be sure, than London, but quite different. Here was a society dominated not by the traditional elite but by factory owners and threatened by a proletariat. Manchester was home to new industry, created by the technology of Arkwright, Crompton, and Watt and tied to foreign trade for both its raw materials and its sales. This city, created by new industrial technology and trade (and Liverpool, Glasgow, and Birmingham like it), shook the foundations of British aristocratic society. Its factory-owning middle class, with their growing economic power, had already forced reform on Parliament and agitated for free trade. Their employees, the new "proletariat," raised more radical demands for the People's Charter—manhood suffrage, secret ballot, equal electoral districts, abolition of property qualifications of MPs, salaries for MPs, and annual Parliaments. The Industrial Revolution may have increased per capita income only slowly, but it had created cities and classes that challenged the established order.

Cities grew to accommodate newly concentrated industry. Industry, particularly cotton, about two-thirds of whose output went overseas, was greatly enlarged by exports. The cotton industry, freed from dependence on rural water power by the steam engine, created the industrial city. By 1840 the populations of both Manchester and Liverpool approached half a million; about the same number lived in the other Lancashire textile towns. Similar, although somewhat less intense, cotton-based urbanization had occurred in the western Scottish Lowlands. Iron had a lesser effect. Birmingham, the center of metal fabrication, had grown rapidly but was still some 25 percent smaller than Liverpool or Manchester.

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[17]Recently, Peter Temin (1997) has suggested that the continued export of manufactured goods from sectors other than those explicitly considered in Table 3.6 should be seen as indicating that technological change in those industries must have been faster than the residual estimate in the Table. For a discussion of Temin's argument see pages 189-191, below.

During the early years of Victoria's reign, British firms dominated the world's modern industry.[18] Many contemporaries and historians have talked of a British monopoly. But despite British dominance, there was no monopoly; rather this was competitive capitalism. Firms entered the cotton industry easily and sold in competitive markets. They were unable to prevent prices from falling to the cost of production, and the benefits of technological change passed to consumers as lower prices. British customers benefitted but so equally did the foreign two-thirds of cotton textile customers. The competitive structure of the cotton textile industry meant that although the world gained from the improved technology in British exports, Britain gained little extra from those exports.

Britain exported cottons to obtain raw materials and foodstuffs. In the twenty-five years after the Napoleonic Wars, technological change nearly halved the labor and capital needed to make a piece of cloth in Lancashire. The competitive market drove textile prices down, and in 1840 an exported piece of cloth could purchase only half the foreign food it had commanded at war's end. The same technological change that generated industry growth caused the terms of trade to deteriorate.

Price changes transferred the benefits of technological change to consumers, whether domestic or foreign. Consequently, conventional aggregation that emphasizes production—for export as well as domestic sales—rather than consumption, while helping us understand the structural shifts in the economy, overstates the benefits to Britain of the cotton industry's growth. As Adam Smith [1776 (1976), bk. ii, p. 179] pointed out in his famous attack on mercantilism: "Consumption is the sole end and purpose of all production; and the interest of the producer ought to be attended to, only so far as it may be necessary for promoting that of the consumer. The maxim is so perfectly self-evident, that it would be absurd to attempt to prove it."

Calculations in Table 3.7 consider cotton production for export as a means of acquiring imports for consumption. They illustrate what is involved and indicate orders of magnitude. In 1841 Britain produced about 5.2 times the quantity of cotton textiles it produced in 1815. British consumers purchased about 40 percent of output in both years and the remaining 60 percent was exported. Think of the exports as first paying for the industry's imported raw cotton and the remainder purchasing a representative bundle of imports for consumption. In 1815 the raw cotton imports cost about a quarter of the total value of output; in 1841, because textile prices had fallen faster than raw cotton prices, the proportion was somewhat higher at 31 percent. About 35 percent of the output (60 minus 25) in 1815 was exported to obtain foreign consumption goods. In 1841 about 29 percent of output was

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[18]Bairoch (1982) estimates that Britain contained more than half of modern industry in 1840. Britain took 55 percent of the world's raw cotton output and accounted for substantially more of value of output because of the higher average count of yarn spun in Britain (Ellison, [1886] 1968, pp. 100, 146).

exported in exchange for foreign consumption goods — 4.3 times as many textiles as in 1815. But a given piece of cotton cloth could now purchase only half as many imports. As a result the quantity of imported consumption goods only about doubled. The quantity of cotton produced increased 5.2 times, but the consumption (cotton goods and imports) the industry provided to British consumers increased by only about three and a half times (3.8 times, if the cotton and imports are valued at 1815 prices, or 3.3 times, if they are valued at 1841 prices; good theoretical arguments suggest the average between the two is the best measure). Expansion of the cotton industry to produce exports thus had only modest direct impact on national income. But, at the same time, exports greatly increased the industry's size and its social impact.

Technological change has loomed large in the preceding analysis, but, in the spirit of economic theories of growth that prevailed in the 1960s and 1970s the sources of technological change have been largely ignored. Technological change has been considered to be exogenous to the economic process of adjustment. This view is, of course, unsatisfactory and economic historians have long devoted attention to the sources of technological change. Recently, economic theorists have redirected their attention to attempting to model growth in a way that does not depend on exogenous technological change. Two types of approaches can characterize the attempts. The first type of theoretical models, now generally recognized to be unsatisfactory, modeled productivity advance as externalities to investment in physical plant or in human capital. Formally, this formulation removed diminishing returns from capital (perhaps aggregated to including human

TABLE 3.7 Cotton Textile Production and Consumption, Effects of Terms of Trade

	Quantities		*Prices*	
	1815	*1841*	*1815*	*1841*
Output of cotton textiles:	100	520	1	0.5
Domestic consumption	40	210		
Exports	60	310		
For raw cotton	25	160		
For consumption	35	150		
Consumption:				
Cotton	40	210	1	0.5
Imports	35	75	1	1
Aggregate Consumption:			Quantity Index, 1815 = 100	
1815 prices	75	285	100	380
1841 prices	55	180	100	327

Sources: Harley (1982); Ellison ([1886] 1968), p.56; Von Tunzelmann (1978), p.229.

capital). As Crafts (1995a; 1995b and 1996) has recently shown this type of formulation is not very helpful in understanding the acceleration of growth in Britain during the Industrial Revolution. Variations in the growth in output are not well correlated with changes in investment rates (but see Greasley and Oxley, 1997).

A second strand in the recent theoretical endogenous growth literature in economics keeps technological change of the sort measured by the Solow residual at the center of analysis but views it as an economic process and considers its source. Paul Romer, one of the leading scholars in this line of research has recently written (1996, p. 204):

> New growth theory started on the technology-as-public-good path and worried about where technology came from, but soon backed up and reconsidered the initial split that economists make in the physical world. New growth theorists now start by dividing the world into two fundamentally different types of productive inputs that can be called "ideas" and "things". Ideas are nonrival goods that could be stored in a bit string. Things are rival goods with mass...This slightly different initial cut leads to insights that do not follow from the neoclassical model. It emphasizes that ideas are goods that are produced and distributed just as other goods are.

Modeling that proceeds from this point of view emphasizes incentives to inventive activity. This emphasis has long been congenial to economic historians. In this context ideas like those of Max Weber concerning the relationship between religion and the spirit of capitalism and those of Douglass North relating to governmental and other institutions come into sharp focus (Weber, 1958; North 1981; 1990; North and Weingast, 1989).

These ideas are surely of primary importance in understanding the long-term origins of modern economic growth and provide a formal framework in which to pursue further investigation of ideas long considered by economic historians. They seem, however, to provide only limited help in understanding the British Industrial Revolution narrowly defined. Changes in the incentives and social framework that support the creation of ideas seems to have evolved over a long time period in Britain and Western Europe generally. Imbedded in a new growth model, this would imply a gradual acceleration of growth. If we take a long enough perspective, this is surely what occurred in the eighteenth and nineteenth centuries. On a more detailed level, however, it does not well characterize British growth from 1700 to 1900. Crafts and his collaborators have applied techniques of modern time-series analysis to characterize the evolution of the rate of growth of industrial production in Britain (Crafts, Leybourne and Mills, 1989, 1991; Crafts and Mills, 1994, 1997). This analysis reveals that while the Industrial Revolution probably occurred as part of a long-term growth acceleration, it was also characterized by a further temporary acceleration. A period of exceptionally rapid growth occurred during the first quarter of the nineteenth century that was not sustained after the 1830s. This suggests that the Industrial Revolution and the export led growth of the leading British industries involved something other than a gradual evolution of the inventive environment. To use Mokyr (1990a, p. 13) insight, we seem to have a "macroinvention…a radical new idea [that] emerges more or less *ab nihilo*." The innovation's effect on industrial production was great, in part because of export opportunities. In due course, however, the output of textiles and iron could not expand by capturing foreign markets. The macroinnovation's effect in creating new opportunities for growth could not extend to new industries.

The Consistency of the Crafts-Harley View in a General Equilibrium Model

The view of British growth that has emerged as a result of Crafts' and my reassessment of the aggregate statistics for the British economy has gained wide acceptance, but controversy remains. The evidential basis of the aggregates remains imperfect and can support some variety of interpretations, although probably a narrower range than critics at times imply (Crafts and Harley, 1992). In addition, some have questioned the theoretical coherence of our view of growth. In particular critics have suggested that the rapid agricultural growth that Crafts proposes is inconsistent with industrialization in a relatively open economy. Jeffrey Williamson, for example, asserts that "Crafts' revisionist view of unbalanced productivity advance favoring agriculture will have a hard time accounting for the relative demise of agriculture and the relative expansion of industry during the industrialization surge after Waterloo" (1987a, p. 274). Recently, Peter Temin (1997) has challenged our view that technology changed only slowly — probably less than in agriculture — in industries other than the famous few of the traditional narratives of the Industrial Revolution. He argues that Britain's continued export of other manufactured goods demonstrates that technological change in these industries must have been substantial and clearly greater than technological change in agriculture.

Assertions regarding the interaction of technological change and the size of agriculture or the structure of British exports rest on models of the British economy. Both Williamson and Temin refer to simple theories of economic general equilibrium to support their arguments. Neither, however, attempts to explore a specific model calibrated to the particular features of the British economy. Computational general equilibrium models can be constructed and explored with the help of modern computers. A model provides numerical indication of general orders of magnitude and highlights key assumptions while insuring that the view is logically consistent. In fact a model that incorporates Crafts' view is able to reproduce the general outline of actual historical changes despite theoretical doubts of the sort raised by Williamson and Temin (Crafts and Harley, 1998).

The general equilibrium model we explored highlights several features of the Crafts-Harley view of British industrialization. First, the portion of manufacturing in which technological change occurred very rapidly is distinguished from the rest of manufacturing and services where change was slow. Textiles and iron amounted to only a little over a third of industry, even in 1840 after their rapid growth. Second, the model emphasizes growing agricultural productivity. Third, diminishing returns in agriculture — arising from limited land resources — and technological change in manufacturing sharply altered British terms of trade. The terms of trade deserve a central place in assessment of the British Industrial Revolution. In some of British manufacturing, technology changed rapidly and output grew fast as domestic and export sales grew. Cotton textiles were at the forefront of the change. The new technology was British, and British firms became the only significant exporters. Technology revolutionized the industry, drove down prices, and caused export growth. Deterioration of the terms of trade reflected the driving force of change.

A fairly simple model containing two trading countries—Britain and "the rest of the world" — demonstrates a consistency between rapidly improving agricultural technology and a decline in the share of agricultural in the economy.[19] The modeled British economy and the rest of the world both contain four producing sectors: agriculture, "modern" industry, other industry, and services. The basic building blocks of the model were functional representations of production technology and consumer preferences. The specific form of these functions represented reasonable guesses; the data did not permit their more formal estimation. Factor markets allow factors to move among sectors and equated factor prices across sectors. A representative, utility maximizing consumer in each country owns all factors (so the model has no class or distribution features) and chooses consumption to maximize a simple multi-good utility function.

Values of output in 1841 provided a benchmark to which the model was calibrated. Model solutions that incorporated stylized changes in technology and factor supply provided analysis of British growth. Pre-Industrial Revolution British agriculture, following Crafts' calculations, used 1.75 times 1841 resources to produce a given output. Production of the goods of the industries where rapid technological change occurred during the Industrial Revolution used 2.8 times as many resources pre unit of output in 1770 as they did in 1841 The rest of the world partially shared technological change in modern industry, at a reasonable guess using 1.5 times the resources in 1770 as were used in 1841. The calculated pre-Industrial Revolution equilibrium supports Crafts' general view. Industrialization emerges as consistent with relatively rapid improvement of agricultural technology. Diminishing returns in agriculture, caused by limited land

[19]The model building has relied on an available computer program (Rutherford, 1988). The modelling follows quite closely similar modelling exercises that have recently been conducted in development economics and in analyzing issues of international trade policy (Robinson, 1989; Shoven and Whalley, 1984).

resources in the face of rapidly increasing population, and the rapid fall in the prices of modern goods together resolve Williamson's dilemma of growing agricultural imports despite improving agricultural technology. When a calculated 1770 equilibrium is compared to the 1841 benchmark, agricultural prices are only about a third higher relative to the price of goods that did not experience technological change, even though output of a given quantity of agricultural goods used seventy five percent more inputs than in 1841. The difference occurs because the lower 1770 population put less pressure on land resources and rents fell to only half their 1840 levels.

Consideration of Temin's belief that exports of other industries demonstrated considerable technological change in those industries requires a more complex model. In the simple model discussed above, exports of other industries were excluded in the specification. A more complex model, in which both industry and exports and imports are modeled in more detail, reveals that Temin's conclusion needs not be valid. Increasing population and diminishing returns in agriculture led to a rapidly increasing demand for imported foodstuffs in Britain. The increase in exports of the goods of the Industrial Revolution was limited in its ability to finance imports because foreign demand was relatively inelastic. Inelastic demand coupled with the lower costs of production resulted in a rapidly deteriorating terms of trade for the new industry. Despite the fact that the quantities of these goods exported rose much faster than British population, the revenue per capita from these exports rose only modestly. Consequently, exports of other goods continued to be necessary to pay for imports.

Although the calculated general equilibrium models support the Crafts-Harley view, they cannot really provide strong evidence of its absolute correctness. The data are sufficiently weak that other specifications could reasonably be considered and similar models could support other narratives.

Summary of the Crafts-Harley View

Revision of the basic aggregate estimates of British growth combined with a neo-classical framework—presented starkly in the computational general equilibrium model above—provides a general view of the changes in the British economy during the late eighteenth and early nineteenth centuries. Revolutionary changes in industry were largely confined to the famous sectors of textiles, iron, and transportation. Even in combination, the technological change in these sectors contributed only modestly to growth of aggregate output. The famous industrial technology caused national income to grow about a third of a percent annually. This would require two centuries to double income. Equally, however, industrial change helped to change social structure, demographic behavior, and savings habits. It certainly remains possible that these social changes stimulated growth. Nonetheless, it seems impossible to sustain the view that British growth was revolutionized in a generation by cotton-spinning innovations.

The new estimates of national income identify a long period of transition. Growth probably began to accelerate in the last years of the seventeenth or the early years of the eighteenth century. In the late eighteenth century, important innovations occurred in some industries, but per capita national income growth accelerated only modestly. Accelerating agricultural change contributed about as much as industrial innovation. Modern economic growth became fully established in Britain only in the railway age.

Despite the moderate impact of industrial technology on aggregate growth, changes in economic activity greatly altered British social structure. By the 1830s a combination of the rapid growth of the urban-based textile industries, that exported most of their product, and the decline in agriculture's share of the labor force produced the first urban industrial economy. Both industrial technology and mobility out of agriculture were important. The rapid technological change in textiles and iron led to dramatic price declines that gave British producers an advantage they quickly seized—the ability to supply large portions of world demand in these industries. In the 1840s, British cotton producers exported some sixty percent of their production (Ellison, [1886] 1968, p. 60). The iron industry exported a quarter of its output and the woolen industry about 20 percent (Deane and Cole, 1967, pp. 196, 225).

Britain's transformation required a movement of labor and other factors of production from agriculture to industry as well as improvements in industrial technology. By historical standards, the British adjusted very rapidly. Agriculture's high level of technological accomplishment, the rapid growth of productivity, and the transfer of labor probably arose from the social structure of rural Britain. A large portion of both agricultural entrepreneurship and labor was separated from control of land. This separation of labor from the means of production made labor much more responsive to market signals than it would otherwise have been.

The Distribution of Income: An Alternative Focus

The Crafts-Harley view combines new macroeconomic estimates with economic modeling to study output growth and structural changes in Britain after 1750. We have emphasized the unevenness of technological change, the movement of productive factors from agriculture to industry, and the impact of particular technological change on Britain's exports and terms of trade. The results help us to understand British industrialization, but the model, as must any attempt at understanding, necessarily simplifies in order to concentrate on certain features of historical experience. We have focused on aggregate growth, trade, and structural change and have not addressed all interesting macroeconomic issues. In particular, many contemporaries and historians have seen issues of income distribution, which our approach is poorly equipped to address, at the heart of the British Industrial Revolution.

Contemporaries, from classical economists to radical reformers, paid close attention to distribution. They saw industrialization as a process that primarily enriched the propertied classes while, at best, bypassing the working class and more likely immiserizing a proletariat. A generation ago, the extent to which Deane and Cole's estimates of per capita income and per capita consumption grew faster than estimates of real wages indicated a considerable redistribution away from the laboring class. Income per capita in 1851 was estimated to be 2.3 times its 1780 level, and per capita consumption 2.4 times its 1780 level but the Phelps Brown and Hopkins index of real wages increased only by 30 percent (1956). Phelps Brown and Hopkins' data referred to workers who fared poorly and their price deflator was narrowly based, but even on Lindert and Williamson's (1983b) high estimate, real wages only doubled[20].

The new estimates of national income have eliminated the clear distributional effects implied by the earlier aggregates. Crafts estimated per capita national income growth at 70 percent between 1780 and 1851 and consumption growth at 75 percent (Crafts, 1985a, p. 103). Williamson and Lindert and Crafts more or less agreed that real wages, on average, grew about 85 percent between 1780 and 1851. Real wage estimation remains bedeviled by the differing experiences of various labor groups, but wages and national income per capita now seem to have grown at about the same rate, removing a presumption for strong shifts in distribution away from labor (Crafts, 1989a, pp. 76-84). Recently, however, Charles Feinstein's (1995, 1997a, 1997b) careful assessment of real wages suggests that real wages grew more slowly than Craft's estimate of national income. The Feinstein estimate indicates either a modest shift in the income distribution against workers or a somewhat slower rate of aggregate growth than Crafts suggests.

Historians have long known that there were a wide variety of experiences within the working classes. In the north, incomes were initially low but improved much faster than in the south. Industrial opportunities improved more than agricultural opportunities. Regional and occupational income patterns altered: northern wages overtook southern wages, and agricultural workers fell behind. Industrial technology impoverished some, most notably the handloom weavers, while creating a "labor aristocracy" of workers with skills made more valuable by technological change. Economic historians have traced the diversity of the Industrial Revolution's impact and have spent much time identifying and studying both winners and losers —both between the propertied and laboring classes and within the laboring classes.

Recently, some of this investigation has been placed explicitly within a macroeconomic view. Peter Lindert and Jeffrey Williamson traced the evolution of the income distribution from the late seventeenth century by reworking and improving estimates of earnings of various classes made by various contemporaries

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[20]Charles Feinstein's recent estimates (1997b, Table 9, p. 37) show real wages increasing between 1780 and 1850 by just a bit more (36%) than Phelps Brown and Hopkins.

(Lindert, 1980, 1986; Lindert and Williamson, 1982, 1983a). Charles Feinstein (1995, 1997a, 1997b) has recently improved estimates of wage earnings after 1780. The work provides a basis for income-based national income estimates to compare with Crafts' production-based estimates. In addition, Williamson has developed a model of British industrialization that directs attention to income distribution and that contrasts sharply with some aspects of the Crafts-Harley view.

Williamson's Model of British Industrialization

In his book *Did British Capitalism Breed Inequality?* (1985) Williamson analyzes the British economy using a model focused on distributional issues. The model deserves consideration both for its distributional focus and because of its disagreements with our views. It had two principal features. First, Williamson followed traditional narratives. He saw rapid technological change in manufacturing industry leading growth, with agriculture lagging, and he contrasted gains for skilled labor with small gains for the lowest classes. In addition, he approached Britain's industrialization using a general view of early industrialization formed by his interpretation of the histories of Japan and the United States and the post-second World War experiences in the Third World (1985, pp. 87-90, 183; 1987a, pp. 269-270, 272-273). To him, economic growth began discontinuously. New industrial technology created a disequilibrium that provided opportunities for an acceleration of investment and growth in manufacturing. "Unbalanced productivity advance has always been viewed as the primary supply-side force driving industrialization and urbanization. Since the rate of technological change has always been viewed as far higher in modern than in traditional sectors, industry 'leads' and agriculture 'lags' in capital formation, output expansion and job creation. So said the qualitative accounts of the British industrial revolution, and now there are some tentative numbers documenting the process" (1985, p. 89).

Williamson's analysis of British industrialization used a multisectoral general equilibrium model. The model possessed four primary inputs — farmland, capital, unskilled, and skilled labor. Separation of labor into two classes provided the distributional features he wished to emphasize. Primary inputs (in some cases combined into "resources," an intermediate good produced by a mining sector) and imported raw materials produced three final goods: agriculture, manufacturing, and services. Agriculture employed unskilled labor, capital, and land but no skilled labor or intermediate products. Mining used only unskilled labor and capital. Manufacturing used skilled and unskilled labor and capital, as well as resources from mining and imported raw materials. Services were produced with skilled and unskilled labor, capital, and domestic intermediate goods (Williamson, 1985, chap. 8).

Two features of Williamson's view contrasted sharply with the Crafts-Harley models. First, we see changes in Britain's terms of trade as central to the Industrial Revolution. In contrast, Williamson modeled Britain as a small country that facing international prices in traded goods, so that prices of agricultural and manufactured goods and of imported raw materials were exogenously determined. The second important difference occurs in our perceptions of technological change, which we and Williamson modeled as exogenous. We felt that it was vital to distinguish between the minority of manufacturing industries that were transformed by technology and the rest of manufacturing, and we accepted evidence showing relatively rapid technological change in agriculture. Williamson did not distinguish among industries in manufacturing but assumed rapid technological advance in industry as a whole (just over 1 percent annually) and slow technological change in agriculture as well as in services and intermediate goods (0.3 percent annually).

Williamson analyzed the economy from 1821 to 1861 (and from 1861 to 1911) by examining the equilibrium output quantities and endogenous prices for factors of production, services, and domestic resources that his model predicted in response to exogenous changes in technology, factor supplies, and international prices. The skilled and unskilled labor pools grew at essentially the same rate. Capital formation occurred at a considerably higher rate than labor force growth. Both technological change and investment stimulated manufacturing. More rapid technological advance drew mobile capital and unskilled labor to industry, and capital formation stimulated the capital-intensive industrial sector. The stimulus to manufacturing was partially, but only partially, offset by exogenous deterioration of manufactured goods' prices — caused by unmodeled international factors (1985, appendix E). In response, the industrial sector grew about 3.2 percent per year, while agricultural output grew about 1.4 percent per year, and income inequality increased.

Williamson's view of the Industrial Revolution emphasized increasing income inequality. The higher growth of industry differentially increased the demand for skilled labor and widened the wage premium of skilled workers. The model predicted an increase in the premium of skilled over unskilled wages of nearly 40 percent between 1821 and 1861 (1985, pp. 130-131, 151-160, cf. table 10.5). Since Williamson also generated new data that showed a similar increase in the skilled wage premium, he saw this result as justifying the use of the model's logic as an explanation of British historical change. Independent assessors have doubts about this data, however, that question the model's usefulness.

Current Knowledge of Distributional Changes, c. 1700 to c. 1850

Williamson's modeling of the Industrial Revolution was heavily influenced by his and Peter Lindert's investigation of occupational patterns and wages. In *Did British Capitalism Breed Inequality?* Williamson presented new wage data that showed an increase in the ratio of the wages of skilled workers to the wages of unskilled workers. Earlier work had focused on unskilled workers and the relatively small subset of skilled workers in manufacturing jobs that became unionized during the nineteenth century.[21] Williamson collected wage data for the clerical and middle classes—skilled occupations that employed a large portion of the labor force — primarily using information about civil service pay. His data showed that wages in these occupations increased much faster than either skilled manufacturing wages or unskilled wages. He concluded that the premium of skilled wages over unskilled wages rose by 40 percent between 1815 and 1851, rather than the 10 percent rise older data had shown.

Unfortunately, independent evidence and the behavior of several of Williamson's new series suggested that the wage quotations were incompatible over time. Experts rejected Williamson's assertion that "incomes levelled across the late eighteenth century and the French Wars; inequality surged from Waterloo to mid-century; and incomes levelled again during the late nineteenth century" (Feinstein, 1988b; Jackson, 1987). After assessing Williamson's estimates, Charles Feinstein concluded "the general picture is one of broad stability, most notably in the ratio of skilled to unskilled pay and in the overall distribution of earnings" (1988b, p. 728).

A second strand of Lindert and Williamson's research on income distribution has made an important contribution to our understanding of incomes in the eighteenth and nineteenth centuries. They carefully re-examined and improved income estimates from the "social tables" that were produced between the late seventeenth and the nineteenth centuries by contemporaries Gregory King, William Massie, Patrick Colquhoun, and Dudley Baxter (Lindert and Williamson, 1982, 1983b). These contemporaries attempted to enumerate the various classes in the kingdom along with their incomes. Gregory King produced the first table toward the end of the seventeenth century to demonstrate the folly of William of Orange's war policy. In 1760, William Massie produced a similar table to demonstrate how the protected West Indian sugar planters exploited British society. In the nineteenth century, similar tables were compiled with more scientific and less polemical intent and benefited from improving basic statistical information. Patrick Colquhoun drew on the first census and the income tax data to estimate incomes in the first years of the nineteenth century. Dudley Baxter enjoyed improved versions of these and other sources when he made his estimate for 1867 (Phelps Brown, 1988, pp. 305-306). The efforts of King, Massie, and Colquhoun were heroic; as E. H. Phelps Brown (p. 306) remarks they generally "have been regarded as having done no more than what was a notable achievement in its day, but as too slightly based to have much chance of being accurate."

Lindert and Williamson, without fully overcoming the basic problems of limited underlying data, have improved these sources "to arrive," as Phelps Brown remarks, "at reasonably firm conclusions." The income distributions show high levels of inequality by standards of modern Britain and other developed countries and also,

[21]Much of this data had been collected by Arthur Bowley and George Wood in the late nineteenth and early twentieth centuries.

although less sharply, by comparison to other late-nineteenth-century societies. Summary measures indicate that inequality increased from the late seventeenth century to the mid-nineteenth century before beginning to fall to twentieth-century levels—a pattern of rising and then falling inequality as growth proceeded that Lindert and Williamson call the Kuznets Curve. This represents a modification of the earlier view (O'Brien and Engerman, 1981; Soltow, 1968) that concluded from the same sources that the income distribution did not change significantly before the twentieth century.[22]

Lindert and Williamson's summary measures, however, do not adequately represent the distributions of income they found for eighteenth- and nineteenth-century Britain. E. H. Phelps Brown has recently analyzed the data using the technique of "Pen parades," which provided greater insights into the differing experiences of various income groups.[23] He concludes that the changes in income distribution between King's and Massie's estimates can be seen as a continuous process (although Colquhoun's data seem to show some wartime interruption with losses by the very poor and gains for the very rich). Phelps Brown's characterizes the changes are quite differently from Williamson and Lindert, and his summary merits quoting at length (pp. 314-315):

> In sum, the structure of incomes had changed between 1688 and 1867 from a stack of three tiers to a smooth gradation. To characterize the structure of 1688 in that way is to simplify it overmuch; but in contrast with the later structure it does appear as formed of three groups — the cottagers and laborers, who made up half the whole number of income recipients; "the aristocracy of labor" — the craftsmen, and with them the farmers and the professional — a middle group with incomes substantially higher than the laborers' and rising fairly steeply within their own bounds; and at the top some very high incomes indeed. By 1867 this arrangement had been changed markedly. The lowest group had risen relatively to the others, and differed less among themselves. The middle group had ceased to differentiate itself so sharply from those below, both in the rate at which incomes rose and as a proportionate part of all income. So far, the movement had been towards greater equality. But the top group had

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[22]Lindert and Williamson's estimates show lower inequality in the early years mainly because of revised occupational figures from Lindert's investigation of burial registers (Lindert, 1980). Crafts has suggested that figures based on King are particularly uncertain and may well understate inequality by failing to consider the very low wages then prevailing in the North (Crafts, 1989a, p. 87).

[23]The "Pen parades," named after the Dutch economist Jan Pen, who originated them, are graphs of individual income levels displayed against percentiles of the income distribution. For a discussion of interpretation of income distributions, see Phelps Brown (1988, chap. 9).

> become relatively richer than ever. The Pen parade serves to display and locate these varied changes, in whose presence any one measure of inequality means little.

The current best assessment of the history of British wage structure leaves Williamson's analysis of British industrialization without crucial support. It seems likely that his model failed to approximate the historical record because technology change and the demand for skill did not occur as he modeled them. Rapid advances in industrial technology appear to have been confined to a relatively small portion of the total industrial sector. Textiles did not notably demand skilled labor. Other, more skill-intensive, industry grew more slowly. After 1830 the major change in the demand for laborbour came from the railroads, stimulated by technological change and capital accumulation. Railroad construction required mainly unskilled workers. In addition, agriculture probably did better than Williamson assumed.

The British certainly experienced varied changes in their well-being during the Industrial Revolution. Incomes in different regions changed at different rates; workers with certain skills and in particular industries clearly benefited and others lost. Some, like the quarter of a million handloom weavers and their families and agricultural workers in the southern grain areas, obviously suffered; others, like most northern workers in industry and agriculture, gained.[24] The labor market and the capital market were segmented along regional, industrial, and class lines and did not equate returns throughout the economy. More efficient factor markets would have increased output, perhaps considerably (Williamson, 1987b). But the inefficiencies did not originate in the eighteenth century and probably declined despite sharp differences in the regional impact of technological change.

Full understanding of Britain's transition to modern economic growth requires consideration of market segmentation due to region, class, custom, and other sources of inertia. Rapid change altered the distribution of income. During extended periods of disequilibrium, some growing sectors gained extraordinary benefits and some declining sectors suffered extraordinary hardship. New equilibria were characterized by altered distributions of income. Regional and industrial variety tend to be obscured in aggregate macroeconomic assessments and need continued careful study before we can fully understand either the sources or the consequences of the Industrial Revolution (Berg and Hudson, 1992).

Why Was Growth so Slow? War and the Nature of British Growth

British economic growth accelerated only gradually before the middle of the nineteenth century. In comparison with the early growth of other now-advanced countries, British growth was slow, slower even than previously thought. Jeffrey

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[24]In various places, Crafts has drawn attention to regional issues (1982; 1985a, pp. 104-107; 1989).

Williamson has suggested that Britain grew more slowly than more recently industrializing societies primarily because of the twenty years of war with Revolutionary France and Napoleon. In making this suggestion, he raises two important issues: What was the nature of early British growth, particularly in comparison with the emergence of modern growth elsewhere? What was the impact of the Napoleonic Wars, which were an important and expensive part of the history of the period?

Competing Overviews of British Growth

Crafts and Williamson brought basically different underlying views to a comparison of British growth with growth that began later in other countries. Williamson worked with the hypothesis that modern economic growth began with a generally applicable pattern exemplified by experiences of the contemporary Third World economies, the nineteenth-century United States, and twentieth-century Japan. These examples led him to expect modernization to begin with rapid growth and with particular emphasis on manufacturing. In the initial spurt, productivity increased rapidly in the modern sectors and capital formation accelerated, driving growth. He felt that only the stress of war deflected Britain from the general pattern (1985, pp. 87-90, 183; 1987a, pp. 269-270, 272-273).

Crafts worked from a different underlying vision that emphasized the differences between Britain and the later industrializing economies of Europe (1985a, chap. 3; 1989c). In his framework the United States, Japan, and the contemporary world are unpersuasive analogies. Britain pioneered industrialization over a long period during which appropriate institutions and technologies slowly emerged. In the late eighteenth century, revolutionary changes occurred in a few manufacturing industries—particularly textiles and primary iron. Most final metal products and most other industrial goods were still produced in old ways. The evidence, imperfect though it is, suggests that agriculture, far from being a lagging sector as in many later industrializations, experienced more rapid technological change than most of the economy outside the new industries.

From Crafts' perspective, the slow emergence of British growth seemed only natural. But from Williamson's perspective, the slow growth during the "'heroic phase' of the First Industrial Revolution" required attention. He commented that "even during productivity slow down, OPEC fuel-crunch, Malthusian burdens, and capital scarcity abroad, the Third World managed per capita income growth rates around 3.2 per cent per annum in the 1970s, ten times that of Britain prior to the 1820s!" In addition, "Britain was a low saver . . . the rate of capital accumulation was so modest that hardly any capital-deepening took place at all" (Williamson, 1985, p. 162).

Williamson suggested possible reasons for this unusual early British growth. He first rejected the possibility "that the conventional dating of the first industrial revolution is just plain wrong." Instead he proposed "that Britain tried to do two things at once—industrialize and fight expensive wars—and she simply did not have the resources to do both effectively" (1985, p.162). In particular, he saw wartime government borrowing crowding out productive investment. In the absence of war, he believed that capital formation, structural shift, and growth would have been much more rapid, following a normal pattern of early industrialization.

War

The French wars greatly complicate analysis of the British Industrial Revolution and Williamson was certainly right in insisting that they not be ignored. Revolutionary France declared war on Britain in 1793, and intense warfare continued until Napoleon's final defeat in 1815. The conflict was one of history's great wars, the conclusion of epic conflict between England and France that began in 1689. During the 126 years from 1689 to 1815, England was at war for 73 years, and at war against France for but 2 of these. Figure 3.4 summarizes British war expenditure in relation to GNP.[25] These were major wars; the Napoleonic Wars stand out less for their intensity—the previous struggles had annually taken about the same share of national income—than for their duration.

Patrick O'Brien (1994) has recently surveyed the impact of the Hanoverian state on the British economy. During the eighteenth century, the modern nation-state evolved from conflicts caused by France's Continental ambitions and Britain's opposition. In the end, with the Treaty of Vienna and the restoration of the French monarchy, the British could take satisfaction: The struggle had been expensive, but British vital interests had been defended and advanced. Although not the dominant power in continental Europe, Britain had emerged as the greatest world power. O'Brien summarizes the economic balance sheet (p. 215):

> By any standards expenditures on the armed forces required to underpin the kingdom's foreign, strategic and commercial policies look massive. At the time opponents of the regime's stance in foreign affairs argued they were profligate and in large part avoidable...In retrospect it can be argued that most of the money seems well spent because between 1688 and 1815 no invasions of the homeland wasted the domestic economy. Before 1805 no great power emerged on the mainland of Europe capable of obstructing the kingdom's trade with the Continent. Foreign aggression against British commerce and territories overseas declined in significance. After the recognition of its independence in 1783 the United States was "reincorporated" into the Atlantic economy with Britain at its hub. Over the period diplomacy backed by military force compelled the rival empires of Portugal, Spain and Holland in the South Americas and Asia and the Mughals in India to concede entrées to British trade and ship. British privateering, together with blockades and assaults upon the mercantile marines of

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[25] The government expenditure figures are the sum of army, navy, and ordnance from Mitchell and Deane (1962, pp. 389-391, 396), deflated by the average of O'Brien's (1985, pp. 787-795) industrial and agricultural price indices. The income figures are Crafts' (Crafts and Harley, 1992, table 4).

> Holland, France and Spain by the Royal Navy (coupled with the vulnerability of Amsterdam and Frankfurt to invading armies on the Continent) formed 'military preconditions' for the City of London's domination of international services by the late eighteenth century.

In the nineteenth century, growth undoubtedly benefitted from the peaceful, liberal, and competitive world order that followed the Treaty of Vienna. The eighteenth-century wars had used about 10 percent of a modest per capita income. If these resources could have been devoted to investment or even to raising the still-modest margin over subsistence for much of the population, they would, other things being equal, have sped growth, just as a "peace dividend" did after 1815. Other things, of course, were not equal. The stability of the nineteenth century arose from the resolution of the conflicts of the eighteenth and the political stability of the states that emerged. Such conditions did not prevail earlier and it is unrealistic to imagine such a counterfactual world. Nonetheless, it is useful to consider Williamson's proposition that military spending primarily diverted resources from investment, thereby seriously slowing growth.

War, of course, was expensive using men and equipment that could otherwise have produced consumption and capital. Furthermore, war disrupted the normal patterns of economic activity. As David Ricardo observed at the time, "The commencement of war after a long peace . . . generally produces considerable distress in trade. It changes in a great degree the nature of the employments to which the respective capitals of the countries were before devoted; and during the interval while they are settling in the situations which new circumstances have made the most beneficial, much fixed capital is unemployed, perhaps wholly lost, and laborers are without full employment" (quoted in Mokyr and Savin, 1976, p. 201). The costs of war—the men and equipment involved and the maladjustments in the economy—had to be met in real terms before or as they were incurred, even though governments borrowed to finance most wartime activity.[26] Some costs were met before the conflict—men were trained, and equipment was produced in peacetime and stored. HMS Victory, Nelson's flagship at Trafalgar, for example, was built in the naval dockyard at Chatham between 1759 and 1778. Figure 3.4 shows, however, that these expenditures covered only a small faction of wartime costs. Government had to obtain large amounts of resources for military use after hostilities began. There were four possible sources those resources: (1) abroad, (2) previously under-utilized capacity, (3) investment, or (4) consumption. Resources from abroad and the mobilization of previously underemployed resources played only minor roles. Increased taxation took resources primarily from consumption. A large part of war

[26]Mokyr and Savin (1976) provides the best attempt to analyze the impact of the Napoleonic Wars. They pay particular attention to disruption as well as diversion to military uses.

expenditure was financed by borrowing; to what extent did this crowd out investment?[27]

In wealth holders' portfolios government debt competed with claims on private assets. In an extreme, every pound of new government debt might have displaced a pound of potential private investment. Government wartime expenditure did not increase the capital stock and future productivity, as private investment did, so growth would slow. Williamson argues "that the one-for-one crowding-out-assumption may not be such a poor description of behavior during the British industrial revolution" (1985, p. 117).

Full-employment macroeconomic models (Modigliani, 1961) inspired the crowding-out hypothesis. In such models, current output and individuals' savings—the willingness to accumulate assets, either real capital or government debt—are exogenous. Government demand for funds pushes the real rate of interest up until private investment is reduced by the amount of government borrowing. The view that wartime crowding-out greatly slowed investment has been challenged by examination of details of the war years. Joel Mokyr points out that Williamson exaggerated the resources that the government obtained by debt finance and that wartime dislocation was probably greater than he estimated (1987, pp. 293-305). The history of savings and the interest rate does not correspond well with the predictions from the crowding-out model. Figure 3.4 summarizes investment, government borrowing, and their sum ("total savings") as a proportion of income in the late eighteenth and early nineteenth centuries. Contrary to the model, "total savings" was not independent of government borrowing but increased sharply during the war and then fell back. The volatility of measured "total savings" was almost entirely reflects the volatility of government borrowing. Charles Feinstein estimates that gross capital formation increased quite steadily through the war despite government borrowing (1988a, p. 446).

In his discussion of crowding out, Williamson points to construction—some two-thirds of investment—as being particularly hurt. If construction had been crowded out, the postwar stock of buildings would have been below its equilibrium value and would have yielded excess profits to its owners. Investors would have responded with a post-war construction boom to compensate for the wartime shortfall. But brick production hardly fell during the war,[28] and Feinstein's decadal estimates of construction increase throughout the wars show no post-war boom. The post-war increase in construction only equaled the increase from the 1790s to the 1800s (1988a, p. 446).

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[27]Williamson's original statements seemed to imply a one-for-one crowding out. He has made it clear that he had a somewhat more modest intent but still saw crowding out as the major source of government funds (Williamson, 1987a, p. 286).

[28]The rate of growth slowed somewhat during the war, but the slowdown cannot be statistically distinguished from the random movement of the series in other years (Mokyr and Savin, 1976, p. 217).

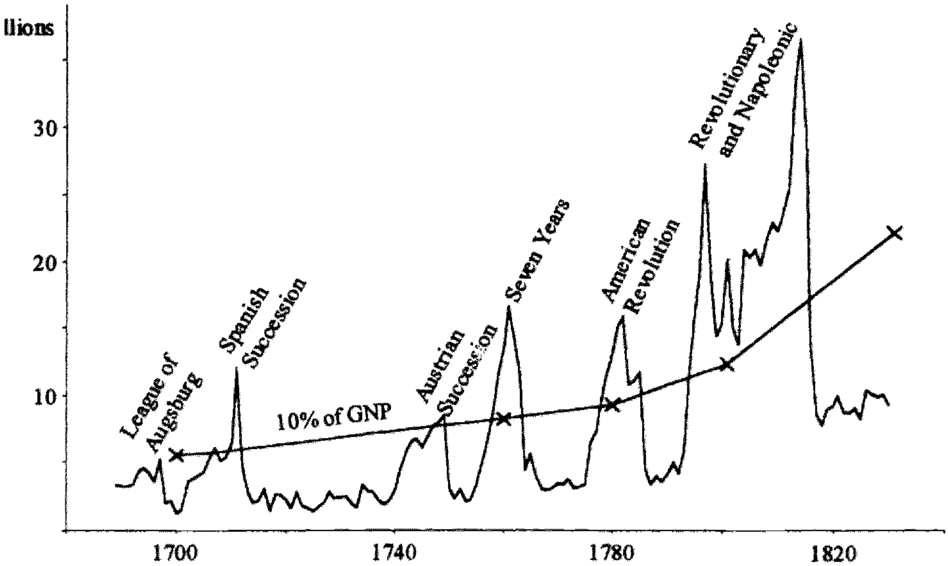

FIGURE 3.4 Military Expenditures and National Income 1690-1830, constant prices
Sources: Crafts and Harley (1992, table 4); Deane and Cole (1967, pp. 78 and 166); Mitchell and Deane (1962, pp. 389-391, 396); O'Brien (1985, pp. 787-795).

Because crowding-out models rely on higher real interest rates discouraging private investment, examination of interest rate movement provides insight into the impact of war finance. The real interest rate is an elusive concept. The 'nominal' or market rate of interest represents the exchange of present and future monetary amounts. Nominal interest rates provide evidence of real interest rates only when corrected for expected changes in the value of money. Certainly, the changes in the value of money concerned investors in the inflationary war years, but there was no easy way for contemporaries to predict the future of prices. On one hand, the Bank of England's abandonment of convertibility of its notes into gold in 1797 and wartime inflation made faith in the stability of money untenable. But informed investors probably expected, realistically as it turned out, that the termination of hostilities would bring the restoration of gold convertibility and price deflation. Various procedures to model expectations of price inflation indicate that nominal interest rates rose less than the expected inflation, so real interest rates fell (Black and Gilmore, 1990; Heim and Mirowski, 1987, 1991; Mokyr, 1987, p. 300; Mokyr and Savin, 1976, p. 209).

The history of investment and interest rates suggests that crowding out of investment was not the principal source of resources for war use. Where, then, did the resources to fight the war come from? An "inflation tax" seems the most likely mechanism (Bordo and White, 1991). By using inflationary finance the government got resources from those—particularly wage earners—who failed to anticipate inflation fully. Inflation also benefited well-placed wealthy individuals who purchased government debt with much of their gains. Real wages certainly lagged during the war years. The distribution of income shows a wartime interruption of the leveling process that had begun in the eighteenth century. In particular, the incomes of the very richest increased (Phelps Brown, 1988, fig. 11.2, pp. 311, 313).

War affected the British economy as it entered into modern economic growth. Military campaigns and the associated government finance diverted resources from uses that would have led to more rapid growth. The precise magnitude of that impact is not yet well understood. In a peaceful, liberally organized international economy, Britain would have grown more rapidly, but a liberal economy only emerged from eighteenth-century warfare. Williamson's hypothesis—that an end to the wars in 1763 would have nearly doubled the rate of capital formation, creating a "heroic phase" of the First Industrial Revolution that would have conformed more closely to the periods of rapid initial growth elsewhere—seems overstated. There is little evidence that government borrowing primarily crowded out private investment. The slow, gradual increase in investment accompanied the long evolution of modern growth.

Conclusion

Recent reassessment of Britain's path to mid-nineteenth-century economic predominance emphasizes three important characteristics. First, the beginnings did not occur as a "heroic" breakthrough in the third quarter of the eighteenth century but as a long evolution. Second, British agriculture—probably because of a greater separation of ownership, entrepreneurship, and labor—developed and adopted productivity-enhancing changes on an unusually large scale. Because agriculture was still a large sector, productivity growth there had substantial impact on the standard of living. Agriculture also released factors of production to other activities, not completely without friction but rapidly by international standards. Third, a few key innovations of exceptional impact established British firms as technological leaders in textiles and iron production. With this technological advantage, British firms came to dominate international trade in those goods, and the growth of these industries converted Britain into an urban industrial economy. The social impact was large, but the technological breakthrough cheapened only a small part of the goods the British consumed and probably contributed less than agricultural change to the growth of per capita income.

Britain's early emergence into modern economic growth occurred as the culmination of long historical processes. Agriculture's growth owed much to the particular class structure of landownership. The British state had provided security in a turbulent international environment successfully, if expensively. Internally, the state had, largely fortuitously, created an institutional framework that supported growth.

The famous technological breakthroughs in industry that we call the "Industrial Revolution" were a part, but probably quite a small part, of the process of growth.

Modern industry first emerged in Britain in part because of the dynamic character of the economy. Much of Britain's particularly industrial and urban character in the nineteenth century resulted, however, from an unusual technological history in cotton and iron. British development of dominance in these new urban industries came from exceptional technological breakthroughs, reinforced by the generation of war that delayed foreign competition. The combination of technological breakthrough and the war's enhancement of the comparative advantage was an unusual event—probably in part a "lucky draw" in the random process of invention (Crafts, 1977). In a long perspective, Britain would probably have led in modern growth, but her particular nineteenth-century position as "workshop of the world" depended on particular—fortuitous—breakthroughs in cotton and iron technology.

Comparative advantage in textiles and iron, coupled with rapid movement of resources from agriculture, led to rapid industrialization and urbanization. Since industrial productivity was only modestly above agricultural productivity, industrialization and urbanization, per se, resulted in little increase in aggregate output and real wages. The competitive structure of British manufacturing industry conferred the benefits of technological change in the new export industries on consumers, many of whom were foreigners. There were some gains from international specialization, but the British gained only modestly from the exports that made their island the "workshop of the world." Growth involved much more than the famous export sectors and the "Industrial Revolution" they brought.

Modern economic growth began in Britain as a particular historical event and followed a different path there than in economies that followed. Recent work on continental European industrialization suggests that Britain is a poor model for initial growth there. These economies, too, accelerated slowly rather than emerging suddenly under the influence of a leading sector. Their structure differed from Britain's. The countries that started to grow later often grew faster than Britain had. Attempts to understand the British Industrial Revolution by suggesting a close correspondence between the experiences of the contemporary Third World, early twentieth-century Japan, and the nineteenth-century United States appear particularly anachronistic. Both the historical circumstances and the particular conditions of the economies were very different from that of eighteenth-century Britain. The United States industrialized as an expanding continental economy protected by high tariffs, and the others were late followers. Britain's pattern was closer to that seen elsewhere in Europe than to more remote economies, but even in the European context, Britain was a leader and followed a different path.

4

Too Much Revolution: Agriculture in the Industrial Revolution, 1700-1860

Gregory Clark

Introduction

The idea that an agricultural revolution accompanied the Industrial Revolution, and indeed contributed more to the overall productivity growth of the British economy in the years 1700 to 1850 than did the revolutionary changes in cotton textiles, still dominates thinking about the Industrial Revolution period.[1] Table 4.1 shows, for example, some recent estimates of productivity growth in English agriculture between 1700 and 1850. The authors vary in where exactly they place the productivity growth, but all find productivity more than doubled between 1700 and 1850, just at the time of the Industrial Revolution.

The existence of the agricultural revolution has profound implications for our thinking about the rate of overall economic growth in the Industrial Revolution, the level of industrialization in England before the Industrial Revolution, and about the cause of the Industrial Revolution. Yet it remains a maddeningly elusive event. It is only observed indirectly, through the shadows it casts on other actors. When we get down to the level of what was happening in the fields and the barns during the Industrial revolution period we see little sign of any major changes. This essay argues that that is because there was no agriculture revolution in England in the Industrial Revolution period, or indeed any time between 1600 and 1914. Instead there were modest gains in output, and even smaller gains in measured productivity, all the way from 1600 to 1914 through minor and incremental changes in agriculture.[2] Agriculture is closer to reactionary torpor than to revolutionary excitement

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[1] Knick Harley, for example, attributes to agriculture more than one third of all the productivity growth in the Industrial Revolution. See page 160.

[2] I use the term "measured productivity" because it is apparent that some of the observed gains in productivity seen comparing the prices of inputs to outputs come because the gains in real land rents were in part the result of unmeasured increases in investment in soil capital.

in the Industrial revolution years. The slow progress of agriculture is shown to imply much slower overall growth in the Industrial Revolution period than even such pessimists as Crafts and Harley estimate.

The Agricultural Revolution Discovered from the Industrial Revolution

Scholars belief in an agricultural revolution in England between 1700 and 1860 mainly because of three things that happened in the economy as a whole: growing population, rising incomes, and urbanization. The population of Britain increased from 6.5 m. in 1700 to almost 21 m. by 1851. Since domestic agriculture still fed four out of five Britons in 1850, the population it fed increased 150% from 1700 to 1851. The upper curve in Figure 4.1 shows a rough estimate of the required food production in Britain from 1700 to 1850 on the assumption that food consumption per person was constant. Since both output per person and real wages are widely believed to have increased in Britain after 1800, that should have boosted food consumption even more since at higher incomes people consume more food. In studies of the value of food consumed compared to income for groups of workers at particular times in the late eighteenth and nineteenth centuries it has been found that consumption per capita, c, is well predicted by a function of the form,

$$c = a.(w/p)^e \tag{4.1}$$

where w/p is real income, and e is the elasticity of demand for food, which seems to be about 0.65. Since even relatively pessimistic estimates such as the recent

TABLE 4.1 Estimated Productivity Levels, 1700-1860

Period	*1700*	*1760*	*1800*	*1850*	*1860*
Crafts	100	135	146	234	259
Allen	100	-	182	234	-
Overton	100	-	142	208	-

Notes: The estimates of Crafts refer to Britain after 1801, England and Wales before, those of Allen to England and Wales, and of Overton to England only. Crafts estimates after 1831 derive from those of Deane and Cole. The productivity estimates ascribed to Overton are derived from his estimates of land and labor productivity giving land and labor equal weight.

Sources: Crafts (1985), pp. 41-4, 84; Deane and Cole (1967), p. 166; Allen (1994), p. 111; Overton (1996), p. 86.

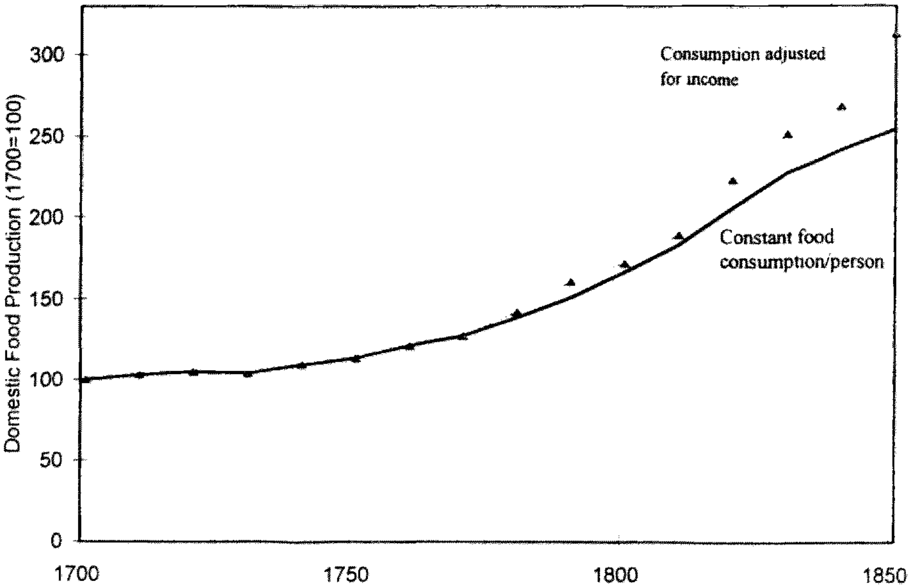

FIGURE 4.1 Predicted Agricultural Output in Britain, 1700-1850
Note: The solid line shows the food output required in Britain to keep consumption per capita constant. The dotted line shows the output required given evidence on real wages in Feinstein (1997b).

ones of Feinstein (1997b) suggest a 43% gain in real incomes between 1770 and 1850, total agricultural output would thus have increase by 220% between 1700 and 1850.[3] The cultivated area seemingly increased little between 1700 to 1860 so yields per acre should have tripled.

There has been equivalent optimism about increases in output per worker. The census of population gives estimates of the share of the work force in agriculture from 1801 onwards, though the earlier figures are very imprecise. These suggest that the share of the adult male labor force in agriculture was 25% in 1851, and 36% in 1801. Before 1801 there are no census figures, so the labor in agriculture must be deduced from other considerations. Wrigley (1985) uses urbanization rates as a guide and concluded 55% of the labor force was in agriculture in 1700. Crafts (1985) use information on occupations gathered from probate inventories by Lindert (1980) to get a similar figure of 56% of workers in agriculture in England

[3] Assuming real incomes in 1780 were the same as in 1700.

in 1700.[4] These considerations imply an adult male labor force in agriculture of about 900,000 in 1700, and 1.1 million in 1851. Thus the swelling food production was largely achieved without greater labor inputs, so that output per worker grew between 100 and 150% between 1700 and 1850. Once these large increases in output per acre and output per worker are concluded, it follows that overall productivity in agriculture increased in the way shown in table 1.

Backing up this indirect route to the agricultural revolution, Deane and Cole (1967) exploit another possible source of information, which is measures of the amount of income generated by the agricultural sector. To this end they use records of land rents generated by the property taxes of 1806 to 1814 and 1842 on, combined with estimates of the earnings of agricultural workers. This allows them to calculate estimated income in agriculture as shown in Table 4.5 below. Dividing this nominal income by a price index for all agricultural products, they conclude that total output doubled between 1801 and 1861, again suggesting impressive productivity growth.[5]

Yet the agricultural revolution has little discernible connection with events in industry. Mechanization was minimal in English agriculture by 1850, the only task substantially affected being grain threshing. And even threshing was still mainly a hand task in much of the south of the country as late as 1850. Similarly there are no heroes of agricultural innovation - no Hargreaves, Arkwrights or Cromptons - just an amorphous collection of anonymous sons of the soil somehow bringing home more bacon. The early stories of the revolution emphasized "Great Men" – Jethro Tull, "Turnip" Townsend, Arthur Young and the like - who pioneered new techniques. But the great men have been shown to be self-publicizing midgets, and all subsequent accounts have been of incremental changes, carried out by a broad swath of farmers across a broad sweep of time (Overton, 1996, p. 4).

Such a diffuse agricultural revolution has powerful implications for the likely cause of the Industrial Revolution. A diffuse revolution occurring precisely at the time of the Industrial Revolution implies that the gains of the Industrial Revolution period most likely stemmed from some economy wide social or institutional change –changed attitudes on the part of all producers as in the Industrious Revolution of Jan de Vries (1994), or improved incentives for all economic actors as in North and

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[4] Crafts (1985), p. 15. Allen estimates the labor force in agriculture circa 1700 and 1750 by estimating the distribution of farm sizes in 1700 and 1750, and then fitting to these farm sizes estimates from Arthur Young's tours circa 1770 of the likely labor inputs per acre at different farm sizes. He concludes labor inputs in 1700 were somewhat greater than Crafts assumes.

[5] This index unfortunately includes such goods as tea, coffee, sugar, rice, olive oil, tobacco, pepper, cinnamon, rum, and whale oil which were not produced on British farms.

Weingast's (1989) analysis of the Glorious Revolution of 1688, or superior incentives to move labor out of agriculture as argued by O'Brien (1996).

However, despite the popularization of the concept of the agricultural revolution by Toynbee and Lord Ernle as long ago as the 1880s, agrarian historians have been singularly unsuccessful in pinning down the details of what allowed this revolutionary improvement in land and labor productivity. Enclosure of common lands, the elimination of peasant agriculture, and new crops such as turnips and clover, have all been placed center stage in the drama of the agricultural revolution. None of these actors, as we shall see, has proved up to playing the lead role in a dramatic agricultural revolution.

Even more puzzling, agricultural historians have been singularly unsuccessful in showing directly that output per acre and per worker did indeed triple as expected. In discussing the agricultural revolution we are at the most basic terms discussing what happened to four simple aggregates: agricultural output, and the inputs of labor, land and capital. The trouble is that for both output and capital we have *no* direct information for the period 1700 to 1850. For labor we have no firm information for any years before 1801. The land area available for agriculture did not change much, but other than that we know little directly. The last major attempt to estimate the volume of agricultural output between 1750 and 1850 by B. A. Holderness (1989, p. 174), for example, concluded with the warning to the reader that "The section on production and productivity is so replete with expressions of doubt, uncertainty, and disbelief that it reads like a litany for skeptics." Holderness's caveats are not false modesty, for his firmest estimates of output, for grains, are still based on pure speculation on the level of grain yields in 1750-70, and in the case of meat and dairy products the speculation is heavily guided by the need to ensure that the resulting figures do not imply too big a decline in consumption per person.

The best we can say of the direct estimates of outputs and inputs in the eighteenth century is that there is evidence of some gains in grain yields per acre between 1700 and 1850, but no firm evidence on pasture yields, which was about half the farm sector, or on labor or capital inputs. The agricultural revolution accepted by such writers on the Industrial Revolution as Crafts (1985), Harley (1993), Allen (1994), O'Brien (1996), and Overton (1996) is one which is derived mainly from population, income, and urbanization.

It is true, nonetheless, that by 1850 British agriculture had achieved levels of land and labor productivity which were far in advance of most European countries. Table 4.2 shows output per acre and per worker for different European countries circa 1850. Though the comparison here is crude because of the nature of the sources, as can be seen output per acre in Britain in 1850 was triple that of Russia,and output per worker was triple or greater. Output per acre in Britain in 1850 was at least twice as high as in 1300, and output per worker may have increased by as much. Britain's productivity advantage in 1850 lay particularly in

TABLE 4.2 Agricultural Performance Circa 1850

Country	*Year*	*Output per acre (England 1851 = 100)*	*Output per worker (England 1851 = 100)*	*Total Productivity (England 1851 = 100)*
Britain	1851	100	100	100
Netherlands	1850	94	54	76
Belgium	1850	122	37	73
Ireland	1851	78	47	67
France	1850	82	44	66
Germany	1850	56	42	56
Romania	1870	51	40	53
Austria	1854	54	32	50
Sweden	1850	45	37	49
Hungary	1854	36	30	41
Russia	1870	24	29	34
England	1300	48	36	50

Note: I assume that the shares of capital, labor and land in costs are .2, .4 and .4 respectively, and that output per unit of capital (which is unobservable) is constant across countries and time. Output per acre in Britain in 1851 is estimated at the equivalent of 12.6 bushels of wheat, and output per worker at the equivalent of 272 bushels of wheat.
Source: Clark (1991, p. 213).

high levels of output per worker. The cross country differences in 1850 do seem to imply that some time between 1300 and 1850 Britain seemingly experienced an agricultural revolution, which made it not only the most efficient producer of industrial goods in 1850, but also one of the countries with the highest output per acre and per worker in agriculture. Indeed as we move from the west to the east of Europe in 1850-70 we seemingly move back in time, with Russian agriculture in the late nineteenth century apparently the equivalent of English agriculture in 1300.

A Biological Revolution?

What adds to the mystery of the agricultural revolution is our inability to locate its source. If productivity rose so much between 1700 and 1860 what was the mechanism of this increase? Two types of explanations have been offered for the advance of agricultural productivity. The first is some type of biological revolution, where after hundreds of years farmers somehow figured out how to grow heavier crops, and to breed more efficient animals. The second is that prior to 1770 English agriculture was hampered by institutional constraints such as common property rights, and small farm sizes. Let us consider these two possible sources of productivity growth in turn.[6]

Grain yields per acre in pre-industrial agriculture were low by modern standards. In medieval England, cereals yielded only 3-6 grains per seed planted. Wheat yielded 11 bushels per acre, for example, while modern wheat yields in England would be more than 70 bushels per acre. Yet to maintain even this very low fertility up to one half of the arable had to lie fallow each year, as compared to almost no fallow land now. Thus one key element in any agricultural revolution was increased grain yields. By 1850 wheat yields had increased to about 26 bushels per acre, and the share of arable land kept fallow had also fallen to a tenth or less.

Our best understanding of why grain yields were so low in the pre-industrial period is that the agricultural system produced little organic nitrogen, nitrogen being the crucial constraint on crop growth. When systematic experiments were first conducted in growing grain under various rotations in Rothamsted in England in 1842 it was soon found that under cultivation conditions similar to those of pre-industrial agriculture, additions of nitrogen alone to plots sown with grains increased wheat yields by over seven bushels per acre and barley yields by over 16 bushels Hall (1917, pp. 36, 73). These increases were maintained on land continuously sown in grain with additions of only nitrogen for over 60 years. Land under continual wheat cultivation produced 20 bushels per acre annually as long as nitrogen alone was supplied, and land under barley produced 29 bushels per acre, much greater than the equivalent medieval yields. Additions of a combination of all other major plant nutrients - phosphorus, potassium, magnesium, and sodium - without extra nitrogen increased per acre yields of wheat at Rothamsted by only two bushels and yields of barley by only seven bushels per acre.

Any agricultural system over the long run must achieve a balance between the outflow and the inflow of any nutrient used in the system. In agriculture in the modern industrialized world this condition does not constrain agricultural output, since we can replace most of the soil nutrients at low cost with manufactured

[6] Allen argues that both these processes occurred, the bulk of the biological revolution occurring in the seventeenth century, and the bulk of the institutional revolution in the eighteenth. Allen (1994).

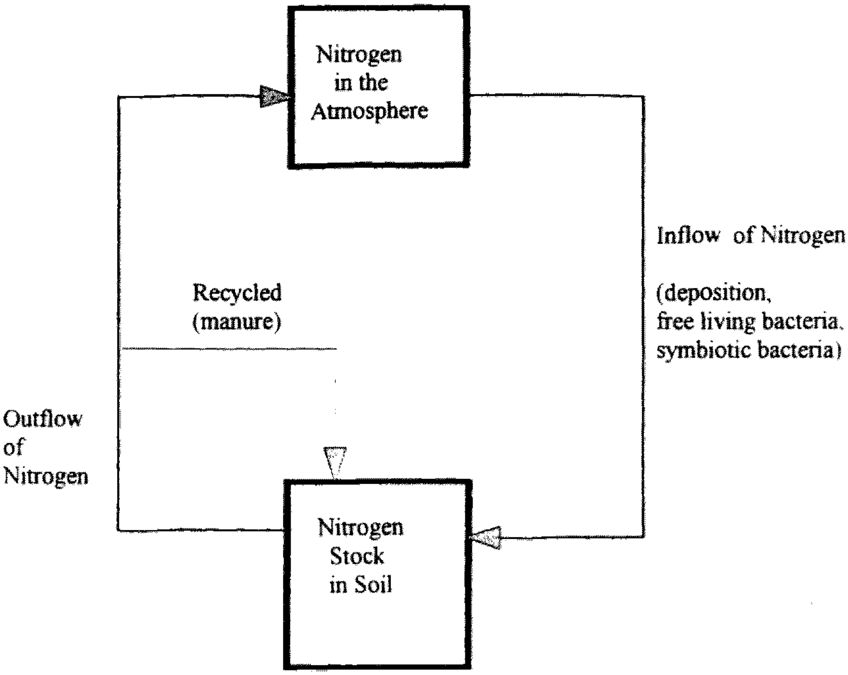

FIGURE 4.2 The Pre-Industrial Nitrogen Cycle

fertilizer. Indeed production now depends on huge inflows of nitrogen, potassium, and other nutrients which are either manufactured using petroleum or mined from soil deposits. If the industrial basis of our agriculture were removed yields would collapse. In the US over 90% of the nitrogen applied to soils is from chemical fertilizers. From 1950 to 1980 the world use of chemical fertilizers increased sevenfold.

There were no manufactured fertilizers in pre-industrial Europe, however. Thus the soil nutrients depleted by crop removal had to be replaced either by returning the waste products of consumption, or by replenishment from within the soil. The system had to be self-sustaining. Figure 4.2 shows the nitrogen economy of the pre-industrial agricultural system. This imposes a heavy constraint on output. Nitrogen enters the soil from the atmosphere in three ways: by direct deposition, through fixing by free-living bacteria in the soil, and through fixing by symbiotic bacteria on the roots of certain plants. We know from the Rothampsted experiments that under continual grain cultivation the inflows of nitrogen from rainfall and non symbiotic fixation can support a long term grain yield of no more than the equivalent of 6 bushels of wheat per acre.

The only way to increase yields without artificial fertilizers is to grow crops that fix nitrogen symbiotically such as clover or legumes. Pasture land also fixes nitrogen from the atmosphere because it contains clovers and other nitrogen fixing plants. The current view of how yields increased between 1700 and 1860 is farmers began using sown clover in arable rotations, observing empirically the effect on grain yields. The clover fixed nitrogen which was made available to the subsequent grain crops through animal manure and as soil residues. By increasing the nitrogen input the total output of the agricultural system was raised also. Calculations based on the Rothamsted experiments suggest clover could double arable yields (Chorley (1981), Clark (1992)).

The clover/nitrogen theory implies, however, that in the other half of English agriculture, the land kept permanently as pasture, yields should have increased little

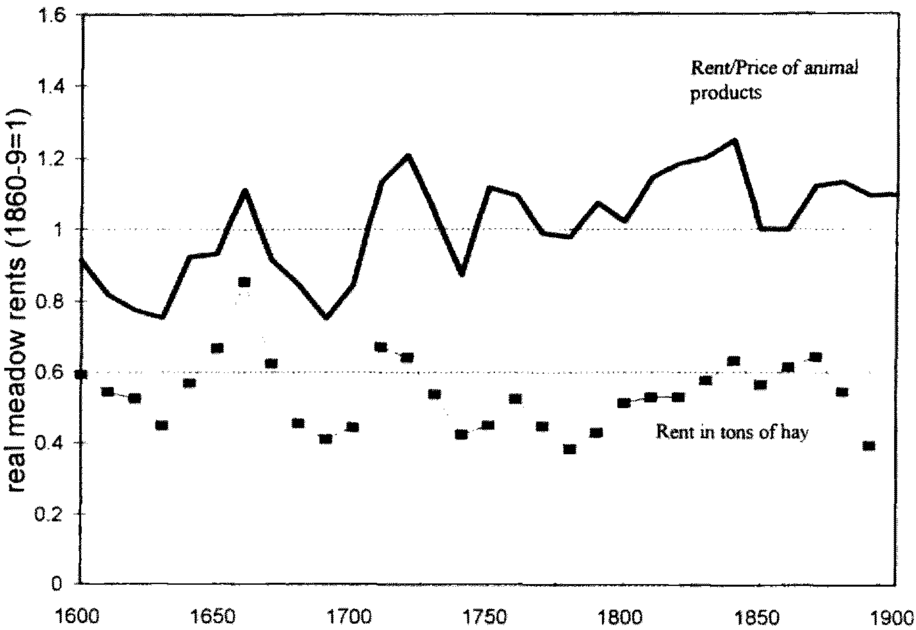

FIGURE 4.3 Rent of Meadows in Terms of Hay and Animal Products
Source: Charity Commission Reports

between 1300 and 1860. For the clovers in natural pastures would ensure that this land had a good inflow of nitrogen even before the introduction of sown clover. Thus the overall yield gain across both arable and pasture per acre from the introduction of clover would be modest – at best about a 50% gain overall. There is indeed evidence that meadow and grass yields increased relatively little in England between 1600 and 1910. If we compare average rental values of meadow land in the south of England held by charities with the price of hay, the product of meadow, we find that the average rental of meadow changed little from 1600 to 1900, measured in terms of tons of hay. All through this period average rentals were about 0.55 tons of hay per acre, as figure 4.3 shows. Since meadow land used very little labor to produce hay, this implies that over this 300 year period there was little gain in meadow yields. Figure 4.3 also shows the rent of meadow in terms of the average price of a basket of animal products: beef, mutton, wool, butter and cheese. Here there is sign of a modest increase in real rental values, but only between 1600 and 1700. After 1700 there is no further gain in the real rental value of meadow. There may have been through better breeding of animals a slight gain in output per ton of fodder produced in the seventeenth century, but thereafter no gains.

On arable, by contrast, there was a slow but steady rise in rent measured in terms of bushels of wheat all the way from 1600 to 1910, as figure 4.4 shows. In the early seventeenth century the rent of arable land was equivalent only to two bushels of wheat or less. By 1900 it was eight bushels. Because rent was typically less than a third of output on arable land, and would be strongly influenced by factors such as the cost of labor and the introduction of labor saving machinery, this quadrupling in rents cannot be used to infer that there was anything like a quadrupling of arable yields. Indeed if labor and other costs per acre of arable, measured in terms of grain, did not change between 1700 and 1860, the rise in arable rents between these years of the equivalent of three bushels of wheat implies a yield increase of only three bushels of wheat per acre in annual yields. Even allowing for extra costs of threshing, harvesting, and carting heavier yields, the total implied gain in yields per acre would still be only the equivalent of four bushels of wheat. Assuming an average net yield per acre of arable in the 1860s of the equivalent of 12 bushels of wheat per acre, which is at the low end of the possible range, this implies a percentage yield gain on the arable of no more than 50% between 1700 and 1860. Thus even the marked and quite distinct rise in real arable rents translates into at best modest gains in grain yields between 1700 and 1850.[7] Even if this yield gain

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[7] Since the burden of the poor rates also increased between 1700 and 1850, and these fell more heavily in arable areas, there was perhaps some additional gain in yields

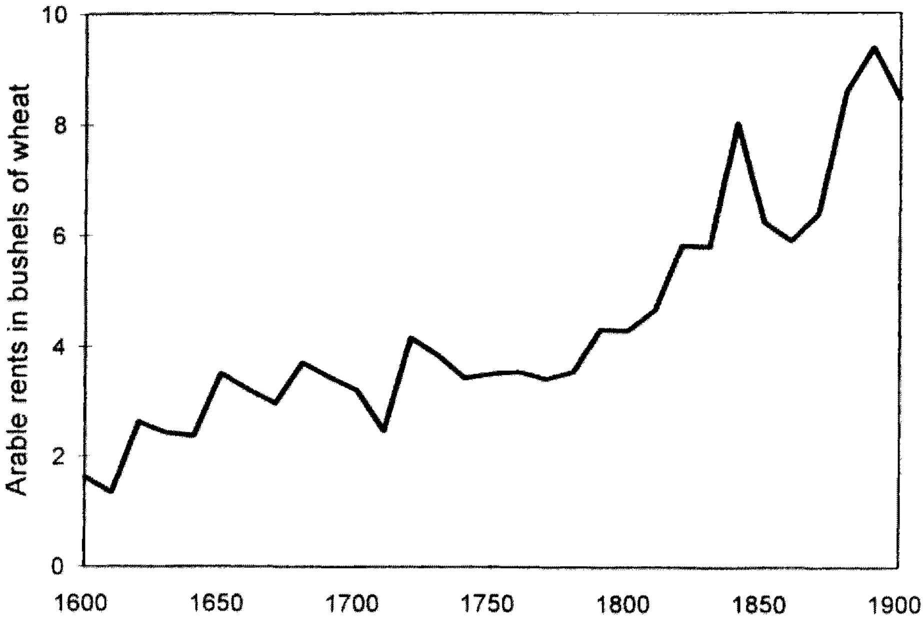

FIGURE 4.4 The Rent of Arable in Bushels of Wheat
Source: Charity Commission Reports

was produced at no extra cost in labor and capital inputs this would generate a total productivity gain between 1700 and 1850 of only 25%.

Thus the rent evidence from the south of England on arable and pasture land supports the idea that low yields in the pre-industrial era were in part created by a lack of nitrogen fixing on the arable land. But at the same time the rent data suggests that the gains from improving the nitrogen inflow in the system were largely limited to the arable sector, and were relatively modest. Even the supposition that the introduction of clover represented a technical breakthrough is not without difficulties, however. While it seems plausible that nitrogen really was a major constraint on yields before 1860, there are good reasons to think that this was not just a problem of the ignorance of earlier farmers of the mechanics of crop growth. While clover was the most efficient way of fixing nitrogen, it was not much better than another simple way which had existed since at least the middle

beyond this 50%.

ages, convertible husbandry. Under convertible husbandry land was used as arable for 5-10 years, then switched to pasture for an equivalent length of time. In the pasture phase the land acquires stocks of nitrogen in the soil which can be utilized by subsequent arable crops. There is no doubt that even medieval cultivators knew of the fertility restoring powers of grass, so why had these techniques not improved yields long before 1700? Skepticism that clover represented a technical innovation on a par with the flying shuttle or the spinning jenny in textiles is strengthened by the study of the determinants of yields on individual farms in the seventeenth and early eighteenth century by Overton using probate inventories. Though clover was rapidly diffusing among farmers in Norfolk and Suffolk in the early eighteenth century the wheat and barley yields on farms growing clover were only very modestly above those on farms with no clover (Overton (1991, p. 314)). The low level of grain yields before 1860 thus seems as much a choice of farmers not to invest in improving soil fertility by growing more grass as the consequence just of ignorance. Clark (1992) points out that the nitrogen stock in the soil is a kind of capital, and the balance kept in this bank of soil fertility should thus be sensitive to the alternative rates of return on capital. The years 1600 to 1750 saw a significant decline in rates of return in England, and this should have induced higher investment in soil nitrogen on the arable.[8]

The clover/nitrogen theory also does little towards explaining the apparently equally impressive rise in labor productivity. For while a rise in arable yields would have increase labor productivity somewhat on arable land, the gains would be very modest. Many of the tasks in pre-industrial agriculture were proportionate to the total output, and were not fixed per acre cultivated. Thus threshing, reaping, mowing, carting, manuring, milking, butter making, and cheese making were all largely dependent in their labor requirements on the total output. There would be some reduction in labor input per unit of output from higher yields through reduced inputs in sowing, plowing, and hedging and ditching, but these were the minority of labor inputs on the farm.

Writers such as Allen and Overton have assumed that the increase in the average slaughter weights of animals over the industrial revolution period was sign of other technological advances in the form of livestock that more efficiently converted fodder into wool, meat and milk. Such improvements in animals should leave their mark, however, in terms of a fall in the prices of animal products relative to the

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[8] It may be objected the that farmers could not have carried out the calculations necessary to incorporate the rate of interest into their cropping decisions. But from earliest times farmers had to make decisions trading off current investments against future returns. Decisions to marl, lime, drain, enclose, and construct barns all have this character. The decision to increase soil fertility was just another case where current income had to be sacrificed, through putting arable into pasture, for a higher yield in future. The cost of borrowing to replace that current income should influence how attractive this prospect was.

price of the main input in producing these products, fodder such as hay and pasture. The price of meat, milk and wool should all fall relative to the price of fodder if animals become more efficient at converting fodder into useful output. But Figure 4.3 which also shows the rent of meadow measured in terms of the prices of a basket of animal products reveals that there is no sign of any decline in the price of these products relative to the price of fodder after 1700. There is little indication of any greater efficiency in conversion of one to the other.

In sum all we see of the biological revolution in agriculture in the years 1700 to 1860 is a gain in grain yields, with no corresponding improvements in either the yield of grassland, or in the efficiency of conversion of fodder into meat.

Institutional Innovation

If a biological revolution supplied little productivity advance, perhaps the lifting of institutional constraints such as common property rights generated significant improvement. To many eighteenth century agricultural reformers such as Arthur Young the major problems of the agricultural sector were the persistence of common property rights, and of many small undercapitalized and "unprogressive" farmers kept afloat by the failure of landlords to charge market rentals for land. Yet we can show that institutional changes played an insignificant role in the advance of English farming between 1700 and 1860.

As late as 1750 almost a quarter of the land in England was held not as exclusive private property, but in some form of joint ownership, where for at least part of the year the land was under communal control. This system is variously called the common field or open field system. In England common land was of many different types: arable and meadow which was private for part of the year, pasture which was common all year (but where access was limited), and "waste" land to which all members of the village community had free access. Common land was often referred to as "open" land and private land as "enclosed" land, because generally individual plots of common land were unfenced and scattered in small parcels in large open fields, while private land was fenced.

The arable land lay in two or more large open fields in each village. After harvest and in fallow years the arable land was pastured in common, but access to this grazing was closely controlled.[9] Meadow land was similarly in unfenced strips, grazed in common by those who owned the grazing rights after the hay was cut. The rules of cultivation were laid down by an assembly of the farmers in the village, this often being the manor court.

Since the arable and meadow strips were close together and unfenced there had to be a high degree of cooperation in cultivating the land. The manorial court would adopt rules which regulated when the fields might be plowed and by when

[9] These grazing rights were not open to all, but attached to ownership of land or cottages in the village.

they had to be harvested. Often the village would also set rules about how and when the harvest had to be gathered, and about the kinds and quantity of animals that could be grazed in the fields.[10] They would also order villagers to maintain the fences of the common fields. The courts had to deal with many cases of trespass by one villager on the strips of another, and of theft of output. Since strips were often marked only by stones or a double furrow there were also cases of "furrow stealing" where one farmer would begin encroaching on the plot of his or her neighbor. Another serious crime in such villages was moving the stone markers which were sometimes used to mark off the individual strips.

In England after 1740 a legal device called Parliamentary Enclosure, which required only that the owners of 75-80% of the land area agree to enclose, was widely employed to terminate common rights. The process is called "enclosure" because the elimination of common property was generally associated with physically fencing the land. Once the owners of the required share agreed, and Parliament passed the bill, a commission would be appointed to reallocate all the land affected. About 21% of the land area of Britain was enclosed by Parliamentary Enclosure from 1750 to 1830 (Chapman, 1987). At least as much land was allegedly enclosed by private means before 1750.

The open-field system has fascinated historians and economists for years. The collective nature of property and the communal regulation of cultivation practices led historians to believe that it was the institutional arrangements of the open-fields which kept yields low in agriculture since they would make the introduction of new cropping practices difficult. Further the multiple claims to land reduced the incentive of individuals to invest in land improvement. The "owner" of a piece of meadow, for example, who increased its fertility by manuring it or draining it saw some of the benefits of his or her investment go to others who grazed the meadow after the hay was harvested. Even steps such as drainage of individual plots was limited because the water would then just be diverted onto neighboring plots.

Until at least the 1960s the open-field system was vilified as a major drag on agricultural efficiency. The large rent increases which were reported when common fields were enclosed in the late eighteenth century seem proof to many of the inefficiency of the system.[11] Rents, it was said, often doubled or tripled upon enclosure. Thus Blum notes that "Everyone agrees that rents rose precipitously immediately after enclosure. The data indicate that they commonly doubled and tripled and in some cases rose even more (Blum 1981, p. 503)." Deirdre McCloskey, however, has pointed out that the doubling of rents on enclosure, while

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[10] A good description of how the open-field system functioned is found in Ault (1972), Slater (1907), and Orwin and Orwin (1938).

[11] McCloskey (1975a, 1975b). McCloskey gives an excellent description of how the system operated.

it indicates that the system was indeed inefficient, also indicates that enclosure in the period 1750 to 1860 would explain very little of the overall doubling of efficiency in the agricultural sector. If labor and capital markets were reasonably competitive, in the short run capital costs and real wages were given for any village. Thus any increase in efficiency upon the enclosure of a single parish will all get transmitted into an increase in rents.[12] We can thus measure the percentage gain in the efficiency of agriculture by dividing the gain in annual rents by the value of output per acre before enclosure. Suppose, for example, that the value of output per acre after enclosure in 1700 was £3. Since rents after enclosure were about one third of the value of output, this implies that the rent before enclosure would be £0.5, and after £1. Assuming that inputs of labor and capital did not changes, the value of output before enclosure would be £2.5. Efficiency would thus have increased by 20% (= 0.5/2.5). Since only one fifth of England was enclosed in the years 1750 to 1860 the overall gain in agricultural efficiency from enclosure would be 4%. Thus enclosure directly contributed little of the apparent gains in efficiency in the agricultural revolution.

Further there is evidence that the gains from enclosure were far lower than has been thought. Robert C. Allen has recently argued that common land was not much less efficient than enclosed land. Grain yields on common fields were only perhaps 10% lower than on enclosed arable (Allen (1992, pp. 133-7)). And labor inputs on common fields seem to have been little higher. Finally the acid test that McCloskey cites, which is the effect of enclosure on rents, turns out to signal much less efficiency gain from enclosure than even McCloskey calculated. First it turns out that the often cited claim that rents doubled on enclosure is based on a very small number of actual cases, which themselves suggest much lower gains. On a large sample of charity land the rent increase from enclosure instead averaged only 40%. Second, there were very substantial costs to enclosure in the form of the commissioners fees and the costs of fencing the land. Again the charity estates allow estimates of these costs. Together these benefit and cost calculations suggest that the gain from enclosure was always modest, and sometimes negative. Figure 4.5 shows the estimated gross rate of return from investment in enclosure by decade between 1600 and 1840. As can be seen the calculated gross return is generally 5% or less from 1600 to 1760, when it rises to between 6 and 7%. The reason for the rise in returns in the latter period is the movement upwards of rents relative to wages in the years after 1760.

The net profit from enclosure, which is the excess rate of return from investing capital in enclosure as opposed to other uses of capital, will be the calculated

[12] See McCloskey (1975, pp. 155-160). None of the gains will appear in higher wages or higher returns to capital since both of these are mobile inputs where competition with other villages determines their price.

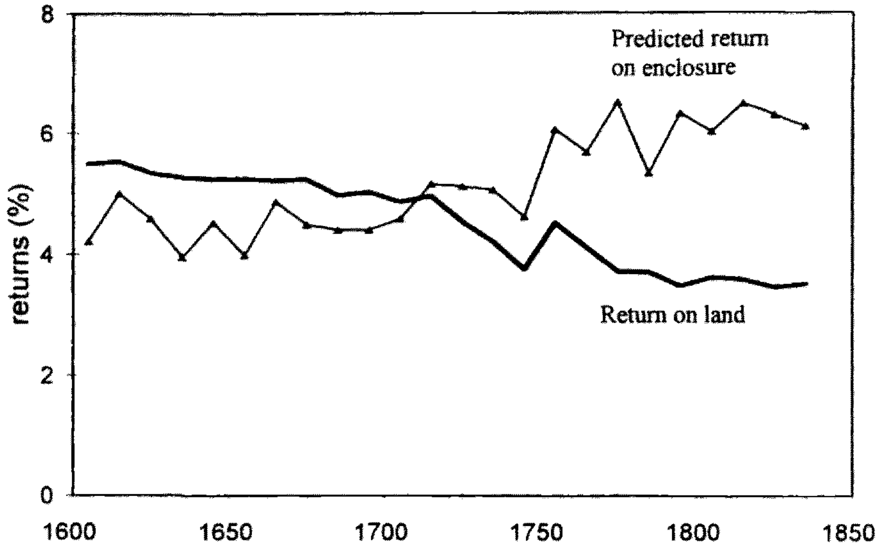

FIGURE 4.5 The Predicted Return from Enclosing Land, 1600-1839
Source: Clark (1998).

percentage return minus the return on capital in other uses. Rational land owners should regard the cost of enclosure as the return on land ownership. For owners could sell some of their land to finance the costs of enclosure on the rest. Thus figure 4.5 also show the return on land ownership. As can be seen the expected returns from enclosure, if rents increased by 40% with enclosure, only significantly exceed the costs after 1750.

Using these figures we can roughly calculate the net social gain from the parliamentary enclosure movement in the years 1730 to 1840. The calculated net profit on the capital invested in enclosure, the gross return on enclosure minus the return on capital invested in land, averages 2.1% over this period. This works out to be an efficiency gain from the enclosure of any given parcel of land of 2.9%, if all of the return above the interest cost of capital is to be counted as economic surplus.[13] This implies that the total gain in efficiency for English agriculture from the entire enclosure movement was 0.6% of output between 1730 and 1840, since only about one fifth of the land was enclosed. No-one would have noticed the drop in output had the enclosure movement never taken place. Since in fact enclosure

13 This efficiency gain is calculated as the gross rent increase per acre from enclosure minus the rent increase needed to cover the capital costs, all divided by the output per acre.

had risks (the rent gain was variable as were the costs of the enclosure) the true social efficiency gain will be even lower than this since land owners had to be compensated for these risks. Thus there is no evidence that common fields in England in the eighteenth century necessarily reduced the efficiency of agriculture by any amount.

The common field system was a relatively efficient institutional arrangement because while land rents were lower on common land, the common fields economized on fencing costs. Land rents were not dramatically lower on common because commons were carefully regulated by the village community, with access rights specified. The only land where unlimited access was allowed was the waste. At least in the case of the charity land waste was typically inherently much less productive land. Only when land values rose relative to wages did it become worthwhile to assert and police private property rights over this land. The systems of property rights in English agriculture thus seems to have been responsive to changing costs and benefits, and not a capricious holdover from a barbaric pre-economic past.

Although enclosure had little effect on productivity measured at the level of the farm, perhaps it had an effect at the level of the rural sector of the economy as a whole. If the modest net gains to landlords from enclosure were achieved mainly by the expropriation of common rights from the rural landless, then the enclosures might have had significant effects on the share of the population remaining in the agricultural sector and hence on the measured labor productivity of agriculture. Marx argues along these lines, for instance, that enclosure indirectly speeded industrialization and urbanization in Britain by creating an impoverished, landless rural proletariat that was rapidly displaced from the countryside (Marx, [1867] 1977, pp. 877-895, 908-913).[14]

This argument of Marx has been nicely formalized by Cohen and Weitzman (1975). In their analysis they assume that owners profited from enclosure purely by eliminating the access of the village poor to various communal rights, such as fuel cutting, grazing, and squatting on the commons. All the rent increase upon enclosure was represented by a loss to the laborers. But curiously in Cohen and Weitzman's analysis, this transfer of ownership rights would still result in an increase in output per worker in agriculture, and would represent an efficiency gain in the economy at large though displacement of "surplus" agricultural labor to the industrial sector.

To see how this works, suppose that there was a minimum income w_0 that a worker in agriculture had to receive to prevent him from leaving the agricultural sector and moving to the urban sector, which income was determined by the

[14] The most clear-cut enunciation of the view that enclosure served to deprive the landless and smallholders of their means of livelihood in the countryside is given by the Hammonds (Hammond and Hammond, 1911).

alternative wage in towns. Assume that the agricultural laborer's income is kept at this minimum level by the rise of the rural population. The income of workers in the countryside, w_0, will have two components: the market wage, w_m, the agricultural worker receives, which is assumed to be the marginal product of labor in agriculture, and the common rights in the village that each worker enjoys, s. $w_0 = w_m + s$. When common rights were extinguished upon enclosure, the rural income would drop below the wage needed to keep labor in the countryside. Thus workers would migrate to the cities until labor became scarce enough that $w_m = w_0$. The workers left in each individual village would be no worse off after enclosure, but there would be fewer of them, and the marginal product of labor would rise. The common rights that had previously been dissipated in keeping extraneous workers in the rural sector would now be a benefit to society, though one that accrued exclusively to landowners. Thus even an enclosure movement that sought purely to grab for the landowners the common rights of the laborers could result in gains to national income, in the sense that the income gained by the landlords would exceed that lost by the workers, since no workers lose income with Cohen and Weitzman's assumptions.

The actual effect of enclosure on pushing labor out of the agricultural sector has been a hotly debated topic. Historians have examined the movement of population over time in villages that were enclosed and unenclosed. The results show that in the post-1750s wave of Parliamentary Enclosures, there was no effect on population growth (Chambers, 1953; Gonner, 1966, pp. 411-415). But Allen (1992) finds that enclosures prior to 1675 did result in locales having significantly lower rates of population growth up until 1850. He conjectures that the reason is that earlier enclosures took place mainly when there was only one landowner or a small number of landowners in a village. The Poor Law in England required each parish to be responsible for all those who had acquired a "settlement" in the parish; normally a settlement was acquired by residing in the parish for more than a year. Since poor relief was financed by a tax on property, large landowners had an incentive to limit population to the available employment opportunities. They would do this by controlling house building, since households were typically limited to one family. But in parishes with a large number of property owners, the incentive of each not to lease land for building would be much smaller. In confirmation of this reasoning, Allen shows that the rate of population growth in villages is predicted better by ownership concentration than by the date of enclosure. Thus Allen conjectures that those parishes that enclosed early would expel their surplus populations, and limit population growth, merely because they were parishes of concentrated ownership (Allen, 1992, pp. 36-55).

The Cohen and Weitzman model depends on the assumption that there were significant common rights that were extinguished upon enclosure. J. D. Chambers, an English agricultural historian of the old school, argued (Chambers, 1953) that access to common land was of very slight value to the average rural family. Jane

Humphries, in contrast has recently argued that the access of the landless to the common waste in open field villages, by enabling families to keep cows, added as much to family income as half the wage of male workers. Similarly, the rights to gather fuel alone she estimates to be worth from two to six weeks wages of a male worker (Humphries, 1990).

The charity lands allow us some estimate of the potential income available to the rural poor from access to the waste. For the years 1700 to 1759 I have information on the amount of common waste land attached to 2,011 plots of charity land in England scattered across 1,343 parishes and townships, derived from information on the waste added to land by later enclosures. On average only 3.6 percent of this land was waste. Thus by the end of the major wave of enclosure from 1760 to 1840 the English poor lost access to only about 0.8 million acres of waste land. Since there were about 870,000 hired adult male agricultural laborers by 1851, this implies that the average family lost access to about 1.1 acres of waste.[15] On average each of those acres of waste represented a gain in rent to land owners of £0.70 or less. Now, as noted above, it seems plausible that a lot of this new rental value was created by the investment of owners in fencing and land improvement. But even if we suppose that all the gain in rents to landowners was a direct theft of common rights from the poor, the average landless family in 1850 would thereby have lost £0.77 in income, which would be about 2 percent of a rural laboring family's income. In and of itself, this would have caused little labor migration from the countryside. There is also evidence from land use on common, old enclosed and newly enclosed land that after 1760 enclosure should not have reduced demand for labor in rural areas. For there is no sign of changes to less labor intensive use of land as pasture or meadow after enclosure. Enclosure at worst would cause only the most marginal reduction in the economic condition of the rural poor.[16]

If the enclosure movement is a complete bust in explaining the growth of agricultural productivity, were there other institutional changes that might more successfully play the role? Allen has recently argued that the increase in average farm sizes between 1600 and 1800, a process he calls "the landlords' revolution" was a major force in increasing agricultural productivity in general, and labor

[15] The number of agricultural laborers is the number of those listing this occupation in the census of 1851 aged 15 and over. Since most of the younger workers would be resident in their parents household or on farms, the number of households is taken as .8 times this number.

[16] In fairness to Humphries, she argues that the value of common rights was not just the rental value but the opportunity they afforded for families to utilize the unemployed labor capacity of women. But most villages in England had numerous small plots of land that the poor could have rented in order to use that labor capacity if it truly had no value to them.

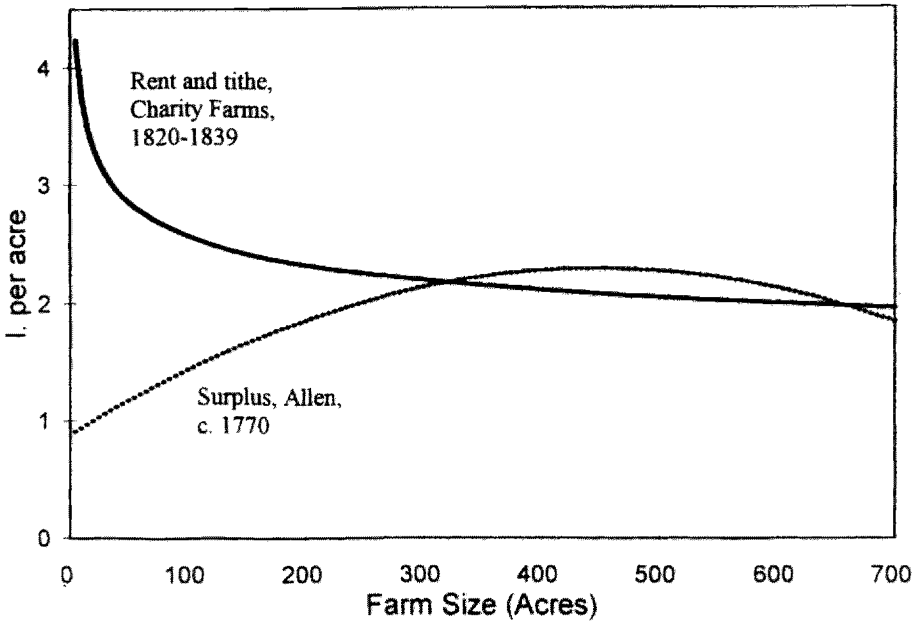

FIGURE 4.6 Predicted Ricardian Surplus Per Acre Versus Rent Per Acre
Source: Allen (1992), p. 214.

productivity in particular. He notes (Allen (1994), p. 114) that "The second reason why agricultural productivity increased during the industrial revolution was because labour per acre declined...The drop in labour per acre resulted from the growth in farm size. Higher rent was the motive behind the creation of larger farms. Big farms could afford to pay a higher rent since their costs were less – in particular, their labour costs."

A measure of the amount of rent a farmer can afford to pay for occupying land is the Ricardian surplus: the difference between output per acre and labor, capital and material costs. Figure 4.7 shows the Allen's estimated Ricardian surplus per acre for a sample of farms of between 5 and 700 acres circa 1770 from information reported by Arthur Young from his tours of the English countryside. For purposes of comparison the surplus is quoted in the prices of 1820-39. As can be seen Allen calculates that farms of 400 acres on average generated a surplus, and hence a rent paying capacity, which was more than twice that of farms of 25 acres.

When I compare the actual rents of farms at of different sizes, however, with the Ricardian surplus estimated by Allen a clear mismatch appears. Figure 4.6 also shows the actual rents per acre paid by 1,789 farmers in the years 1820-39 who occupied farms owned by charities as a function of the farm size in acres. As can be seen, rent and tithe per acre declined steadily with size, and were about 60% higher for farms of 25 acres than for farms of 600 acres. This decline of rents with farm size is starkly at variance with what Allen predicts. Now it may be that small farms are found only on more fertile soils, or only in areas near cities where land values are greater, obscuring a true increase in rents per acre with size once these variables are accounted for. But the rent/size relationship in the figure is drawn controlling for the parish population density which is strongly associated with land values and is a good indicator of which parishes had fertile soils or were close to urban areas. So some of the more obvious variation in land quality and in demand for land has already been controlled for.

The rent data above suggests that the "landlords' revolution" was as unimportant a source of productivity growth in the industrial revolution period as the enclosure movement. Thus if we are looking for a doubling of agricultural productivity between 1700 and 1860 then neither the introduction of new rotations nor institutional changes will do it for us.

An Industrious Revolution in the Countryside?

The difficulty in finding the wellsprings of the agricultural revolution in either technical innovation, or in institutional change suggests looking for broader social changes in the countryside. Jan de Vries (1993, 1994) has recently suggested that there was in urban England an "Industrious Revolution" of the seventeenth and early eighteenth century which preceded the industrial revolution. This was a revolution in peoples' desires created by the appearance of a whole new set of consumer goods in the seventeenth century. The desire for these goods prompted families to labor more: men, women and children all worked more days per year to earn income to accumulate possessions.

Though de Vries is focused on the town dweller, it does raise the issue of whether there was such a change in the countryside. Did output per worker in agriculture rise so greatly in the industrial revolution years because farm workers worked more days per year, and worked more intensely on the days they labored? And did a larger share of the rural population engage in farm labor?

Consider first the amount worked per day. Suppose we have a manual task which is unchanged over time and which produces a measurable output. Suppose also that the task is paid for sometimes with a day wage and sometimes through a piece rate. Then in a competitive labor market the amount of work completed per day by piece workers will be such that, approximately,

$$\textit{day wage} = \textit{work rate} \times \textit{piece rate}$$

$$\textit{work rate} = \textit{day wage} \,/\, \textit{piece rate}$$

The work rate will depend both on the number of hours worked per day and on the intensity of labor per hour.[17]

One task in agriculture which was often paid by a piece rate, and which changed little from medieval times until 1860 was hand threshing of grain. Table 4.3 shows threshing rates, shown as the number of bushels of wheat threshed per day, calculated by half century from 1600-49 to 1860 for England. As can be seen there is no sign that when at work workers were doing any more in 1860 than in 1600 or 1700. Threshing was one of the major tasks in pre-industrial agriculture and accounted for about a quarter of the labor input on arable land. Yet here we see there is no sign of any gain in labor productivity at a time when labor productivity in agriculture allegedly more than doubled.

We can use similar logic to infer the days typically worked per week. Where the same workers were employed by the day or for the week then again

$$\textit{days per week} = \textit{weekly wage/day wage}$$

If we calculate this ratio using data from farm accounts for the years 1670-1739 the average implied days worked per week is close to six.

TABLE 4.3 Threshing Rates by Half Century, 1600-1850

Period	*Number of Individual Observations*	*Number of Observations (10 year averages)*	*Threshing Rates (bushels of wheat per day)*
1600-49	34	26	4.36
1650-99	71	46	3.85
1700-49	101	45	3.75
1750-99	250	95	4.24
1800-49	109	20	3.83
1850	80	35	3.98

Sources: Clark and van der Werf (1998).

[17]There may be a premium paid to piece rate workers as compensation for a greater risk of unemployment, or for harder work, in which case the units completed per day will be just proportional to the day wage divided by the piece rate. But as long as the premium does not change over time the relative work rate over time can be estimated from as above.

When we turn to days worked per worker per year we get strong indications that even as early as 1700 the norm for full employment was a week of six full days, and a work year of 300 days or more. Some farm accounts from the seventeenth and early eighteenth century allow us to calculate for a few regular workers, those who show up as paid in most weeks of the year, how many days work they put in. These workers were typically paid for 290-300 days per year, showing that the norms for full time workers were for a work year that would be little different than for full time workers in 1850.

These accounts also generally show much employment of irregular workers who work anything from one day to large chunks of the year. We do not know what these workings were doing the rest of the time – they may have been working for other employers, or working on their own holdings. It has been generally assumed that many farm workers were unemployed in the winter months, because labor demand was very peaked. But for this to affect labor productivity per farm worker over time, the degree of unemployment had to be less by the mid nineteenth century. There was no change in farm technology which would have caused this. The major

TABLE 4.4 Numbers of Recorded Wage Payments by Month, 1690-1730

Month	*All farm work*		*Threshing*	*Hedging, fencing and ditching*
	Payments	*Amount (£.)*	*Payments*	*Payments*
January	173	103	43	18
February	208	89	41	22
March	211	168	50	21
April	229	78	33	35
May	224	68	24	21
June	195	79	14	7
July	244	157	13	10
August	166	134	7	10
September	219	74	21	8
October	205	90	27	15
November	196	77	48	12
December	204	91	52	16

Sources: See text.

task that was partly mechanized was threshing, which was a task mainly performed in the winter months. Indeed the evidence from farm accounts in the years 1690-1729 years is of surprisingly little seasonality in labor inputs. Thus table 4.4 shows both the numbers of payments where the date was identified made to workers in each month, and the total amounts paid. The number of payments recorded tend to be distributed fairly evenly throughout the year, with only a modest peak in July.

Again where we take the total payments made to workers each month there is only modest evidence of a summer peak in payments. But since wages at hay and harvest were higher than in winter, the variation in days worked between July and the months with the lowest payments is not very great. The reason for this is clear when we look at the distribution for payments over the year by work type. While mowing and reaping were heavily concentrated in the summer months, activities like threshing and hedging, which were not so time sensitive, were concentrated in the winter months. Thus the peak month for threshing payments was December. We thus see in these records of wage payments no indication that agricultural workers in 1700 behaved any differently in terms of days worked than those in 1850. Full time, year round work seems to have been the norm then as later.

Trouble on the Land

Could it be that we can find no convincing way of explaining the agricultural revolution because it never took place? Despite the evidence of increased output from consumption demands discussed above, there is even stronger evidence available that shows that the agricultural revolution envisioned by Crafts, Harley, Allen and Overton cannot have taken place.

This evidence comes in two forms. The first is that it is possible to construct measures of average land rents, wages, returns on farm capital, and agricultural prices for English agriculture in the years 1600 to 1912. With these measures we can construct three key series: the rent of land in terms of farm output prices, the day wages of farm workers in terms of farm output prices, and the percentage return on farm capital. Figure 4.7 shows each of these three series adjusted so that 1860-9 is set to 100 in each case. The return on farm capital is calculated as the return paid by farmland plus 5% for depreciation. As can be seen the return on capital falls through much of this period, real farmland rents rise by about 70% between 1700 and 1860, but farm day wages increase by only about 10%. It is easy to show that these figures, far from implying a more than doubling of productivity between 1700 and 1860, instead suggest that productivity grew by less than 25% between 1700 and 1860. Just the fact that the value of inputs has to add up to the value of output implies that the productivity growth rate in any sector of the economy can be calculated as

$$\begin{aligned} g_A &= a.g_r + b.g_w + c.g_s - g_p \\ &= a.g_{r/p} + b.g_{w/p} + c.g_{s/p} \qquad (4.2) \end{aligned}$$

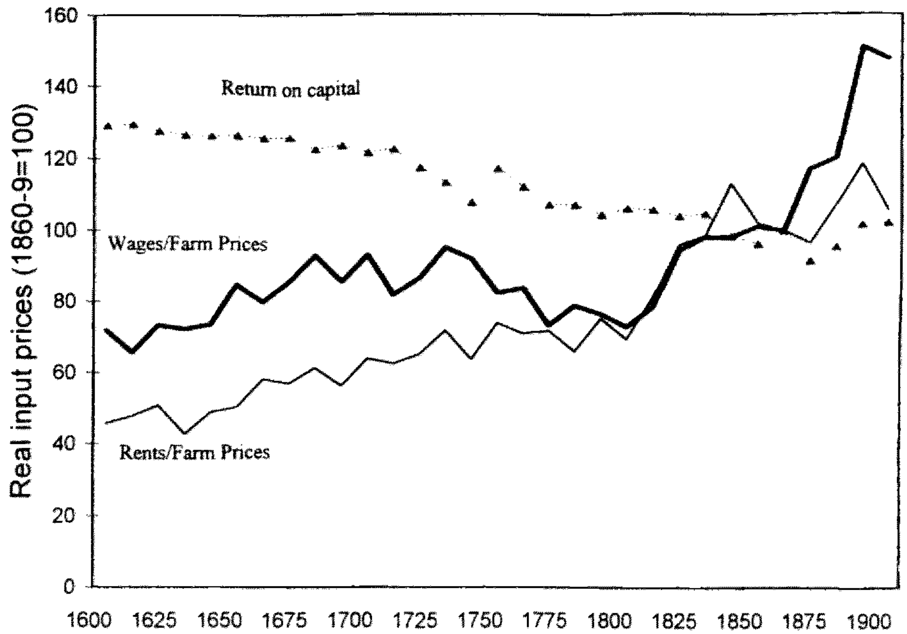

FIGURE 4.7 Real Rents, Wages, and Return on Capital
Sources: Rents and return on capital, Charity Commission reports. Wages, Clark (1998)

where a, b, and c are the shares of capital, land and labor in the value of output, g_r, g_w, g_s, and g_p are the growth rates of the rental on capital, wages, land rents, and output prices for that sector, and $g_{r/p}$, $g_{w/p}$ and $g_{s/p}$ are the growth rates of real capital rents, real wages and real land rents measured in terms of output prices. The appendix gives a formal demonstration of this. Thus the rate of productivity growth is the weighted growth rate of input prices minus the growth rate of the output price. Alternately it is the average of the growth rates of real capital costs, real wages and real rents measured in output prices. Suppose, for example, that the costs of capital wages and land are all growing at 5%, but the output price is growing at only 2%. Then there is productivity growth of 3% per year. Figure 4.8 shows productivity calculated this way for English agriculture from 1700 to 1860-9, compared to the productivity levels implied by Crafts's estimates. The shares of land and wages are taken as 40% each, and capital as 20%. As can be seen between 1700 and 1860 productivity grew by a total of less than 25%, compared to the 150% growth predicted by Crafts. Further what little measured productivity growth occurred is

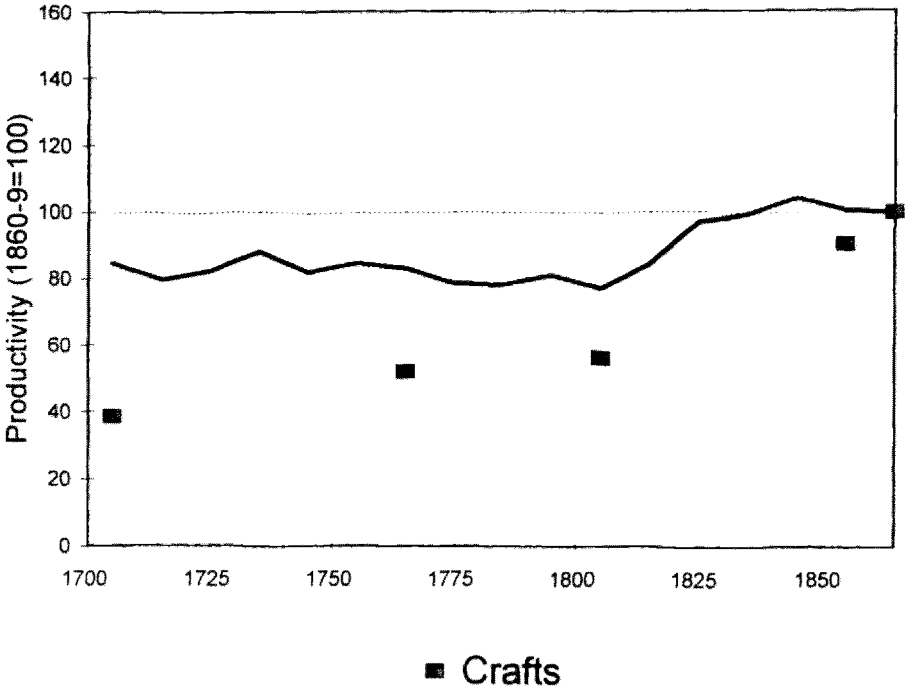

FIGURE 4.8 Productivity Growth in English Agriculture
Note: Crafts' productivity estimates relative to 1861 are given by the filled boxes.

concentrated in the first three decades of the nineteenth century. From 1700 to 1800 there is no measured productivity growth at all. Combining the rent, wage and capital returns data with estimates for employment in agriculture for the 1801 to 1861 censuses, and from Crafts for 1700, it is possible to use these numbers to roughly estimate real agricultural income, which will be equal to the real output assuming that there are few purchased inputs in agriculture. These estimates are shown in table 4.5. They are constructed by adding rents, annual wages times the estimated numbers of workers, and an allowance for capital costs. The capital cost allowance is calculated by assuming the capital output ratio is fixed. As can be seen the new output estimates imply no growth of output between 1700 and 1800, and only a 42% gain all the way from 1700 to 1861.

TABLE 4.5 Nominal and Real Agricultural Output, 1700-1861

Year	*Male farm Employment (million) England*	*Nominal Agricultural Income (£. million) England*	*Nominal Agricultural Income (Deane and Cole, £. m.) Britain*	*Real Agricultural Income (1700=100) England*
1700	0.897	38.3	-	100
1801	0.919	72.8	75.5	98
1811	1.024	95.0	107.5	103
1821	1.125	101.7	76.0	125
1831	1.199	97.4	79.5	143
1841	1.109	98.1	99.9	149
1851	1.137	99.0	106.5	148
1861	1.043	100.8	118.8	142

Sources: Deane and Cole (1967), p. 166.

The estimated output for 1700 of £38.3 million, based on an assumed 56% of the labor force in agriculture is between two and two and a half times the outputs implied by Crafts (£15.7 m.), Allen (£14.5 m.), and Overton (£17.6 m.). But it is easy to show that if the wage and rent data for this period are correct these other estimates could not possibly be correct. With an estimated 897,000 male farm workers the wage bill alone for adult males, given a winter day wage of 11 d. per day, would be £13.8 m.[18] There will have been some underemployment in winter, but this wage bill includes nothing for the wages of women and children which would more than offset this overcounting. Since wages were traditionally regarded in this period as being one third of output, getting the wage bill down to a level to be consistent with these earlier output figures would imply that the full time male labor force in agriculture in 1700 was no more than 340,000. This would be only 21% of the adult male labor force. Even if labor got half of output, adult male employed in agriculture would have to be no more than 32% of all adult males. If the problem of wages could be dealt with, land rents and tithes are independently estimated at £13.6 million, again nearly as much as these authors estimate for output. Furthermore, we can find corroborating evidence for this figure in the details of the land tax, first imposed in 1693.

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[18] This is assuming a 300 day work year and double wages for six weeks in hay and harvest.

The land tax assessment of 1693 valued land, houses and tithes in England outside most major towns at £8.3 m.[19] It is well known, however, that the land tax was heavily under-assessed in the north and in the west. So this £8.3 m figure would be very much a lower bound estimate of rents and tithes in the 1690s, though even this lower bound figure still constitutes 53% of Crafts' estimated agricultural output circa 1700. The peculiarities of the administration of the land tax allow us to use the charity observations to calculate what the corrected total of rents should be based on the land tax assessments. The assessed values of property and income in 1693, supposedly 20% of the rental value of real property, were used to set permanent county quotas of the land tax used from 1698 on. Within each county land tax commissioners allocated quotas of the tax to each parish or township. But these local quotas quickly became ossified in the early eighteenth century and subsequently remained unchanged. Within townships reallocation of the tax burden among land parcels could and did take place. But *on average* in rural parishes the land tax burden on a given piece of land in any year after 1710 would represent one fifth of the assessed rental value of the land in 1693. On many of the charity plots we have the land tax payments made after 1798 when the tax became fixed at the 20 percent rate. When I compare these assessed values with the actual rental value of the same charity land back in the years 1690 to 1729 I find that even in the south of the country the land tax assessment was only 66 percent of the rental value of land in these decades, and in the north the assessments were a mere 26 percent of the true value of land. Overall this would imply that if the land tax assessed all rent and tithe at close to £8.3 million in the 1690s, the true rental value of land and tithe was possibly as high as £14.6 million, almost as great as Crafts total implied output.

All this implies that output must have grown by much less than everyone expects between 1700 and 1860, a mere 42%. There is no agricultural revolution.

Agriculture as Producer of Food, Energy and Raw Materials

If output in English agriculture increased by only 50% or less from 1700 to 1850, then there was a decline in agricultural production in England per head of population, and this clearly is problematic. In the prices of 1850, production per person of agricultural products in Britain in 1851 was £6.7. If output rose only by 50% then English agricultural production per person in 1700, measured in 1850 prices, was £14.1 per person. How could output of agricultural products per person decline so greatly from 1700 to 1851, especially in a time of economic growth?

The answer, at least in part, lies in the fact that while Overton, Allen, Crafts, Harley and others who argue for an agricultural revolution based on population

[19] This is from Browning (1953), pp. 318-21, where the tax yield is given separately for each of 61 towns, and for the counties outside these towns. The implied value of property in the towns was £0.85 m.

growth focus on agriculture as a producer of food, in the pre-industrial economy agriculture provided not only food for human consumption, it also provided the raw materials for clothing and bedding (wool, flax, dyestuffs, hides), housing and furnishings (wood), and energy in the form of wood and fodder for horses, as well as energy for human labor. By the mid nineteenth century there were large imports into Britain not only of foodstuffs, but even more significantly of fibers, hides, dyes, and wood that previously must have come from the agricultural sector. The most important of these in the 1850s, counting only imports used for domestic consumption, were timber (£9.7 m.), seeds, tallow, and oils (£9.7 m.), cotton (£7.6 million), flax, hemp and jute (£5.4 m.), and silk (£5.3 m.). Wool used for domestic consumption was a smaller import, but this represented a considerable change from 1700 when wool embodied in cloth was a major export.

Further the coal industry in Britain increased its output more than twenty fold from 1700 to 1850. This supplied coal for fuel to households who would have previously relied on wood, turf, or furze for fuel. Thus coal used for domestic consumption is estimated for Britain in 1700 at as low as 0.2 tons per capita. By 1855, coal consumption per capita for domestic purposes had climbed to 0.73 tons per capita. But coal also substituted for fodder as motive power in the transportation system. Coal also replaced wood as the energy source in such energy intensive activities as iron and steel, brick and pottery making. Thus coal consumption per

TABLE 4.6 Production and Imports of Food, Raw Materials and Energy, 1700-1850

			Domestic Output (£ m.)			*Food, Energy, and Raw Materials (£) Per Capita*
Period	*Area*	*Population (m.)*	*Farm*	*Non-Farm (Coal)*	*Imports - Exports (£ m.)*	
1700	England	5.24	73.8	2.5	1.0	14.8
1850	Britain	20.82	138.7	53.8	92.0	13.7

Notes: Cotton, wool and silk retained for home consumption are estimated by subtracting the raw material content of textile exports estimated using figures given in Deane and Cole (1968).

Sources: Coal production: Flynn (1984, p. 26) and Church (1986, pp. 19, 53, 85-97). Imports 1854-6: Davis (1979, Appendix tables 50, 57). Imports 1700-4: Schumpeter (1960, tables XV, XVII). Exports 1700-4: Schumpeter (1960, tables VII, IX, X, XII, XIII), Mitchell (1988), pp. 221-2).

capita in England circa 1700 was only 0.4-0.5 tons, whereas by 1854-6 consumption per capita was 2.6 tons Hatcher (1983, p. 68, p. 409), Church (1983, p. 19). Either energy consumption for heating, construction, and transportation in 1700 was at one fifth the level of the 1850s, or the agricultural sector in 1700 was supplying significant energy supplies in the form of underwood, furze, and turf, and grains and fodder for horses. To take one example, it is estimated that iron production in England in the early eighteenth century was a very modest 17,000 tons annually. Each ton seems to have required about 1,800 cubic feet of wood. How many cubic feet of wood an acre of woodland would produce in a year is not known. Modern sources note that woodland in England can produce "up to 100 cubic feet per year" (Hammersley , 1973, pp. 604-5). At this upper estimate of timber growth rates iron production in England in the early eighteenth century would require about 310,000 acres of woodland to sustain it. This is nearly 1.5% of the agricultural area of England.[20]

Table 4.6 shows estimated farm output per capita for 1700 for England and 1850 for Britain in the prices of 1850, as well as supplies of food, raw materials and energy from imports and from the coal industry. As can be seen once we count all of these sources of supply of food, raw materials and energy, despite the absence of an agricultural revolution there is only a modest decline in the consumption of food, raw materials and energy per capita. As a result of greater trade opportunities British agriculture in the period of the Industrial Revolution was becoming more specialized in food production and was getting out of producing such things as dyes, fuel, wood, and fibers. The idea that food consumption per capita might have fallen slightly between 1700 and 1860 is still rather problematic, given the expectation we have of significant growth of income per capita in the Industrial Revolution period. Clark, Huberman and Lindert (1995) explore how the lack of growth of food consumption per capita might be possible in a period of growth of income per capita. But the difficulties this cause us are slight compared with the problems any attempt to maintain a doubling or tripling of agricultural output creates.

The Industrial Revolution Without The Agricultural Revolution

These new estimates of agricultural output growth in the Industrial Revolution have implications for the overall growth rate. Agricultural output is much greater than expected in 1700, and even in 1800. Thus growth rates in the Industrial Revolution will be slower because of less growth of agricultural output. Since agriculture is only 18% of GNP in 1861 this might appear to have a small overall

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[20]Wrigley (1988), p. 80, quotes the conventional figure that one ton or iron required felling 10 acres of wood. If this number is correct, and if woodland was felled every 15 years, then iron consumption would require 2.55 m. acres of woodland in the early eighteenth century.

impact. But slower growth of agricultural output means that agriculture has a larger weight in total output in the economy before 1861. This means that there is a further effect of slow growth in agriculture – its bigger size in earlier years reduces the impact on overall growth of the rapidly expanding manufacturing sector. Moreover, from 1700 to 1800 Crafts estimates the growth rate of the commercial sector, 16% of the economy, as being the rate of growth of overall output. Thus again before 1800 lower growth estimates for agriculture mean lower growth estimates for services. Table 4.7 shows total output and output per capita in Britain or England as estimated by Crafts, Crafts and Harley and Deane and Cole between 1700 and 1861. Also shown are the revised growth estimates adjusting for slower agricultural growth as I have outlined.

The latest Crafts and Harley estimates of economic growth suggest that real income per person grew by 98% between 1700 and 1861, and by 64% from 1760 to 1861. Interestingly Feinstein's study of real incomes suggests that the incomes of wage earners rose by only 35-40% from 1770 to 1861, significantly slower than the overall rate of growth. It is also interesting that on the Crafts-Harley story there is a very big difference in output per capita between agriculture and industry in 1700, which largely disappears by 1860. Thus looking at the share of GNP generated by agriculture in the table compared to the share of employment we see that in 1700 output per worker in agriculture was less than half that of output per worker in the rest of the economy. This despite the fact that in 1700 most employment outside agriculture was in traditional trades and activities, and that wages were reputedly only one third of the value of output in agriculture (which would be smaller than their share in the value of output in the rest of the economy). Hence the Crafts-Harley view implies a large misallocation of labor in the pre-industrial economy in England. This is in line with the view of O'Brien (1996) that what was unusual about British experience in this period was the elimination of surplus labor from the agricultural sector.

Using the new output estimates for agriculture I find three things. The first is that output growth in the Industrial Revolution period was even slower than Crafts et al. pessimistically estimate. Output per person increases by only 44% between 1700 and 1861, compared to Crafts et als. 98%. In the years 1760 to 1861 the gain is 31%, not the old 64%. As noted the reason the revisions to agricultural growth rates have such dramatic effects on overall growth is in part because they reduce the share of the fast growing industrial sector in GNP in earlier years. To illustrate this note that Crafts (1985) implies a value added in industry in 1770 at the beginning of the Industrial Revolution of £23 m. compared to a value added in agriculture which is only slightly higher at £27 m. I estimate agricultural output in 1770 at £45 m, which makes the agricultural sector still about double the size of the industrial sector.

These new figures are more in concordance with Feinstein's estimates of real wages from 1770 to 1861 (Feinstein (1997b)). Further output per person in 1801 is only estimated to be 10% higher than in 1700. Thus the onset of growth in income per capita is pushed forward in time into the early nineteenth century. I also find that relative output per capita in non-agricultural and agricultural employment changes little between 1700 and 1860. Thus output per capita in non-agricultural employment is 32% higher than in agriculture in 1700, and 7% higher than in agriculture in 1861. There is thus little sign of a massive reallocation of labor out of relatively low productivity agricultural activities in the eighteenth century towards much higher productivity trade and industry. By 1700 there is no labor surplus to be extracted at low cost from agriculture and put to work in industry.[21]

It also appears from these new estimates of agricultural output that GNP growth did not accelerate in the last 30 years of the Industrial Revolution as Crafts and Harley estimate. Instead because there was seemingly no growth of agricultural

TABLE 4.7 Estimated Output Levels, 1700-1860

Period	*1700*	*1760*	*1801*	*1831*	*1861*
Old Estimates (Crafts et. al.)					
GNP	100	151	230	406	750
GNP per capita	100	120	130	151	198
Agriculture's assumed share in GNP(%)	37	37	26	23	18
Agriculture's share in Employment (%)	56	48	36	32	19
Relative output per worker (Agric./non-agric.)	.46	.64	.62	.63	.93
New Estimates					
GNP	100	138	194	348	544
GNP per capita	100	110	110	129	144
Agriculture's assumed share in GNP(%)	49	49	32	29	18
Relative output per worker (Agric./non-agric.)	.75	1.04	.84	.87	0.93

Sources: Crafts (1985); Crafts and Harley (1992), Industry, GNP post 1760; Wrigley and Schofield (1997), population.

[21]Here I am assuming that the marginal product of labor in agriculture was close to the average product, but as noted above there is little sign of underemployment in English agriculture back in 1700 or 1770.

output in this period, the overall growth rate of output is slower between 1831 and 1861 than in the years 1801 to 1831.

These much reduced estimates of growth in the Industrial Revolution period also suggest a different assignment of importance to various factors in the Industrial Revolution. Modern scholarship has promoted technological change as being key to the Industrial Revolution. But imagine the following picture. Suppose that there had been no productivity advance in manufacturing from 1700 to 1860. Suppose also, however, that at fixed terms of trade Britain could import food and export manufactures. Then the marginal productivity of labor in industry would be constant. As population began to grow in the eighteenth century against a background of little improvement in agriculture there would be a movement of labor out of agriculture into manufacturing, increased imports of food and increased exports of manufactures. Population growth alone would drive industrialization. Had there been no technical change in textiles then we can still imagine a Britain of 1860 with nearly four times the population of 1700, with only a small fraction of the labor force in agriculture, and with an industrial sector that exported textiles and other manufactures, but manufactures produced still in hand powered industry. It would be a Britain in which living standards in 1860 were no higher, and probably somewhat lower, than in 1700.

But assuming that commerce, government and housing were always about 30% of GNP such a Britain would still have seen a growth in "manufactures" (including as do Crafts et al. mining and building) from the combined effect of a growth in population and a fixed land area for agriculture of *twelve fold*. Employment in industry would have gone from 14% of the population to 48%. Crafts and Harley estimate that industrial output, with the advantage of rapid technical advances in textiles, actually grew by 15 fold. So the role of the technical advances in textiles on Britain in the industrial revolution period turns out to be surprisingly minor. It allowed real incomes in Britain to rise, but since the advances in textiles turned the terms of trade against Britain, that increase would be by much less than even the modest gains in output per capita. It increased the rate of expansion of the industrial sector. But would Britain have looked dramatically different in 1861 without a textile revolution? No.

These new productivity and output estimates also have implications for our view of England prior to the Industrial Revolution. For we did see in table 4.2 that English agriculture was very productive relative to the rest of Europe by 1850. If there was little productivity growth between 1700 and 1850 then it implies that English agriculture in 1700 was also highly productive, even relative to the standards of most European countries in the late nineteenth century. Since land productivity seemingly grew more than labor productivity between 1700 and 1850, England's advantage even in 1700 is estimated to be in unusually high output per worker in agriculture—in 1700 it was already nearly double that of any other

European country as late as 1850. England on these measures looks different from Europe long before the Industrial Revolution.

The narrower view of productivity advance in the Industrial Revolution given here also lends support to the views of those who see the Industrial Revolution as essentially an accident. For it seems that English agriculture achieved high levels of productivity long before the breakthrough in cotton textiles, and yet there was no sign of any connection between this earlier agricultural advance and industrial progress. The stagnation of agricultural productivity in the Industrial revolution period makes the advances in textiles more of an isolated event in the economy, rather than one of a host of innovations occurring across areas with no technological connection.

Appendix: Measuring Productivity Through Prices

In any competitive economy the value of the output of an industry has to equal the value of the inputs. That is,

$$pQ = rK + wL + sT$$

where Q, K, L and T are output, capital, labor, and land, and p, r, w, and s are their prices (assuming just one type of output). Now as the economy goes from one year to the next then the values of p, Q, and all the other variables may change, but it must be the case next year that,

$$\begin{aligned}(p + \nabla p)(Q + \nabla Q) &= \\ (r + \nabla r)(K + \nabla K) + (w + \nabla w)(L + \nabla L) &+ (s + \nabla s)(T + \nabla T) \qquad (4.4)\end{aligned}$$

where the ∇s represent the change in a variable from one year to the next.

If we subtract each side of (4.3) from (4.4), and throw out such terms as $\nabla p \nabla Q$ which will be very small, then we get

$$\nabla pQ + p\nabla Q \;=\; \nabla rK + r\nabla K \;+\; \nabla wL + w\nabla L \;+\; \nabla sT + s\nabla T$$

Rearranging all the terms with the quantity changes so that they are on the left hand side gives us,

$$p\nabla Q - r\nabla K - w\nabla L - s\nabla T \;=\; \nabla rK + \nabla wL + \nabla sT - \nabla pQ$$

Dividing both sides by pQ and rearranging we get,

$$g_Q - a.g_K - b.g_L - g.g_T = a.g_r + b.g_w + g.g_s - g_p$$

where as above $rK/Q = a$ is the share of capital rents in the value of output, $wL/Q = b$ is the share of labor, and $sT/Q = g$ is the share of land rents, and $g_Q = \nabla Q/Q$, and so on. But the left hand side above is equal to, g_A, the growth rate of efficiency. Thus in consequence,

$$g_A = a.g_r + b.g_w + g.g_s - g_p$$

If the shares a, b, and g are constant then the level of efficiency A will be given by.

$$A = (r / p)^a (w / p)^b (s / p)^c$$

This is how productivity levels in figure 4.8 are calculated. The results will be only approximate since the weights used are those for 1850 and might differ earlier.

5

The Role of Education and Skill in the British Industrial Revolution

David Mitch

Human capital has featured prominently in studies of twentieth century economic growth. Thus, Denison (1962) concluded that for the United States between 1910 and 1960, 23 percent of the annual growth of output could be accounted for by improvements in the educational attainment of the labor force. Numerous cross country studies using observations from the second half of the twentieth century have found that measures of human capital investment have statistically significant effects on rates of output growth (for a brief overview of these studies see Tallman and Wang, 1992, p.8). In contrast, the prevailing view of the British Industrial Revolution has downplayed the contribution of human capital (Sanderson, 1972a; 1995; Schofield, 1973). The basic reasons for this are the consistent findings of educational stagnation in England during the Industrial Revolution period and findings that in key expanding sectors of the British economy, such as cotton textiles, educational levels were actually declining. This latter result is reinforced by analysis which suggests that formal education had little role to play in most parts of the manufacturing labor force.

Recent work, however, has pointed to rethinking the role that education played in the Industrial Revolution. Thus, on the one hand, Crafts (1995a) in an analysis of the implications of recent growth theory for reassessing the Industrial Revolution argues that a simple broadening of the notion of capital to include human capital is not a promising avenue for understanding why Britain was the first country to experience rapid industrialization. But on the other hand, he does suggest that a consideration of more indirect effects of human capital through affecting rates of technical change may be a quite fruitful direction of research albeit requiring further examination of the nature of human capital.

These contrasting findings between Industrial Revolution Britain and late twentieth century cross-country variations in rates of economic growth suggest the following questions. First, how sensitive is the claim that educational stagnation prevailed in Britain during its Industrial Revolution and that the contribution of education to economic growth was small to the manner of measurement and specification? Second, how can the slow expansion of education during a period of accelerating economic growth in Britain be explained; to what extent was it due to a lack of demand for educated labor and to what extent to limitations of supply? Third, were there important indirect contributions of human capital to economic growth of the sort highlighted in recent work on economic growth present during the British Industrial Revolution that are not captured by conventional measures of skill and educational levels and their impact on earnings? Finally, insofar as the case of Britain demonstrates that it has been possible to experience an acceleration in economic growth without increasing workforce educational levels, to what extent was this exceptional and why might the case of Britain during the Industrial Revolution differ from late twentieth century economies with respect to the contribution of education to economic growth. This chapter will take up these issues in turn.

Educational Stagnation and the Direct Contribution of Human Capital to Economic Growth During the British Industrial Revolution

Conventional analyses of the contribution of education to economic growth measure this contribution in terms of the improvement in the quality of the labor force. The magnitude of the contribution to growth thus depends on the increase in the educational levels of the labor force. Insofar as an economy experiences little or no improvement in the educational levels of its workforce, one would expect using this perspective little or no contribution of education to economic growth. Since in the later nineteenth and twentieth centuries, most economies of the world have experienced quite sizable improvements in the educational attainments of their workforces, it is not surprising that some economic historians have found that the contribution of education to economic growth over this period has also been sizable (Easterlin, 1981). In the case of Britain, Matthews et al. attribute 15 percent of the growth in GDP in Britain over the period 1856 to 1973 to improvements in the education of the British labor force (Matthews et al, 1982, pp.136, 500). They estimate that between 1871 and 1961 the average number of years of schooling of the male labor force of England more than doubled rising from 4.21 years to 9.78 years (Matthews et al, 1982, p.573).

For the earlier period of the Industrial Revolution, however, most assessments of educational trends suggest stagnation or at best quite modest improvement. Insofar as this was the case, it suggests little or no scope for improvements in labor force quality via educational improvements to accelerate economic growth. A review of the evidence supporting the claim of educational stagnation is thus in order so as to assess how much the direct contribution of educational improvement to economic growth can be minimized during the English Industrial Revolution.

Educational Stagnation?

At first glance, there seems little question about general educational trends in England during its Industrial Revolution, 1780 to 1830. The national sample of 274 parishes constructed by Schofield reveals a modest improvement in signature rates at marriage during this period, rising from about 60 percent for grooms and 40 percent for brides in 1780 to about 65 percent for grooms and 50 percent for brides in 1830 (Schofield, 1973). These trends seem sluggish compared with the marked rise to almost universal literacy in the 70 years after 1830. Although some of those who could not sign their names may still have been able to read, studies suggest that signature ability correlates with the ability to read well (Schofield, 1968).[1] Despite an apparently uniform national trend in literacy, there was considerable variation in trends among individual regions, with some areas experiencing marked increases in literacy, others marked decreases, along with areas experiencing the stagnant literacy trends that characterized the country as a whole (Sanderson 1995, pp.4-10; Stephens 1987, pp.5-10). Moreover, for some regions and population groups literacy trends changed direction during the late eighteenth and early nineteenth centuries. For example, Nicholas and Nicholas (1992) found in a study of a sample of English convicts transported to Australia that for male convicts from urban areas, those who had reached the age of ten around 1807 actually had markedly higher literacy rates than those who had reached the age of ten between 1790 and 1795. They also report a less marked improvement in literacy for male convicts from rural areas for those who reached age ten around 1817 compared with those who reached age ten in the early 1790s. But for convicts reaching the age of ten after 1807 for urban males and after 1817 for rural males, Nicholas and Nicholas (1992) find that through 1835 literacy rates fell back towards their levels in the early 1790s.[2]

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[1] Detailed examinations of the relationship between signature ability and other types of literacy skills in nineteenth century England have admittedly raised some doubts about how closely various types of literacy ability move together over time. See Reay, 1991; and Reay, 1996.

[2] Nicholas and Nicholas (1992) measure literacy by the responses in convict records to questions as to whether convicts were able to read and write, could read only, or could neither read nor write. This could account for some of the difference between their findings and those of Schofield (1973), who measures literacy by signature ability. Nicholas and Nicholas do not report whether there were shifts in the regional composition of their sample over time. If such shifts were present, then this might make their sample less suitable for

While local and regional trends and trends over time in literacy were by no means uniform, in turning to the question of the improvement in the basic educational levels of the English labor force as a whole during the Industrial Revolution, the perspective provided by Schofield's national level sample seems appropriate. There was at best sluggish improvement in literacy during the Industrial Revolution.

The signature rate at marriage is not an infallible measure of literacy; as already noted above, some could read without being able to sign their names and others could sign their names without being able to write much else or be very fluent in reading ability. For this reason, evidence on primary schooling trends might be considered as a check on the significance of literacy trends.[3] It was not uncommon for people to acquire basic literacy skills informally from relatives, acquaintances, or neighbors (Laqueur, 1976a; Spufford, 1979). But there is substantial evidence from working class autobiographies and educational surveys that by the mid-nineteenth century, attendance at primary day schools had come to play a central role in how the English working classes learned to read and write (Mitch 1992, pp.136-140; Mitch 1982, pp.230-253; Stephens 1987, p.13).

Although no national level school surveys were undertaken prior to the early nineteenth century, one can consider whether there is evidence of increased efforts at primary schooling provision during the Industrial Revolution period of a magnitude sufficient to cast doubt on whether literacy trends were as stagnant as implied by Schofield's estimates. On the eve of its Industrial Revolution, England lacked a centralized organization for the propagation of elementary schooling. Local endowments and charitable subscriptions, some existing for centuries, supported primary and secondary schools. The Society for Promoting Christian Knowledge sponsored charity schools earlier in the eighteenth century, but it is a matter of dispute how widespread they actually were (Jones, 1938; Simon, 1968). It can be noted that the 1818 survey of parochial schooling indicates that over 98 percent of the population in 8 sample counties resided in parishes where at least one school was present. (Mitch 1982, p.222). However, this does not necessary imply convenient access. Moreover, most students were enrolled in private, for-profit schools, and questions have been raised about the educational effectiveness of such schools (Mitch 1982, p.226).

Subsidized schools may have been required to bring the fees for effective teaching down to a level that most working-class parents would be willing to utilize. There was a surge in the provision of subsidized schools by religiously affiliated

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measuring national trends than Schofield's sample.

[3]For careful studies pursuing these points, see Reay 1991 and Reay, 1996.

national level organizations beginning in the early nineteenth century (Sanderson 1972c; Mitch 1992, p.117; Stephens 1987, p.12). Nevertheless, in both the 1818 and 1833 parochial surveys of elementary schooling, the proportion of all students enrolled in subsized schools remained constant at 42 percent (Mitch 1982, p.226). While this constancy could have been due to more effective counting of private school enrollments in 1833 than in 1818, it would not suggest increased access to subsidized schools during the first third of the nineteenth century of sufficient magnitude to overturn the testimony of Schofield's aggregate literacy figures. The one type of working-class educational institution for which there is clear evidence of a marked rise in usage during the Industrial Revolution period is the Sunday School. Sunday school instruction was not widespread before 1780. But by 1801, according to a recent estimate, enrollment had grown to over 200,000, by 1818 to 450,000, or 17.6 percent of the English population aged 5 to 15, and by 1833 to 1.36 million, or 45 percent (Laqueur, 1976b, p. 44). At this latter date, enrollment in Sunday schools was 1.2 times enrollment in day schools (Mitch, 1982, p. 230).

Throughout the Industrial Revolution, Sunday schools had a religious sponsorship and orientation from the Church of England and a variety of other denominations.[4] According to Hannah More, one of the early leaders of the Sunday school movement, the purpose of the schools was "to train up the lower classes in habits of industry and piety" (Lawson and Silver, 1973, p. 239). However, at least through the first half of nineteenth century, they also played a role in the secular instruction of the working classes.[5] Based on surveys administered by the Sunday

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[4]In 1851, after over half a century of rapid expansion, only 3 percent of the Sunday school enrollments reported by the Census of Religion were in nondenominational schools (Laqueur, 1976b, p. 179). In the mid-nineteenth century, somewhat more Sunday schools were affiliated with dissenting denominations than with the Church of England. The tendency of denominational affiliations earlier in the century is less certain (Laqueur, 1976b, pp. 46-53).

[5]Alexander Field has challenged the view that Sunday schools offered secular instruction (Field, 1979). His challenge is based on his findings for Lancashire communities in 1841 that the ratio between Sunday school and week-day school enrollment was systematically related to occupational structure. Field finds that communities with a relatively high proportion of their workforces engaged in cotton textile production also had relatively high Sunday school enrollment rates. His explanation of this result is that communities with relatively large numbers of cotton textile workers were more likely to demand education for its socializing role than for cognitive training. He asserts that Sunday schools were more likely to emphasize the socializing aspects of education and day schools were more likely to emphasize cognitive training and that is why cotton textile communities put more emphasis on Sunday schools. Although Field's results are of interest, they

schools themselves and by autobiographical evidence, Laqueur (1976b) concludes that the contribution of Sunday schools to working-class literacy was significant. However, quantitative analysis raises doubts about whether or not Sunday school attendance improved literacy. Regression analysis of the relationship between literacy rates and both day school and Sunday school enrollment rates at the county and the registration district levels indicates that while day school enrollment had a statistically significant positive association with literacy, Sunday school enrollment had a statistically significant negative association (Mitch 1992, 147).[6] To return to Schofield's figures, the modest improvement in signature rates at marriage that followed the several fold increase in enrollment rates in Sunday schools is perhaps the most telling indication of their limited contribution to working-class literacy.[7]

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encounter some difficulties. First, in his regression analysis he enters no controls for child labor demand and thus cannot rule out the possibility that cotton textile areas made more use of Sunday schools because of a relatively high week-day demand for child labor. Second, there is no reason why both week-day and Sunday schools could not have offered both cognitive instruction and instruction focussing on morality and orderly behavior. There is abundant evidence that week-day schools did attempt to teach morality and orderliness as well as cognitive skills (Johnson, 1976; 1977). Admittedly, Sunday schools may have placed more emphasis on moral and religious training than weekday schools, but working class children and adults attending Sunday schools could still have focussed more on the cognitive training they offered than on their moral and religious agenda.

[6]This finding probably reflects the fact that Sunday school enrollment was likely to be higher in an environment not conducive to the acquisition of literacy. Educational production function studies for the twentieth century U.S. have frequently found that measures of school inputs fail to produce positive effects on school outcomes. How schools are run and the overall educational experience of the child seem to matter more than the amount of resources spent per student (Hanushek, 1996). Given these findings, it is not surprising that a marked rise in Sunday school enrollments without sustained follow up experience in day schools would fail to show a positive impact on literacy levels.

[7]The most optimistic interpretation of the signature rate series constructed by Schofield points to the fall in the proportion of brides unable to sign their names from about 65 percent in 1805 to just under 50 percent in 1840 and a decline for grooms from just over 40 percent to about 35 percent (Schofield, 1973; West, 1978). Schofield does attribute some of the improvement in female literacy to the rise of Sunday schools. However, over this same period, Laqueur's estimates indicate the Sunday school enrollment rates increased at least fivefold (Laqueur, 1976b, p. 44). In assessing the educational contribution of Sunday schools, one should allow both for the adverse influences on education they may have been offsetting and for their role in religious and moral instruction over and above any instruction in literacy skills. But their impact on literacy still appears modest relative to their spectacular increases in enrollments.

The quality of education at higher levels in the mid-eighteenth century has commonly been viewed as even more stagnant than elementary schooling. Revisionist historians (Lawson and Silver, 1973, p. 212; O'Day, 1982, p. 275; Sutherland, 1973) have effectively argued that these depictions are exaggerated, but they do not give reason for thinking that accomplishments in secondary and higher education during the eighteenth and early nineteenth century were more than mediocre.

Conflicting forces were at work on secondary education during the eighteenth century. On the one hand, the endowments of many grammar schools had diminished in value in the late seventeenth and early eighteenth centuries (O'Day 1982, pp.197-204). On the other hand, a new source of demand for secondary education was coming from students seeking commercial and other types of practical education, as reflected in the rise of the dissenting academies (Parker 1969; O'Day 1982, pp. 213-15). The lack of aggregate figures on secondary enrollments or their trends during the eighteenth century makes it difficult to establish the net effect of these conflicting forces. There is not enough evidence to completely overturn traditional views of mediocrity, but, clearly, secondary education was not universally stagnant.

Indications of decline at the university level are the most telling of all. Enrollments at Oxford and Cambridge were lower in the mid-eighteenth century than at any other point between 1650 and 1850 (Stone, 1974). In 1776, Adam Smith wrote of Oxford in the *Wealth of Nations* that, "the greater part of the publick professors have, for these many years, given up altogether the pretence of teaching." (Smith, [1776] 1976, p. 761). Numerous other accounts have echoed Smith's scorn (Lawson and Silver, 1973, pp. 212, 214; Gibbon, [1796] (1961), chap. 3; Sutherland, 1973).

By the end of the Industrial Revolution, reform at the university level was just beginning. In the early nineteenth century, examination reforms were implemented, and efforts were made to address the corruption of fellowships and professors who failed to lecture. But it was only in the 1850s, however, that a parliamentary commission was appointed to look into the full-scale reform of Oxford and Cambridge (Green, 1969; Lawson and Silver, 1973, pp. 297-99). Not

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The very marked increase in literacy during the early Industrial Revolution that Nicholas and Nicholas (1992, p.9) report for their sample of English convicts could be interpreted as reflecting the contribution of the growth of Sunday schools. However, the problem then remains of accounting for the fall in literacy rates that Nicholas and Nicholas report for the later Industrial Revolution, a period when the growth of Sunday school enrollments continued to be robust.

until the last half of the century did the scholar/researcher come to prominence over the cleric at the two universities (Rothblatt, 1968). After accelerating in the very early nineteenth century, enrollments for the next fifty years at Oxford and Cambridge failed to keep up with population growth (Sanderson, 1972b, p. 3). Both the University of London, a secular institution, and King's College, an institution in London with Anglican affiliations, were founded in 1828 and both had a more professional, utilitarian orientation than Oxford and Cambridge. But any influence of these two institutions would have come only at the very end of the Industrial Revolution.

Nevertheless, in evaluating England's intellectual resources at the start of its Industrial Revolution, it is important not to focus too heavily on the shortcomings of Oxford and Cambridge. Higher intellectual pursuits in the sciences and arts could flourish outside the universities through a variety of informal institutions. According to some historians, if one takes into consideration England's informal intellectual resources, the educational level of its workforce at the end of the Industrial Revolution was not at all undistinguished (Inkster, 1991; Musson and Robinson, 1969; Jacob, 1988, 1997). By the early eighteenth century, it was common for freelance lecturers in the sciences to offer a series of lectures for an admission fee in London and the major provincial cities, such as Birmingham, Leeds, Sheffield, and Manchester and even smaller towns such as Salisbury (O'Day, 1982, p. 210; Musson and Robinson, 1969, pp.103-111,120-21, 129-31, 144,151,164).[8] Although such lecture courses may have fallen far short of universities as intellectual communities, they did offer flexibility and responsiveness to community interests (Inkster, 1991). Intellectual associations, with heterogeneous aims and membership, proliferated throughout the eighteenth century.[9] The early nineteenth century saw the establishment of the so-called

[8]For example, John Desaguliers gave lectures in London on mathematics and natural philosophy between 1712 and 1744. He presented a course on mechanics, hydrostatics, pneumatics, and optics that met one evening a week during 1724 and 1725 at a cost of two and a half guineas (O'Day, 1982, p. 210; Lawson and Silver, 1973, pp. 218-19).

[9]The Royal Society of London, which was founded in the seventeenth century and boasted such distinguished members as Newton, Boyle, and Hooke, began during the eighteenth century, to cultivate an interest in the applied and utilitarian aspects of science (Musson and Robinson, 1969; Jacob, 1988). In the first half of the eighteenth century, literary and philosophical societies were established in Spalding, Stamford, Peterborough, Boston, and Doncaster (Musson and Robinson, 1969, p. 138), and they became more common in the second half of the century. The Manchester Literary and Philosophical Society was established in 1781 (Thackray, 1974). The focus of the societies began to shift from literary and philosophical to more scientific and technological ones. Numerous

mechanics institutes. Initially their aim was to provide instruction in science, especially its utilitarian applications, primarily for the more skilled segments of the working classes. There has been some debate about the success of mechanics institutes and whether their clientele increasingly became middle class or came from the working classes seeking education in the rudiments of literacy (Inkster, 1985; 1976; 1983).[10] Nevertheless, they provide yet another example of the diversity of educational resources available to England during the Industrial Revolution.

Whatever upward movement may have occurred in secondary and university enrollments during the Industrial Revolution was unlikely to offset the impact of stagnant trends in literacy and primary schooling on overall changes in the educational level of the English labor force during this period. The number of students enrolled in English universities was well under 1 percent of the numbers enrolled in primary schools. Enrollments in secondary schools were unlikely to have been over 5 percent of primary enrollments.[11] Thus, the modest rise of literacy already noted was unlikely to have been substantially augmented from expansion

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offshoots of these as well as new entities with utilitarian interests in science were established. Their activities included organizing lecture series, paper presentations and discussions on both scientific and more general cultural topics; establishing libraries for the use of members; and arranging for the demonstration and, sometimes, the purchase of scientific equipment. Some of these societies were relatively small and closely knit, such as the famous Lunar Society, which met in Birmingham and consisted of such distinguished members as Boulton, Watt, and Wedgwood (Schofield, 1963). The members of these organizations were commonly middle class with nonconformist religious affiliations, although their backgrounds could vary widely (Jacob, 1988; Watts, 1998). The agricultural society constituted yet another type of intellectual society with utilitarian interests.

[10]Some mechanics institutes seem to have evolved from earlier literary and philosphical societies (Inkster, 1985, pp. 4-6). By 1851, enrollments, as reported by the Census of Education, at evening schools (which would have included some mechanics institutes) amounted to only about 40,000; Inkster, however, conjectures that true participation in all forms of these organizations (which he has dubbed "Steam Intellect Societies") could have been almost 500,000 (Inkster, 1985, p. 16). In Liverpool alone around 1850, there were some 39 mechanics institutes and similar self-improvement societies (Inkster, 1985, p. 48). In conjunction with the activities of these societies, numerous libraries and museums were established in the first half of the nineteenth century.

[11]The limits for relative enrollments in universities compared with primary schools are based on the 1881 ratio of university enrollments as reported in Lowe (1983) to enrollment in inspected elementary schools in the same year from Parliamentary Papers 1882. The limits for relative enrollments in secondary schools to primary schools are based on the ratio of secondary enrollments for 1911 estimated by Schmidt (1995) to Lowe's 1983 estimates for universities in the same year.

at the secondary and higher levels. By their very nature, it is harder to gauge the proportion of the population influenced by more informal activities. The impact of such activity can only be given brief consideration below in turning to more indirect affects of educational activity.

Any rise in skill levels of the English labor force during the Industrial Revolution was at best modest. This is suggested by Lindert and Williamson's finding of a rise between 1759 and 1803 in the proportion of family heads classified as "labourers and the poor" in Lindert and Williamson's reworking of Massie's and Colquhoun's social tables for those two dates (Lindert and Williamson, 1982). Their estimates place 28 percent of all English family heads in the "labourers and the poor" category in 1759 and 35 percent in that category in 1801-3. The underlying occupational data on which these estimates are based are fragile and uncertain, especially in the absence of any occupational census for this time period, while Lindert and Williamson's revisions are based on considerable guesswork. However, they are the best estimates available on trends in occupational distribution for England during this period and they seem consistent with the view that educational and skill levels of the English work force were stagnant during the Industrial Revolution.

The Direct Contribution of Education to Economic Growth

Although the preponderance of the evidence considered above indicates educational stagnation, quantitative assessment of the impact of educational change does depend on how educational change is measured and on how that change is modelled as impacting economic growth. This point comes through forcefully in Crafts (1995a) estimate of the contribution of human capital to economic growth. He finds that as much as 26.4 percent of the average percentage increase in national income in Britain beween 1780 and 1831 of economic growth can be accounted for by human capital. This figure is three quarters of the 35 percent accounted for in Craft's estimates by conventionally measured capital growth and over double the 12 percent contributed by total factor productivity growth.

In putting forward these estimates, Crafts acknowledges the difficulties in measuring human capital. His basic argument is that even a very generous allowance for the contribution of human capital will not fully explain the residual as some of the growth models he considers have attempted to do. However, his estimates are based on a rather generous allowance for the extent of human capital growth since they imply translating an increase in male signature ability at marriage in England from 62 percent in 1780 to 70 percent in 1830 into an almost two and a half fold increase in the average years of schooling of the labor force over the same time period.[12]

Given the absence of any national level schooling surveys prior to 1818, Crafts estimates the change in average years of schooling between 1780 and 1830 on the assumption that each 1 percentage point change in the male signature rate at marriage translates into a tenth of a year change in the average years of schooling of the labor force. How literacy rate changes should translate into changes in average years of schooling depends on what is assumed for any given change in literacy rates about the percentage of the workforce whose years of schooling change and about the number of years of change in schooling for those whose years of schooling change. It also depends on what is assumed about the relation between the signature rate for a cohort marrying in a given time period and the educational levels for all cohorts in the labor force. Crafts' assumption that a 1 percentage point change in literacy translates into a tenth of a year change in average years of schooling is more or less in accord with estimates of average years of schooling and literacy figures for the mid to late nineteenth century.[13] However, during this

[12]According to Crafts'(1995a) estimate using an Augmented-Solow Growth accounting model, human capital contributed 0.45% per year to the growth of output between 1780 and 1831 employing a weight of 0.25 on human capital. This implies that human capital increased at a rate of .45/.25 = 1.8 percent per year over this time period. Cumulated over 51 years, this annual rate of increase implies an increase of 2.48 times over the entire time period. Crafts measures human capital in these calculations in terms of average years of schooling of the labor force.

[13]The average years of schooling of the labor force estimates reported in Matthews et al (1982, p.573) and male literacy figures reported by the registrar general are as follows for 1871 and 1891:

	Average Years of Schooling of the Labor Force	Signature Rate of Grooms
1871	4.21	80.6
1891	5.32	94

Thus the change in average years of schooling divided by the change in signature rate at marriage between 1871 and 1891 was 1.11/13.4 = .083. Matthews et al do not estimate average years of schooling for the entire labor force prior to 1871. However, as a lower bound estimate for 1831, one can use their estimate for the cohort born prior to 1805 of 2.3. This then translates into a change in average years of schooling between 1831 and 1871 of 4.21 - 2.3 = 1.91. Thus an upper bound for the change in average years of schooling divided by the male signature rate of marriage between 1831 and 1871 would be 1.91/13.4 = .14.

period, much of the labor force would have acquired years of schooling well beyond what was required to attain basic literacy as attendance into the 4th, 5th, and 6th years of elementary school became increasingly common. During the later eighteenth and early nineteenth centuries, one would expect that whatever expansion of mass schooling did occur occurred primarily in the first 3 years of schooling, with an instructional emphasis on the rudiments of reading and writing. Moreover, as noted above, there is evidence that in late eighteenth and early nineteenth century informal alternatives to schooling played a more prominent role in literacy acquisition than was the case by the mid-nineteenth century (Mitch, 1992, pp.135-140).

The sensitivity of Crafts' results to how the growth of average years' of schooling is estimated is evident if one considers an alternative way of estimating it based on the likely relationship between literacy and average years of schooling prior to 1831. Mid-nineteenth century curricular guidelines suggest that for a working-class child to acquire basic literacy typically involved about 3 years of primary school attendance (Mitch, 1992, pp.231-232). Consider the following two assumptions: first, that the reported male signature rate of marriage in 1780 of 62 percent (Schofield 1973) occurred because 62 percent of the labor force had acquired 3 years of schooling and 38 percent had never attended school, and second, that an increase in the male signature rate to 70 percent by 1831 increased the percentage with 3 years of schooling correspondingly and decreased the percentage with none correspondingly.[14] This implies that average years of schooling of the male labor force between 1780 and 1831 increased from .62x3 = 1.86 to .7x3 =2.1 between those two dates. This translates into a 0.24% annual increase in average years of schooling over this period in contrast with the 1.8% annual increase implied in Crafts' estimates.[15] The contribution to the growth of national income over this

(Based a signature rate of grooms in 1831 of 67 percent from Schofield 1973).

[14]These assumptions are subject to offsetting biases in estimating the change in average years of schooling. On the one hand, many of those who could not sign their names may still have had some schooling, which leads to an overstatement of the change in average years of schooling. On the other hand, a certain proportion of those who would have obtained enough schooling to able to sign their names may have increased their years of schooling beyond what was required for that level of ability, leading to an understatement of the change in average years of schooling. Insofar as many who could not sign their names might still have obtained some schooling, the tendency to overstatement may dominate (Mitch 1992).

[15]Crafts overestimate of school enrollment trends based on the method he uses for converting literacy rate changes into school enrollment changes also imply an overestimate in the rise he finds in the human development index during the industrial revolution (Crafts

period in turn falls, using the parameters of Crafts' model to .25x.24 = .06 % per year in contrast with the 0.45% per year of Crafts' estimate. Thus estimated, human capital only accounts for 3.5 percent of annual output growth in comparison with the 26 percent of Crafts, and human capital's contribution is only 30 percent of that of total factor productivity in comparison with a contribution for Crafts' estimate of 2.25 times that of total factor productivity for this time period.

In addition to being sensitive to how it is measured, human capital's impact on economic growth is also sensitive to how it is modelled as influencing aggregate production. Crafts' estimates of human capital contribution to economic growth assigns human capital a weight of 0.25 based on an estimate of the share of labor's income in national income in excess of the share earned by common labor (Crafts, 1995a, p.752). What this implies about the wage premium to skilled over unskilled labor depends on the proportions of the labor force viewed as constituting skilled and unskilled labor, with the higher the proportion of the labor force skilled, the lower the implied premium to skill.[16] Lindert and Williamson (1982) estimate that 28 percent of English household heads were in the "labourers and the poor" category in 1759. If one infers from this that in the same year and throughout the Industrial Revolution, 72 percent of the English labor force were in skilled occupations, then the premium to skill would have equalled the unskilled wage. In

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1997). Crafts (1997) finds a rise in the human development index during the industrial revolution counter to trends based on height measures. This rise is in large part due to the marked rise in average years of schooling estimated by Crafts. The analysis here indicates that Crafts has considerably overstated the actual increase in average years of schooling over the industrial revolution period.

[16]This can be derived as follows. Let W_u = the wage of unskilled labor; W_s = the wage of skilled labor; L_u = the number of unskilled workers; L_s = the number of skilled workers; $L = L_s + L_u$; NI = national income. Let M_u = unskilled labor's share in national income and M_s = skilled labor's share in national income. M_u is defined as including the share of unskilled labor's wages and the unskilled component of skilled labor's wages. M_s is defined as the share of national income paid to skilled workers over and above the payment to the unskilled component of their labor

Then $M_u = W_u x L/NI$.

$$M_s = (W_s - W_u) x L_s/NI.$$

$$M_s/M_u = [(W_s - W_u)/W_u] \text{ x } L/L_s$$

Thus, $(W_s - W_u)/W_u = (M_s/M_u) \text{ x } (L/L_s)$.

other words, on average skilled workers received double the wage of unskilled workers.[17] Increasing the proportion of unskilled workers would raise the skill premium even higher. Crafts then proceeds to use average years of schooling as his unit of human capital. His approach thus implies that an increase in the education of the labor force by one average year of schooling yields a return equal to the payment to unskilled labor. This is a high return to one additional average year of schooling and probably imputes to schooling skill premiums that reflect innate or at least more informally acquired talents and abilities.

The relatively large contribution of human capital in Crafts' estimates also reflect the use of the Augmented-Solow model in which human capital is entered multiplicatively with other factors of production in contrast to a conventional growth accounting approach in which education is treated as augmenting the size of the labor force, with the latter approach subjecting human capital increases to more rapidly diminishing returns.[18]

As a reference point, for gauging the impact of specification both with respect to the weighting assigned human capital and to how it is entered into the production function, one can consider the contribution of estimated increases in average years of schooling using the more conventional growth accounting approach in which the contribution of education is viewed as augmenting the units of labor in the economy as employed by Matthews et al (1982). Both Crafts' estimates and the revised estimates just suggested of changes in average years of schooling over the Industrial Revolution period 1780 to 1830 will be considered for this purpose. Matthews et al (1982, p.107) assume a 6 percent increase in earnings for each additional average

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[17] Using the equation derived in the previous footnote,

$$(W_s - W_u)/W_u = (M_s/M_u) \times (L/L_s).$$

Crafts sets $M_s = 0.25$ and $M_u = 0.35$ so

$$(W_s - W_u)/W_u = (.25/.35) \times (L/L_s).$$

If 0.28 is taken as the percentage of unskilled workers in the English labor force following Lindert and Williamson's (1982) reworking of Massie's 1759 figure, then

$$(W_s - W_u)/ W_u = .714 \times (1/.72) = 0.99.$$

[18] For the development of the Solow growth model with human capital added see Mankiw, Romer, and Weil (1992). For a discussion of the problems of specifying how education should be entered in an aggregate production function see Blaug (1970), pp.89-100.

year of schooling of the labor force. The calculations will also put labor's share in national income at .6 which is in the range employed by Matthews et al (1982, p.208-9). Using this approach, the implied contribution to annual output growth of Crafts' human capital estimate that average years of schooling rose at 1.8 percent between 1780 and 1831 is .6x.06x1.8 = 0.0648 percent per year in contrast with the 0.45 percent he finds using the Augmented-Solow model. Using the revised figures just suggested for average years of schooling growth of 0.24 percent per year, the contribution using the labor augmented model to economic growth is .6x.06x.24 = 0.00864 percent per year, only 1.9 percent of the 0.45 percent total annual output growth over this period attributable to human capital estimated by Crafts.

The estimated contribution of human capital to economic growth thus depends critically on how human capital is measured and how it is modelled as entering into the aggregate production function. The estimates of average years of schooling increase suggested here when used in the conventional growth accounting framework of Matthews et al (1982) indicate far smaller contributions of human capital to economic growth during the Industrial Revolution period than later time periods.[19] Thus these estimates would seem to confirm the traditional view of at best a very limited contribution of education to economic growth during the Industrial Revolution.

Another type of analysis that provides an alternative perspective of human capital's contribution to economic growth is based on estimates of the human capital investment flows combined with rate of return analysis. West (1970, p.87) has estimated that approximately 1 percent of English national income in 1833 was devoted to educational investment. He used this estimate to defend the level of provision made by private schooling markets in England prior to major involvement by the government in provision of education. Hurt (1971) argued that West overstated the quality and enrollment rates for working-class schooling. While on these grounds, West's estimate could be taken as an upperbound, for purposes of estimating the value of resources invested in education, West's estimate makes no allowance for opportunity cost. As a rough adjustment for opportunity costs, one can assume that about one third of children in school had alternative uses of their time worth 3 shillings per week; the rest being too young, could be considered as having no opportunity cost. This would lead one to increase West's estimate of 9 pence per child expenditure on schooling by 2.33 times up to 21 pence per week for a total investment of 2.33 percent of 1833 national income. To get an upperbound

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[19]Recall that it was noted above that Matthews et al. (1982) estimate that 15 percent of the growth in GDP in Britain between 1856 and 1973 can be attributed to improvements in the education of the labor force.

estimate on the contribution this made to economic growth, consider the following assumptions: first, that this expenditure pertained primarily to children aged 5 to 10 and hence that a given one year age cohort would have received one sixth of this investment; second, that 50 such cohorts were active in the labor force; third, that the return on human capital investment was 42.5 percent per year compared with a 5 percent return on physical capital investment (see Mitch, 1984 on these rate of return estimates); fourth,, that all human capital investment was diverted from physical capital investment; and fifth, that investment in human capital in 1780 was half of its level in 1831, which surely considerably understates the 1780 level, as the discussion of schooling trends above indicates. Then an investment in education of 2.33 percent of national income in 1833 would have made national income 1/6 x 50 x (.425-.05) x .5 x 2.33% higher in 1833 or 3.64 percent higher which is only 2.7 percent of the total increase over this period of 136%.[20] The basic reason for the modest contribution implied by these estimates is simply the low level of expenditure involved in investing in formal schooling, even allowing for opportunity costs, compared with other forms of investment. West's (1970, p.87) estimates of direct expenditure on schooling of 3 million pounds is 8 percent of Feinstein's estimate of average annual Gross domestic fixed capital formation for Great Britain over the decade 1831-40 of 36.93 million pounds (as reported in Mitchell, 1988, p.857). Adjusting the capital formation estimate downward as West does with national income by England's pro rata population share in British population yields a figure of 31.575 million pounds. This implies that West's estimate of direct education expenditures of 3 million pounds in 1833 was just under 10 percent of annual gross domestic capital formation over the 1830's. Making the same allowance as above for opportunity costs would increase educational investments to just under a quarter of gross domestic capital investment over this period.

One can question the implied assumptions in the above calculation; it presumes that education is capital augmenting rather than labor augmenting. However, the low implied investment in human capital due to the relatively low level of expenditure per pupil involved in the dominant form of education at this time, primary education, supports the finding of a relatively modest contribution from any remotely plausible increase in human capital investment during this time. Since, the actual levels of increase are likely to have been far smaller than what is allowed for in these estimates, the implied contribution of human capital accumulation directly as such is likely to have been small.

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[20] The increase in national income between 1780 and 1831 is based on figures in Crafts, 1995a, p. 752.

Nevertheless, many questions remain about more indirect contributions. If on balance the unskilled proportion of the labor force did not decline, there may have been substantial shifts between various types of skilled labor that made important contributions to growth and that were promoted by human capital formation. More generally, the question arises of why the contribution of human capital to economic growth was far smaller during the English Industrial Revolution than for most economies of the world during the later twentieth century. This leads to the question of trends in the demand and supply for educated and skilled labor during the Industrial Revolution.

Accounting for the Limited Expansion of Education During the Industrial Revolution

Insofar as the quite limited growth of educational levels during the Industrial Revolution suggest a quite limited contribution to economic growth, the issue arises of why educational levels did not expand faster given the acceleration which occurred in economic growth. Most explanations have focused on the demand side, arguing that most occupations in the English labor force and especially occupations in the expanding textile industries did not require or utilize formal education (Landes, 1969; Sanderson, 1972; Sanderson, 1995; Schofield, 1973; Vincent, 1989). Claims of supply side failure in the provision of educated labor for Britain have primarily focussed on the later nineteenth century with the view that Britain lost its position as technological leader to Germany because of failure to provide for the technical and scientific education of key segments of its workforce (Roderick and Stephens, 1978; Landes, 1969; Wrigley, 1986; Barnett, 1986). However, Williamson (1985) has also offered a supply side explanation for limited skill expansion during the early Industrial Revolution period, arguing that an inelastic supply of skills and formal schooling led to a surging skill premium in Britain during the first half of the nineteenth century. Both contemporaries and more recent historians have been critical of the provision of schools for working-class children during the Industrial Revolution (see, for example, Hurt, 1971; and Sanderson, 1972a). Thus, both types of explanations deserve further examination in considering why the role of human capital may have been different in the British Industrial Revolution than it came to be later and in other places experiencing rapid economic growth.

Trends in the Demand for Educated and Skilled Labor

The overall trends in the derived demand for educated and skilled labor can be decomposed into trends in demand *within* individual industries and occupations, and into shifts in the composition of occupations and industry *between* more and less skill-intensive occupations and industries (Williamson, 1985 and Lindert and Williamson, 1985). Changes in the demand for skilled labor within industries could have been driven by biases in technical change, by capital-skill complementarity in the presence of capital accumulation, or by changes in the supply of unskilled labor. If the conventional view of a limited growth of derived demand for human capital is to be explained by the nature of technical change within industries, some combination of skill-saving and unskilled- labor-using technical change should have been present. The lack of capital skill complementarity within industries during the Industrial Revolution could provide another explanation for stagnant trends in demand for skilled labor. Another possibility is that expansion in supplies of unskilled labor during this period lowered the wage of unskilled labor and caused substitution towards unskilled labor in production. Finally shifts in the overall composition of the economy towards activities relatively unintensive in the use of educated and skilled labor could account for a limited growth in the derived demand for human capital.

Literacy and Skills in the Early Nineteenth Century British Labor Market

Before proceeding with examination of changes over time in the demand for educated and skilled labor, it should be noted that prior to the later nineteenth century, formal education was considered of little value in most working class occupations but that some working-class occupations clearly did encompass a role for the more informal acquisition of skill.

This is not to say that formal education had no labor market value. Literacy did enhance opportunities for economic advancement. Studies grouping the occupations reported by grooms at marriage and their fathers into five broad categories according to status have found that for grooms whose fathers had a given occupational status, literate grooms tended to have a higher occupational status than illiterate grooms (Mitch, 1992, pp. 22-25; Vincent, 1989, pp. 129-31).[21] Literacy

[21] For example, in a sample of marriages from 1839-43, of grooms whose fathers were unskilled laborers, half of those who could sign their names reported occupations with a status higher than unskilled compared with only 20 percent of those who were unable to sign (Mitch, 1992, p. 24). These comparisons suggest not only that those who could read and write had an advantage over those who could not in reaching higher-status occupations but also that literacy was neither essential for obtaining a high-status occupation nor an assurance of avoiding a low-status one. A plausible explanation is that literacy had to be combined with other skills, attitudes, and aptitudes to provide an advantage.

However, one indication that much of the advantage of literates over illiterates was due to literacy alone is that the types of occupations in which literates had the most advantage in entering were those in which literacy was most likely to be used. Of the higher probability also influenced the labor market prospects of women. Comparisons of the occupations reported by literate and illiterate brides for 1839-43 indicate that literate brides were more likely to hold jobs in service and clothing manufacture, while illiterate brides were more likely to report occupations related to textile manufacture (Mitch, 1992, pp. 33-35).[22]

However, if the English labor force in 1841 is classified by occupations according to the degree to which literacy was used, one finds that 4.9 percent of male workers were in occupations that required literacy; 22.5 percent were in occupations in which literacy was likely to have been useful; 25.7 percent, in occupations in which literacy was possibly useful; and 49.7 percent, in occupations in which literacy was unlikely to have been useful (Mitch, 1992, pp. 14-15). Among female workers, 2.2 percent in 1841 were in occupations in which literacy was required; 5.2 percent, in occupations in which literacy was likely to have been useful; 67.9 percent, in occupations in which literacy was possibly useful; and 24.7 percent, in occupations in which literacy was unlikely to have been useful.

More generally, skills and human capital during the Industrial Revolution were developed through various forms of labor market experience at least as much as through formal schooling, and literacy was hardly the only dimension of skill. Thus, even if literacy levels may have been relatively low and declining, levels of skills acquired outside of formal schooling could have been rising.[23]

More (1980) has identified three significant forms of on-the-job training in England during this time period: apprenticeship, migration, and "following-up." Formal apprenticeship, the oldest form, traditionally involved a written contract, known as an indenture, which bound apprentice to master. The contract stipulated that the master would instruct the apprentice in his craft and provide the apprentice

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of literate sons in reporting an occupation other than unskilled in the study of 1839-43 marriages, over 80 percent is attributable to an advantage in movement into occupations where literacy was at least possibly useful (Mitch, 1992, p. 26). Although literates did have an advantage over illiterates in entering textile manufacturing, where literacy was generally not very useful, they had no advantage in mining, another important industry in which ordinary operatives had no occasion to use literacy on the job (Mitch, 1992a, p. 28).

[22]Literate brides were also, not surprisingly, far more likely than illiterate brides to work as shopkeepers and school teachers, although only a small percentage of the female labor force held such occupations. But although literate and illiterate women tended to enter different occupations, evidence is lacking on whether the occupations entered by literates paid more than those entered by illiterates.

[23]A study of the nineteenth century Catalan textile industry has found that the proportion of skilled workers in the labor force did rise over time. See Roses (1997).

with board and lodging; in exchange, the apprentice would work for a set period of time, commonly five to seven years, at lower wages than the apprentice might otherwise earn. Apprenticeship agreements, both oral and written, were certainly common throughout the eighteenth and nineteenth centuries (Thompson, 1963; More, 1980; Elbaum, 1989), even if they were not legally enforced. Apprenticeship was most commonly associated with such artisanal crafts as hatting, flint glass making, cabinet making, carriage building, and wheel wrighting, as well as with many construction occupations and with the metalworking trades of Sheffield and the West Midlands (More, 1980, Chap.3). There is no evidence, however, that apprenticeship rose markedly during the Industrial Revolution, while there is general agreement that it was on the decline by the last half of the nineteenth century (More, 1980, Chap.3). According to More, apprenticeship was not used in growing occupations such as cotton spinning commonly associated with the Industrial Revolution.

The second method of on-the-job training, migration, involved rotating trainees from task to task within a given firm and by moving them among firms. This method most commonly occurred in occupations that involved tending machinery, in the metalwork trades of Birmingham, and in coal hewing and railway work (More, 1980, Chap. 6; Flinn, 1984, pp.347-349).

The third method, following-up, proceeded by assigning a trainee to a gang or as an assistant to a more skilled worker. While working full-time, the trainee would also learn the task of the more skilled workers in his unit. This method of training was used in a number of the occupations often associated with the leading industries of the Industrial Revolution, for example cotton spinning. Boys would enter the industry in their teens and would be assigned the task of piecing together broken cotton threads; by their mid-twenties, if openings were available, they would work their way up to be minders of the cotton spinning machinery (Lazonick, 1990, Chap.3; More, 1980, Chap. 6). Following-up was also used to train iron and steel workers (More, 1980, Chap.6).

By some accounts, the length of time involved in acquiring the skills required for occupations such as coal mining and cotton spinning was considerably longer than the three years or so of schooling commonly involved in acquiring literacy. Flinn (1984, p.347) indicates that during the Industrial Revolution period, boys were recruited into mining between the ages of 8 and 10 and would then take another ten to twelve years to progress through various grades of work before being assigned work as a full-fledged hewer. He indicates that recruitment into underground mining work during adulthood was rare. Flinn (1984, p.349) accounts for this early entry by the presence of:

> a positive belief that skilled 'pitmen' could only be created by an early acculturation in the environment of the mine. Training was not, as it might be today, in a set of specific skills and the acquisition of a specific body of information but by familiarity with and total immersion in the routines, skills and dangers of the mine.

Thus, a dozen years of experience beginning at a relatively early age could be required to be become a coal hewer.

Similarly, Boot (1995, p.289) argues that workers in Lancashire cotton textile factories began acquiring the skills required on obtaining factory employment at around age 10. He argues that recruitment to mill work was rare after age 16. After going through a period of training involving either the process of migration or of following-up described above, by age 20, the basic process of skill acquisition for factory textile work was complete. Boot (1985, p.289) argues that a training period of up to ten years was required in order to acquire sufficient dexterity, knowledge, and experience with the machines and raw materials being utilized. It should be noted that other accounts question whether so much time was really required to master the skills involved in cotton spinning and would reduce it to a matter of months rather than years (Huberman, 1996; Marglin 1974-1975). Redford notes that three weeks was the amount of time allotted in the New Bailey, Manchester for teaching a prisoner to weave calico (Redford 1926 (1976), p.42). Church (1986, pp.204, 215) cites sources indicating that at most one or two years experience was required to master the coal hewer's tasks and arrives at his own assessment that perhaps no more than one or two months experience was really required.

Biases in Technical Advance and the Role of Capital-Skill Complementarity

It is commonly presumed that technological advance will be skill/education-using and that capital-skill complementarity is present in production. Insofar as technological advance and capital accumulation are the driving forces behind economic growth, this would explain why education is regarded as playing an important role in economic growth. However, there is no theoretical reason why either technological advance need be education using or that there be complementarity between capital and skill. Indeed, Lindert and Williamson (1985) explicitly acknowledge examples of reversals of the former. Goldin and Katz (1996) have recently made the point that the empirical evidence supporting capital-skill complementarity comes mainly from the later twentieth century. They argue that historically there have been important periods and situations in which capital accumulation and technical change have been deskilling or unskilled-labor using. They suggest that the shift from the artisan work-shop to the factory was unskilled-labor using and that only with the shift from the factory to batch production methods and continuous process production did technical change and capital accumulation become skill-using.

If skill is acquired primarily by formal education, then insofar as technological advance is education-using, activities experiencing above average rates of technical advance should experience rising educational levels of their labor forces other things equal. This is because rising demand would cause them to bid educated workers away from less rapidly advancing sectors, even if the overall educational level of the labor force is not improving (Williamson, 1985).

What has been striking in the historiography of the British Industrial Revolution has been the reported finding that literacy rates in the cotton textile industry were actually relatively low compared with other sectors of the economy. Michael Sanderson based on Lancashire marriage registers from the 1830s finds that literacy rates in spinning and weaving occupations for factory cotton production were well under 50 percent and were far lower than literacy rates in more traditional craft occupations. Sanderson summarizes his findings as follows: "One thus finds the interesting situation of an emerging economy creating a whole range of <u>new</u> occupations which required even <u>less</u> literacy and education than the old ones" (Sanderson, 1972a, p. 89 [Sanderson's emphasis]). Sanderson explains the low literacy rates of workers in cotton textile factories by citing a description of cotton manufacture in the twentieth century, which states that "the main difficulty in developing the cotton industry lies rather in the fact that it embodies in its 'know-how' a large element of manipulation or skill, i.e., that its processes cannot be described in such detail that a list of instructions can be given for every job...." (Sanderson, 1972a, p. 91).

Although prominent, cotton textiles was by no means the only industry experiencing technical advance. A fuller perspective is provided by considering occupational literacy trends as reported in Schofield (1973) for both sectors of the economy identified by Harley (above) as modernizing or in other words with above average rates of total factor productivity advance and for other important sectors such as agriculture (see Table 1). One finds that not only in textiles but in two other modernizing sectors identified by Harley, metal and transport, literacy rates declined in the first part of the Industrial Revolution and then improved modestly thereafter. However, reverse trends may have been present in agriculture with the declining importance of husbandmen and rising relative importance of those in the farmer category; this represents a net shift toward a more literate group. This is significant given that a sizable share of the contribution to technical advance estimated by Harley can be attributed to agriculture.

TABLE 5.1 Male Illiteracy by Occupational Group for English Parishes

Occupational group	*1754-1784*	*1785-1814*	*1815-1844*
Textiles	20	39	16
Metal	22	29	19
Transport	31	38	30
Yeomen and Farmers	19	18	17
Husbandmen	46	56	52
All	36	39	35

Source: Schofield, 1973, p. 450.

Illiteracy at first rose during the early Industrial Revolution and then fell in the first half of the nineteenth century for various modernizing occupations, for husbandmen, as well as for bride grooms generally. This finding is not consistent either with a uniform literacy-using or with a uniform literacy-saving tendency for technical change throughout the Industrial Revolution. It does suggest a possible reversal and rise of literacy-using tendencies in the first half of the nineteenth century. However, it is difficult to point to any specific force leading in that direction. This lack of clear direction is further reinforced by Nicholas and Nicholas (1992) finding of trends in illiteracy the reverse of those reported by Schofield, with illiteracy falling in their sample of transported convicts over the period 1780 to 1810 and then rising from 1810 to 1835.

If one looks beyond literacy to the use of skills more generally, no clear trends are evident over the industrial revolution either within particular industries or across the economy as a whole. In agriculture, the employment of less skilled women and children declined, while the employment of male labourers rose at the expense of small scale farmers (Allen, 1994). In textiles, employment of less skilled women and children was on the rise, but more skilled male occupations were also emerging (Boot 1995; Huberman 1996; Lazonick 1990, Chap.3).

Given the lack of experience of children and adult women's uncertain length of activity in the labor market, increases in the employment of women and children could be regarded as evidence of unskilled-labor-using tendencies in technological change and capital accumulation. This would seem consistent with Goldin and Sokoloff's (1982) finding that early industrialization made extensive use of women and children. Available evidence does indicate extensive employment of women and children in many industries by the end of the Industrial Revolution. In textile factories in 1835, 63 percent of the work force consisted of children aged 8 to 12 and women (Nardinelli, 1990, p.106). Tuttle (1998) has argued that technical change during the Industrial Revolution increased the use of women and children in textiles and mining, thus implying that technical change in these industries was unskilled-labor-using. Women and children were conspicuous in other significant activities such as agriculture and domestic service (Bythell, 1993, pp.35-36). However, available quantitative evidence does not allow one to ascertain the direction of change in the extent of employment of women and children over the course of the Industrial Revolution. Humphries' labeling of aggregate trends in the employment of women over the Industrial Revolution as "the great unknown" thus seems appropriate. Her own assessment of trends in the employment of women is that "perhaps on average, job creation matched job destruction for the first 60 years or so of the Industrial Revolution" (Humphries 1995, p. 98).

General assessments are conflicting as to whether skill levels were rising or falling over the Industrial Revolution. Marx [1887] (1967, Vol.1, pp.422-23) and Thompson (1963, pp.257-62) argue that, overall, skill levels fell; Marx points to the substitution of machinery for skilled labor, Thompson to the repeal in 1814 of the Statute of Apprentices. In contrast, Samuel argues that skilled handicraft occupations grew apace with industrialization and that "nineteenth century capitalism created many more skills than it destroyed," (Samuel, 1977, p.59). Harris (1976, p.182) maintains that the growing number of technologies using coal as an energy source created occupations that comprised "a precarious combination of manipulative skill embodying a physical training and a judgment requiring both experience and intelligence." Given these diverse assessments and the lack of detailed quantitative evidence on the overall occupational composition of the labor force, one can only second Pollard's (1978, p.123) agnosticism regarding trends in skill and state that no uniform tendency towards skill-using or skill-saving technical change or capital-skill complementarity is evident across sectors of the British economy during its Industrial Revolution.

Outward Shifts in the Supply of Unskilled Labor

The aggregate supply curve of labor in England was shifting out in the late eighteenth and early nineteenth centuries due to the growth of population; and connections have been made between aggregate population growth during this period and falling real wage levels (Schofield, 1994, pp.64-66, 78). Furthermore, there has been the long-standing claim that the enclosures lowered the supply price of labor into industry. However, this connection has been challenged on the grounds that labor was not mobile over long distances from rural areas of excess labor supply to manufacturing areas of growing labor demand because of settlement laws restricting migration and more generally because of poorly integrated labor markets (Redford [1926] (1976); Allen, 1992, Chap.12). At any rate, the absence of any clear tendency for production across various industries to move in a skill-saving direction, as just noted above, indicates that an increasing supply of unskilled labor was at best one of a number of influences on the skill levels of the work force.

Compositional Effects

Trends in the demand for educated and skilled labor were influenced by shifts in the composition of the labor force among sectors of the British economy over and above trends within sectors. However, available evidence does not suggest a marked redistribution of the labor force towards occupations relatively high in education and skill requirements.

The limited extent of any increase in demand for educated labor is evident if one focuses on basic literacy, as commonly measured by signature ability. Occupational information from the 1841 census together with information about the use of literacy in specific occupations, allows one to estimate the proportion of the English labor force in occupations requiring literacy (Mitch, 1992a, pp. 14-15). In 1841 only 4.9 percent of male workers and only 2.2 percent of female workers were in occupations in which literacy was strictly required. Insofar as these percentages were no higher during the hundred years before 1841 -- and there is no reason to think that they were -- there was very little scope for a shift into occupations requiring literacy during the Industrial Revolution.[24]

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[24] Addressing this issue is made difficult by the lack of reliable information on occupational distributions for the English labor force before 1841, when the census began collecting relevant data. However, it is reasonably certain that before 1841 only a small percentage of the labor force held occupations that required extensive formal education. Those categories that would require formal education were commerce and trade, large-scale farming -- which involved accounting and staying apace of new agricultural techniques -- and the professions. Lindert and Williamson's reworking of Massie's social tables for 1759 and Colquhoun's for 1802-1803 indicates a decline between those years in the percentage of the English labor force engaged in commerce and trade, agriculture -- excluding farm labor -- and the professions (Crafts, 1985, p. 13). Deane and Cole's estimates of labor force distributions indicate that the percentage of the British labor force engaged in trade and transport between 1801 and 1841 rose by only 2 percentage points, the percentage engaged in public service and professional occupations declined, while the number of farmers changed very little over the nineteenth century (Deane and Cole, 1967, pp. 143-44). In fact,

Ascertaining trends in composition during the Industrial Revolution period is made difficult because of the lack of occupational censuses for this period. However, as already noted, Lindert and Williamson's social tables (1982) exhibit if anything a tendency for an increase in the proportion of the labor force in unskilled occupations between 1759 and 1801-3. Moreover, the 1841 and 1851 occupational censuses for England and Wales indicate that about one fourth of the male labor force were in agricultural or general labouring occupations, a proportion considerably higher than the 16 percent estimated as labourers in 1759 and 1801-3 by Lindert and Williamson (1982).[25]

Supply Elasticities of Education and Skill

Williamson (1985) has argued that inelastic supply curves of skilled labor during the Industrial Revolution led to surging wage premiums for skilled labor in the first half of the nineteenth century. He explains this by labor market segmentation between skilled and unskilled labor in the manufacturing sector (Williamson 1985; also see the discussion in Jackson, 1987, pp.569-570). However, the only evidence he offers for an inelastic supply of skill is an estimated rising skill premium based on aggregate wage data, an estimate which has been disputed, as will be explained in further detail below (see Feinstein, 1988; Jackson, 1987). Thus, the question of how inelastic was the supply of skilled labor deserves further consideration.

It is implausible that there was an inelastic supply curve of literate workers. As already noted, most accounts of manufacturing employment practices during the Industrial Revolution indicate that for the most part no account was taken of whether a worker could read or write. Hence many literate workers did not command a premium for that particular skill. Although some time must be allowed for adequate investment flows in human capital to accumulate so that there would

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there has been some debate over trends in land ownership and numbers of farmers over the late eighteenth and early nineteenth centuries. Clapham (1930, pp. 98-105) suggests that the number of small farmers declined but warns against overstating this decline. Mingay (1963, pp. 94-99) suggests that the number of farmers dropped, which is consistent with Lindert's estimates for the later eighteenth century. Ashton and Clapham, to be sure, suggest that the number and role of middlemen expanded during the eighteenth century (Ashton, 1955, pp. 66-67; Clapham, 1930, chap. VI). But in sum, although there is much uncertainty surrounding changes in the occupational distribution, available evidence does not suggest that the overall demand for educated labor increased and there may have been a shift away from sectors that required educated workers.

[25]The proportion of the male labor force who were laborers in the 1841 and 1851 censuses is calculated from the census figures tabulated in W.A.Armstrong, 1972.

have been lags in increasing the stock of literate workers, these lags need not have been long. Three years were enough time to allow even an adult worker to acquire basic literacy skills. One can estimate the direct cost of the requisite instruction from unsubsidized private sources at about 2 pounds and the opportunity cost as about 7 pounds. Thus, one can place the total cost as not having to be more than about 10 pounds. In comparison, if literacy provided a 1 shilling per week wage premium, which is approximately 7 percent of a 14 shilling per week working class wage, then with 20 years of working life at a five percent discount rate, the present value would be just over 30 pounds. In other words, a noticable labor market premium to literacy was likely to generate an expected present value sufficient to justify the cost of acquiring literacy.

Furthermore, there is ample evidence of a quite elastic supply of schooling by the private schooling market. It was a common practice for women to set up schools in their homes as a source of casual income (Gardner 1984). Both contemporaries and subsequent historians have dismissed such operations as primarily child-minding services (Hurt, 1971). But Gardner (1984) has offered evidence that such schools were responsive to parental demands for literacy instruction. If further literacy instruction was demanded on account of labor market demands, there is every reason to think that these dame schools, as they were called, could have supplied it.

However, in considering skills acquired through work place experience, it was already noted above that in mining and textile spinning, ten or more years or experience could be expected for skills to fully develop. Flinn (1984, pp.340-361, 386-395) argues that the lengthy period of training beginning at relatively young ages did imply an upward sloping supply curve of hewers as the coal industry expanded during the Industrial Revolution and that wages for coal miners thus rose. However, Church (1986, p.233) estimates that between 1831 and 1861 about 30 percent of the coal industry's new recruits came from adults originally engaged in occupations other than mining, and finds no evidence that aggregate wage movements in the coal industry rose because of upward sloping labor supply despite a rising demand for labor over this period (Church 1986, p.233, 753, 756). In cotton spinning, Huberman estimates that although initially there was heavy reliance on female labor, between 1811 and 1830, the number of male cotton spinners doubled in Lancashire (Huberman 1996, p.36-37). He also argues that the number of spinner slots was small enough relative to the numbers of children and young people who would have been acquiring experience in supporting tasks, that even though expanding, recruitment could have been done solely through internal recruitment. For every spinner, there were two or three younger piecers accumulating experience that would eventually permit replacement and expansion.

Over the long term both cotton spinning and coal mining do seem to have been able to recruit sizable amounts of additional skilled male workers (see Huberman 1996; Flinn 1984). One study of intergenerational occupational recruitment based on a national sample of marriages indicates that almost half of those reporting skilled textile occupations in the 1840's had fathers in non-textile occupations (Mitch 1987). In the same sample, however, 75 percent of miners had fathers who were miners, confirming the high rates of occupational self-recruitment often thought typical in mining but by the 1870's rates of occupational self-recruitment had fallen to 40 percent for miners, supporting Church's view of extensive external adult recruitment into mining (Church 1986, pp.224-234). Thus, the available evidence contradicts Williamson's view of an inelastic supply of skilled labor during the Industrial Revolution.

Trends in Skill Premiums?

Williamson (1985) proceeds to resolve the overall balance between supply and demand shifts and their elasticities by considering wage differentials between skilled and unskilled labor. But the evidence as to whether there was a rising skill premium during the Industrial Revolution is conflicting and controversial. Williamson has argued that the evidence points to a rising skill premium over the first half of the nineteenth century and has suggested that this reflects a demand curve for skilled labor shifting to the right because of skill-intensive technical change along an inelastic supply of skills. However, Williamson's finding of a rising skill premium in the first half of the nineteenth century has been criticized on the grounds that it results to a large extent from inclusion in the skill category of rather suspect, unrepresentative income figures for government employed attorneys, doctors and other professionals (see Jackson, 1987; Feinstein, 1988).

As Jackson (1987) has pointed out, wage series constructed to exclude these suspect figures indicate a much less pronounced rise in skill premia, and if the focus is shifted from economy wide skill premia to manufacturing, no upward trend is evident between 1815 and 1851. Trends prior to 1815 are difficult to assess because of the uncertainty as to what weights to give wages in particular occupations, but Williamson's own figures indicate falling skill premia between 1781 and 1815, in the middle of the Industrial Revolution (Williamson 1982b). Williamson attributes this to the disruption due to the Napoleonic wars. However, the point remains that skill premiums would not seem to have been subject to any dominant upward force over this period. Indeed, as Feinstein (1988), Jackson (1987), and McKinnon (1985) have pointed out, the wages in component occupations frequently moved in different directions, making the resulting aggregate skill ratios sensitive to the weightings used.

Some of these points are evident in Table 5.2 which make a few further revisions to the adjustments in Williamson's skill ratios already considered by Jackson. First, mining is excluded from the group of unskilled occupations. Flinn's (1984) account calls into question whether mining should be regarded as unskilled and the relative pay standing of miners changes considerably over this period in Williamson's own

TABLE 5.2 Skilled Wage Premiums

Date	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
1755	1.89	1.92	1.45	1.47	1.80	1.83
1781	1.73	1.77	1.26	1.29	1.88	1.92
1797	1.30	1.30	1.13	1.13	1.89	1.89
1805	1.33	1.31	1.21	1.18	1.66	1.63
1810	1.33	1.31	1.16	1.19	1.56	1.60
1815	1.49	1.59	1.23	1.32	1.47	1.58
1819	1.43	1.58	1.18	1.31	1.44	1.60
1827	1.65	1.76	1.15	1.23	1.40	1.49
1835	1.65	1.72	1.21	1.26	1.54	1.61
1851	1.66	1.78	1.14	1.21	1.38	1.47

Definition of Columns: (1): Ratio of average wages in skilled occupations, classifying mining as a skilled occupation. Williamson's categories 2H through 6H are included plus his category 6L (mining) to average wages in unskilled occupations, including agricultural laborers as unskilled (Williamson's categories 1L to 5L). (2): Ratio of average wages in skilled occupations, *excluding* mining as a skilled occupation. (3): Ratio of average wages in skilled occupations, *including* mining, to unskilled wages *excluding* agriculture (4): Ratio of average skilled wages *excluding* mining, to unskilled wages *excluding* agriculture. (5): Ratio of average wages in skilled occupations, *including* mining, to wages of unskilled labor (Williamson's category 2L only). (6): Ratio of average skilled wages *excluding* mining, to unskilled labor (Williamson's category 2L only).

Note: The average wage is determined for each of the above, by weighting the wage reported by Williamson for a given category by its share of the total number of all workers for the categories included for a given variable, using Williamson's estimates of the number of workers for each category.

Source: Based on the wage series reported in Williamson (1982b).

numbers. Second, adjustments for nonagricultural unskilled are made by excluding Williamson's government non-agricultural unskilled-- messengers, porters, and police (his categories 3L to 5L.) In other words only his category 2L is included. The argument for these adjustments is that frequently over the period 1781 to 1851, wages in "low pay" categories 3L through 6L were as high or higher than in a number of Williamson's skilled category.

The first four skilled to unskilled wage ratios in Table 5.2 decline from 1755 to 1797, then remain more or less level from 1797 to 1810. Only the first two wage ratios show a clearly rising trend from 1810 to 1850 and they still do not reach the original 1755 level. The last two wage ratios (in columns 5 and 6), rise slightly from 1755 to 1797, then decline to 1810 and exhibit no clear upward or downward trend thereafter. Thus, these ratios do not support the presence of a uniform widening premium to skill over the Industrial Revolution period. There was no clear shift in demand towards more human capital intensive activities. Insofar as there was a shift out in demand for more skilled workers it would appear that the labor market was able to supply suitably qualified workers. In sum, the evidence reviewed here would seem consistent with the traditional emphasis on the demand side rather than the supply side as to why education and skill development were not central to the English Industrial Revolution.

Indirect Contributions of Human Capital

Recent discussions of the contribution of education to economic growth have considered more indirect routes of influence than that of direct improvement of labor force quality. As already noted above, Crafts (1995a) has found such indirect influences more promising for explaining the British Industrial Revolution than simply broadening capital stock measures to include human capital.

Human Capital and Technological Advance

One major line of inquiry has concerned influences on the rate of technological advance. Despite England's resources at the university level, it has been argued that technological advance during the British Industrial Revolution was primarily due to practical experience by men of little or no formal scientific training (Landes 1969; Berman 1972; Hall 1974).

However, if formal education and institutionally sponsored research activity had a limited impact on rates of technological advance, human capital in the form of more informal communication and learning networks may have been quite significant (see Young, 1993; Allen, 1983; Saxenian 1991). In applying recently developed models of endogenous innovation, Crafts has suggested that "it may be that British innovation and growth relied on superior learning capabilities triggered by technological shocks..." (Crafts, 1995a, p.766). One can point to evidence of informal learning communities in Britain during the Industrial Revolution and to their role in the diffusion of innovation. Thus, MacDonald (1979) points to the role of informal contacts in the spread of agricultural innovation. Moreover, there appears to have been an ongoing process of improvement and and learning by doing in cotton textile manufactures (see Hills 1979; Lazonick 1990, Chap. 3). Thackray (1974) has argued that there was a well-developed cultural, technical and scientific community in the major cotton-textile producing city of Manchester during the Industrial Revolution. Learning by doing seems to have been important in the development of mining practice (MacLeod 1988, pp.100-102; Flinn 1984, pp.57-68, Chaps. 3 and 4).

What could have facilitated the development of learning networks? Epstein (1998) argues that guilds performed this function in preindustrial Europe. Factors facilitating contact and ongoing communication between practitioners clearly were involved. Urbanization could have been one such factor as suggested by Jacobs (1961; 1984). However, as already noted, effective learning networks also seem to have developed in rural areas (MacDonald 1979). Jacobs (1961; 1984) also argues that learning networks are facilitated by relative openness and tolerance to outsiders and foreigners, which enhances receptiveness to new ideas. Inkster (1991, pp.43-45) argues that England had an advantage over France in this regard through having a more spontaneous and less bureaucratic development of intellectual networks. In Mokyr's terms, the enhanced state of informal learning networks in eighteenth and early nineteenth century Britain may have given it a comparative advantage in microinventions and this may have constituted one important indirect means by which human capital influenced the British Industrial Revolution (Mokyr, 1990a; Crafts, 1995a, p.765).

Socializing Effects

Numerous scholars have argued that education's role has been primarily in shaping behaviors, attitudes, and values (Bowles and Gintis, 1976; Easterlin, 1981, p. 9); that is, in socialization, and this aspect of education has been emphasized in the educational history of Britain over the last thirty years. Discussions of socializing effects of education have considered three different types: (1) education as a means of instilling work discipline; (2) education as a means of preventing working-class crime, strikes, and rebellions; and (3) education as a tool for the middle- and upper-classes in imposing cultural hegemony and in counteracting working-class resistance in the struggle for power between social classes.

It is unlikely that formal schooling contributed to the development of a disciplined factory work force or that a growing demand for disciplined factory workers played a major role in the rise of mass education in England. Clark (1994) has argued that English factory overseers during the Industrial Revolution were able to impose discipline on their workers, if the workers received a sufficient wage premium for the extra effort implied by such discipline. Formal education receives only passing mention in accounts of how factories obtained disciplined workers in the early Industrial Revolution (Pollard, 1963, pp. 268-69; McKendrick, 1961, p. 55). Indeed, Sanderson's findings, cited above, point to the relatively low levels of formal education, as evidenced by literacy skills, among Lancashire textile workers; and investigators for the Newcastle Commission in the late 1850s also noted the low levels of formal education among textile workers, miners, and metalworkers in the midlands (Parliamentary Papers, 1861, p. 249). It is significant that both weekday school enrollment rates and local funding for subsidizing weekday elementary schools were relatively low in industrial districts through the first half of the nineteenth century (Mitch, 1992, pp. 118, 121-22; Marsden, 1987).[26] Whether the rise of Methodism influenced factory work-habits and whether 'Methodism controlled or was controlled by the working classes' has been extensively debated without a clear resolution (Thompson, 1963; Malmgreen, 1985, p.178). Although a significant share of those attending Methodist churches were drawn from the working classes, by the end of the industrial revolution the overwhelming preponderance of the working classes appear to have had little involvement with formal religion (Gilbert, 1976, pp.47-48; Koditschek, 1990, Chap.10). Some middle class reformers clearly did perceive that by educating the working classes, the incidence of crime, strikes, and riots would decline. Investigators for local statistical societies, such as Joseph Fletcher, seemed almost obsessed with establishing that ignorance was a major cause of working-class crime (Cullen, 1975, pp. 142-44). A serious riot in Wales precipitated a major parliamentary investigation into educational conditions in Wales in 1847 (Parliamentary Papers, 1847). Following a miners' strike in 1844, according to Colls, mine owners in Northumberland and Durham established schools in their miners' villages (Colls, 1976; 1981). Johnson (1976), among others, has noted that

[26] Field (1979) and Quick (1974) have suggested that Sunday schools may have been the main agencies for conveying moral training in industrial areas while providing little in the way of literacy instruction. But neither they nor anyone else has demonstrated that Sunday school training alone had a significant impact on the work habits of the industrial workforce or that the desire to influence these work habits was a major force behind the Sunday school movement. The willingness of textile factory owners to provide schooling for their child employees in the first third of the nineteenth century appears to have varied considerably, with owners of larger factories being more likely to provide schools. See Sanderson (1967).

the government began to provide elementary education in the 1830s and 1840s, just as working-class revolutionary movements, such as Chartism, were reaching their peak. The notion that working-class education could serve as a form of "moral police" recurred among its advocates (Field, 1979; Johnson, 1970; 1976; Quick, 1974). However, not only is the effectiveness of mass schooling as a form of moral police open to doubt, but one must also explain why working-class parents began to send, and pay to send, their children to schools designed primarily for this purpose (Quick, 1974, p. 192).

At a more general level, it has been argued that mass education was used by the middle- and upper-classes as a way of coping with class conflict and counteracting working-class efforts to overthrow the existing order (Bowles and Gintis, 1976; Johnson, 1976; Quick, 1974). However, the notion of education as "social control" probably oversimplifies the reasons for upper- and middle-class support for education, neglects the possibility of working-class resistance to education provided for this purpose, and oversimplifies the nature of class conflict (Heesom, 1981; Duffy, 1981; Stedman Jones, 1977; Marcham, 1978; Silver, 1977).

Despite these reservations about these three particular channels through which schooling influenced working-class behavior, the more general proposition that schooling has had an important influence in shaping behaviors, attitudes and values remains plausible and would seem to reflect the perceptions of those who mobilized support for increased provision of working-class schooling from government and philanthropic sources (Vincent 1989). But establishing the nature of that influence or its economic consequences remains elusive.

The Allocation of Talent

The effects of human capital may be indirect in that what may be of more importance is not the extent of the human capital stock but how that human capital stock is allocated across various activities in an economy. One important application of this principle has been with respect to the pursuits of the most talented in an economy. Murphy et al (1991) and Baumol (1990) have recently argued that an economy's growth prospects may depend on the incentives the most able in an economy find to allocate their talents towards productive, inventive or entrepreneurial activity compared with unproductive rent-seeking activity. If the highest rewards in an economy go to rent-seeking, then the best talent is diverted away from productive growth enhancing activity and growth rates are reduced. Indeed Baumol has noted that talent can be diverted into outright destructive activity.

One common application of this model to the British case is based on the Murphy et al (1991) observation that when rent-seeking is the highest return activity for talent and there are barriers to some minority group in entering the rent-seeking activity, then the barrier by diverting the most talented members of the minority to the productive activity can help correct for the superior returns to rent-seeking. In the case of the British Industrial Revolution, this has taken the form of observing that prominent industrialists and inventors during the Industrial Revolution seem to have come disproportionately from dissenting religious sects. This observation, insofar as it is true, has often been explained by distinctive features of protestant theology or on implied attitudes that would have resulted from a dissenting religious upbringing. But the explanation most in keeping with the allocation of talent model of Murphy et al and Baumol is one offered by Ashton (1948, p.15), namely "that the exclusion of Dissenters from the universities, and from office in government and administration, forced many to seek an outlet for their abilities in industry and trade."

Hagen (1962) found quantitative support for the view that innovators in English manufacturing during Industrial Revolution came disproportionately from Nonconformist sects. However, Rubinstein (1981) has questioned the representativeness of Hagen's sample, which consisted of 92 names associated with innovation listed in Ashton's book. Rubinstein finds based on his own study of British who were wealthy at death, that the proportion who were of various religious affiliations was roughly in line with the proportions of these affiliations in the overall population with the notable exception of disproportionate numbers of Jews among British millionaires. He does find that among those who earned their wealth in manufacturing, that disproportionate numbers were Nonconformists; however he argues that British prosperity in the nineteenth century was based more on finance and commerce than on industry. Thus, Rubinstein's analysis points to the two problems of establishing a representative sample of entrepreneurs for purposes of examining their characteristics and of how in a specific historical setting one distinguishes between productive and unproductive uses of talent.

The basic premise that rent-seeking opportunities obtained via a university education and other paths not open to nonconformists offered greater rewards than those in trade and manufacturing in fact appears questionable. Gregory King's estimates in the 1690's indicate that a lawyer would make on average £154 per annum and a clergyman £72 compared with the £400 earned by an overseas merchant. In 1803, the differential advantage may have widened, with Colquhoun reporting that while a lawyer would make £350 and a superior clergyman £600, a leading merchant or baker would earn £2600 and a master manufacturer £800 (cited in Corfield, 1995, p.234).

The English advantage may have been in small relative rewards to rent-seeking activities compared with continental countries, most notably France (see Crafts

1995a). The number of civil litigation cases in England fell markedly in the first half of the eighteenth century and rose only modestly in the last half of the century. Far less legal activity was required to resolve transactional disputes in commercial and industrial activity than in landed society (Brooks, 1989). Assessments of the French situation have noted an excessive expansion of law and related place-seeking activity (see for example, Root, 1994 and Berlanstein, 1981). However, Berlanstein's assessment is that by the time of the French Revolution, the marginal returns to such activities had been dissipated and that incomes of lawyers were no better than artisans. More generally, O'Boyle (1970) has documented the general perception of an excess supply of educated men throughout Western Europe (including England, France, and Germany) in the first half of the nineteenth century, while continuing to second the common assessment of a disproportionate allocation of more abler people to rent-seeking activity in France. This may reflect Smith's ([1776] 1976, Bk I, Chap.10) principle of the overweening conceit people place in their own abilities in the willingness to pursue a small chance of a large gain. Although one source of British success may have lain in relatively lower rewards to rent-seeking compared with France and other European countries, further examination of this possibility requires distinguishing between marginal returns to place-seeking, apparently small in most areas of Europe by the mid-nineteenth century, as suggested by O'Boyle (1970), and the extent of infra-marginal allocation of talent to these activities, which allegedly was greater in France than elsewhere and hence a more considerable impediment to growth. Simple measures such as the ratio of lawyers to the labor force or population are probably not sufficient to capture the types of place seeking possible and as Berlanstein (1981) notes, in the absence of professional associations and censuses are difficult to estimate for this time period. Furthermore, classifying activities as productive or unproductive is in practice problematic. For example, mercantile or manufacturing activity that might prima facie be considered as productive compared with law may entail substantial elements of rent-seeking in establishing monopoly privileges and protective tariffs (see for example Root (1994) for the case of merchants in France). On the other hand, legal activity may have productive value in lowering transaction costs. What may be most relevant is how the external effects of innovation and entrepreneurship differed among various activities which leads us back to the indirect effects considered above under the role of human capital in technical change.

Women's Human Capital and Domestic Skills

Signature rates for brides rose in Schofield's (1973) sample from about 40 percent in 1760 to about 50 percent in 1840, while groom's signature rates remained stagnant at about 60 percent throughout the same period. The direct contribution of rising female literacy to improving the quality of the labor force during the Industrial Revolution was probably considerably dampened by low rates of female labor force participation (Mitch 1984). Although as already noted, quantitative evidence is lacking on trends over this period in female labor force participation, by the end of the period, it was below 50 percent. If Humphries' (1995) assessment is valid, it would not have risen much above that level throughout the Industrial Revolution. However, this neglects the contribution of rising literacy to enhancing women's productivity in household activities (Edelstein, 1984, p.602). That this contribution could have been important is suggested by studies of developing countries in the late twentieth century which have consistently found substantial negative associations between women's educational levels and rates of infant and child mortality (Schultz 1993). However, Preston (1985) finds that the association between maternal education and child mortality was far weaker prior to the twentieth century and attributes this to the lack of expert medical knowledge that education could usefully transmit in earlier times. Although infant and child mortality do appear to have fallen over the Industrial Revolution, rising female literacy is not among the numerous factors that Wrigley et al (1997, pp.214-261) consider that might have contributed to this fall.

Instead the issue that has been raised in the historiography of women's experience during the Industrial Revolution is whether women's factory work, especially during childhood and adolescence led to a deterioration of domestic skills. This issue surfaced in contemporary industrial fiction. Thus, Elizabeth Gaskell ([1848] 1970) has the character Mrs. Wilson in her novel *Mary Barton*, about life in a Lancashire factory town, say about her preparation for domestic life:

> If you'll believe me, Mary, there never was such a born goose at house-keeping as I were, and yet he married me. I had been in the factory sin' five years old a'most, and I knew nought about cleaning or cooking, let alone washingand such-like Work.

She goes on to describe how she ruined the first dinner she cooked for her husband. Parliamentary investigators into the employment of women seconded Mrs. Wilson's view regarding the adverse effects of industrial employment on women's domestic skills (for a survey see Hewitt (1958), pp.72-75). While Hewitt (1958) argues that working-class domestic skills in Britain at this time were generally poor, in rural areas as much as in manufacturing centers, she also cites (p. 74) working girls and women from industrial areas who maintained that despite long hours of factory work, they had sufficient opportunity to practise domestic tasks. Humphries (1981), too, argues that claims by Parliamentary investigators of inadequate domestic skills by working females reflect class biases with respect to the gendered division of labor. To argue that domestic skills remained completely undeveloped in industrial areas considerably underestimates the adaptive abilities of working-class women. Such adaptations should be recognized as a form of human capital.[27]

However, it is of interest to note that Roberts (1984, pp.158-161) in her comparison of women in the three Lancashire towns of Barrow, Lancaster, and Preston in the early twentieth century, found that in Preston, with married labor force participation rates for women far higher than in the other two towns, women put far less effort into meal preparation. Preston also had a much higher ratio of fish and chip shops and convenience meal sellers than the other two towns. Based on oral interviews, Roberts also finds that this tendency persisted for Preston women even after they left factory employment to spend full-time at home. Projecting these tendencies back to the early nineteenth century is admittedly speculative. However, they are suggestive of the indirect role that human capital may have played and the informal routes by which it was developed during the Industrial Revolution, as women drew on both previous domestic traditions and further intelligence and judgment in adapting them to the new domestic circumstances associated with industrialization.

It is perhaps not surprising that none of the indirect routes of influence considered in this section can clearly be established as important causal factors contributing to the Industrial Revolution. Nevertheless, the possible influence of the establishment of learning networks on diffusion of new technology and the adaptive way in which domestic skills were probably developed suggest that these indirect effects may have been important. Thus, one can second Crafts' (1995a) suggestion that indirect effects of human capital deserve further scrutiny, even if evidence on these effects is not likely to come easily.

What Lessons Does the British Case Offer for How Human Capital Contributes to Economic Growth?

Insofar as studies of growth in more recent times indicate that education is a significant positive determinant of growth rates (see Barro and Sala-i-Martin 1995), the question arises of why education seems to have featured so less prominently in the case of the British Industrial Revolution than more recently. Several possibilities come to mind.

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[27] For a survey of the changes in housework associated with the Industrial Revolution and of women's adaptation to these changes see Davidson, 1982, pp.201-206.

One obvious role for education is in facilitating technological transfer as part of a more general process of convergence towards best practice. Barro and Sala-I-Martin (1995) report findings from cross-country regressions for the late twentieth century that countries with higher levels of education experience faster rates of convergence. Insofar as Britain in the late eighteenth century was a technological leader, however, in the sectors making the most important contributions to economic growth, there would be little role for education to play in facilitating British convergence.

Britain had also become distinctive in the organization of its agriculture by the mid-eighteenth century, with production decisions largely concentrated in labor-employing farmers rather than dispersed more widely in a peasantry farming smaller plots of land. Its agricultural sector had already become relatively small by the time of the Industrial Revolution. Thus, decision making may have become far more centralized in the British agricultural work force than it was to remain across much of Europe and America well into the nineteenth century. Hence the spread of popular education was of far less economic consequence in England than elsewhere.

The role of education itself in production may well have changed since the mid-nineteenth century. Technological change has become increasingly science-based. The development of newer mass production methods have led to far greater capital-skill complementarity (Goldin and Katz 1996). Furthermore, the effect of changes in the role of skill and education in production may have been amplified by increased specialization with increased integration of the international economy. The British Industrial Revolution may have occurred at a relatively early stage in the development of comparative advantage patterns in which skill later came to play an increasingly prominent role in determining specialization patterns. Wood and Ridao-Cano (1996) have developed a model in which increasing openness to trade can widen the premium to skill across countries and hence widen differences in skill levels. At the time of the Industrial Revolution, Britain may have been close to the international mean in skill levels. By the end of the nineteenth century this may have changed leading to increasing specialization in relatively unskilled activities (Crafts and Thomas, 1986). In contrast, the ability of the economies of South Korea and Taiwan to shift their exports towards more skill-intensive products such as consumer electronics in the 1960's and 1970's has been attributed to the relatively high educational attainment of their workforces which may reflect the increased importance since the mid-nineteenth century in the role of skill in determining comparative advantage patterns (Amsden 1989; Kwack 1990, p.113; Lau 1990, p.242; Vogel 1991, pp.20-22, 48).

One theme that seems to underlie all of these perspectives is the pervasiveness of substitution and the presence of a variety of feasible strategies for increasing rates of economic growth. This, in turn, harks back to two key themes of this survey. First, education was not indispensable to economic growth during England's Industrial Revolution, although it surely did make a positive contribution. Second, numerous forms of informal instruction served as alternatives to formal education. Thus, the first Industrial Revolution provides evidence that, at least under some circumstances, other factors of production can substitute for an educated labor force. More generally, the limited role of human capital in the British Industrial Revolution compared to the role it appears to have played subsequently supports the proposition that there was more than one path to attaining rapid economic growth.

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About the Book

The Industrial Revolution remains a defining moment in the economic history of the modern world. But what kind and how much a revolution was it really? Why did it take place when and where it did, and how did it lead to modern economic growth? These are just a few of the questions that economic historians continue to debate. In this volume, a group of distinguished scholars present the most up-to-date findings and defend their latest views on essential aspects of the Industrial Revolution. The editor's introduction is a major survey and evaluation of contemporary research in the field.

This second edition of a widely praised and read collection remains essential for economic historians and indeed for historians of Great Britain and economists with an interest of economic change in the past.

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