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The industrial revolution 1780–1860: a survey

The quiet revolution and its historians

In the eighty years or so after 1780 the population of Britain nearly tripled, the towns of Liverpool and Manchester became gigantic cities, the average income of the population more than doubled, the share of farming fell from just under half to just under one-fifth of the nation's output, and the making of textiles and iron moved into the steam-driven factories. So strange were these events that before they happened they were not anticipated, and while they were happening they were not comprehended. In 1700 a percipient observer of Britain looking towards 1780 might have anticipated its enlarged foreign trade and more active workshops (as, in fact, Daniel Defoe had); in 1860 he might have anticipated the competition of new industrial nations or the application of science to factory and farm during the half-century to come, and by 1900 he would at least have comprehended these events happening (as, in fact, the economist Alfred Marshall and others did). Yet in 1776 Adam Smith predicted a Britain of merchants, farmers, and artificers increasing their incomes at a moderate pace through specialisation and trade (after which national income increased in eight decades by a factor of nearly seven); in 1817 David Ricardo predicted that landlords would swallow whatever the increase would bring (after which rents as a share of national income fell, 1801 to 1861, from about 17 per cent to about 8½ per cent); and in 1848 Karl Marx, in the midst of economic events belying his prediction, predicted that monopoly capital would swallow all (after which the share of labour in income rose, and the real wages of the exploited classes increased in ten or fifteen years by some fifteen per cent and in fifty years by eighty per cent). The British economy from 1780 to 1860 was unpredictable because it was novel, not to say bizarre.

By analogy with the political revolution in France in the 1790s the transformation of economic life in Britain was called, after it had happened, an 'industrial revolution', although its impact on the way people lived was greater, if slower, than most political revolutions. True, its immediate impact on culture or politics was slight. Althought some novelists – sociologists before sociology – depicted industrial characters, poets and painters locked their gaze on mountains and marigolds, the odd satanic mill aside. A contemporaneous but otherwise unrelated rationalisation of methods of government had perhaps as much impact on the Reform Bil of 1832 or the crumbling of mercantilist restrictions culminating in the repeal of the Corn Laws in 1846 as did the new economic power of Manchester. Landed wealth bought members and membership of Parliament and staffed its governments until well after commercial and manufacturing wealth had come to exceed land in economic weight. From the introduction of a liberal dole for agricultural workers in the revolutionary year of 1795 to the panic of the 'last labourers' revolt' in 1830 the agricultural poor and their revolutionary potential exercised the thoughts of ministers and militia officers well after factory hands had outnumbered farm hands.

Yet, for all that, the industrial revolution was the central event of modern history, British of other, more in memory than in happening. The British example of the early nineteenth century inspired frantic emulation in the late nineteenth century, and myths of how Britain did it influence economic policy to this day. 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. The ghosts of grasping capitalists, expropriated small farmers, and exploited factory workers still haunt economics and politics.

The economic transformation of Britain from 1780 to 1860, then, is strange and important. Although explaining it has been the preoccupation of a battalion of scholars for a century or more, they have so far had only partial success. The history was not a simple experiment. The growth of cities, the increase in population, the rise in national income per head, and the shift from farm to factory happened together, were in some ways connected, but were not connected by mutual necessity. Britain could have industrialised without expanding her population or urbanised without enriching herself. Yet in fact she did all these things at once, confounding the effects of one with the effects of the other. Nor was the experiment controlled. Britain fought, for example, an expensive war against Napoleon in the middle of the period, and her governments, reacting to this and other vicissitudes, repeatedly altered the import duties, monetary arrangements, taxes, and regulations of economic life. The evidence of the experiment is elusive. The evidence is there, waiting to be mined from archives in large quantities, but the proportion of miners to consumers of this intellectual ore has been low. Oddly, much of the quantitative evidence of Britain's industrialisation has been uncovered by foreign scholars. Until Deane and Cole produced their pathbreaking estimates of national income for the period (Deane 1955, 1957a, 1961; Deane and Cole 1967), the statistics of industrial output (Hoffmann 1955), the balance of payments (Imlah 1958), foreign trade (Schlöte 1952), prices (Rousseaux 1938), and the business cycle

(Gayer, Rostow, and Schwartz 1953a), were imports to Britain. The evidence has sometimes been mishandled by accumulating data in favour of an interpretation rather than searching for data that might put the interpretation in jeopardy, a choice of method to be expected in the history of a period so charged with political passion. Finally, and most important, the interpretations of the evidence have been armoured against testing by clothing them in metaphors and abstraction, conveying the impression of understanding without its substance. Some of these metaphorical abstractions are merely vacuous, such as 'the process of industrialisation' or 'primary growth sector'; some are short-cuts to unwarranted conclusions, such as the assertion that the British people 'depended' on foreign trade or that foreign trade was 'an engine of growth'; and some, such as W. W. Rostow's famous assertion (1960) that Britain in this period experienced a 'take-off into self-sustained growth' summarise a grand if empty theory with the merit, at least, of stimulating controversy but the demerit of turning the controversy off the trail.

More and richer people

The cure for excess in metaphor is counting:

Boswell: Sir Alexander Dick tells me, that he remembers having a thousand people in a year to dine at his house...
Johnson: That, Sir, is about three a day.
Boswell: How your statement lessens the idea.
Johnson: That, Sir, is the good of counting. It brings everything to a certainty, which before floated in the mind indefinitely.
(Boswell's *Life of Johnson* (Everyman edition, London, 1949), vol. II, p. 456)

The most important count, made difficult by the absence of a census until 1801, is of heads. For all the difficulty it is plain that from 1780 to 1860 the population increased to an astonishing and unprecedented degree, increasing in England and Wales by about $1\frac{1}{4}$ per cent per year, with a rising rate in the first half of the period and a falling rate in the second. One and a quarter per cent per year does not sound large, but it was in fact near the highest in Europe at the time and among the highest rates of growth observed in settled communities before the twentieth century. Like Johnson's calculation, the percentage lessens the idea: the result was that for each Englishman in 1780 there were in 1860 2.7; for each in 1760 there were 3.0.

The histories surrounding this statistic are rich. Population grows when births exceed the total of deaths and emigrations, posing the question of which one changed and why. From what statistics have been gathered so far it would appear that from 1780 to 1860 the main change in the nation as a whole was a fall in the death rate (but see chapter 2 above). Whether and why this was so is still uncertain, because the work of recording births and deaths was not taken over by the state from the Church of England until 1838, well after nonconformity and a deterioration in the quality of parish registers had introduced biases into the figures. In any case, as T. H. Marshall remarked fifty years ago, 'a horizontal line on a graph may be as dynamic as a diagonal; the forces that prevent a birth-rate from falling may be as significant as those that make it rise' (1929: 107). What one believes must be explained depends on what one expects, a point that recurs many times in this book. What one expects is altered if British population is viewed from other countries at the time rather than from Britain earlier, for the growth of population was great elsewhere in Europe as well. Until the famine of the 1840s, for example, it was great in Ireland: in 1801 a hostile Catholic island off the coast of Britain had a population over a third of the new United Kingdom; in 1861 it was just over a fifth and, as O'Briens and O'Connors had fewer children and sent large numbers of them to New York, Liverpool and Glasgow, the proportion was falling rapidly.

The cities grew faster than other places, the choice of explanation for this depending once again on what one has come to expect. The arithmetical reasons for the relative growth of cities were, of course, continued migration from the countryside and, less obviously, a fall in the urban death rate that by around 1800 (judging from the statistics for London) allowed cities for the first time to grow more people then they killed. London was by far the largest city, as always, but grew slower than the rest. In 1801 one in seven Englishmen lived in cities larger than 50000 people, and three-quarters of these were Londoners: in 1860 over one in four did, and less than half were Londoners. The list of cities growing fastest – Liverpool, Manchester, Birmingham, Leeds, and Sheffield among the largest ones in 1861; Bradford, Salford, Oldham, Preston and Wolverhampton among the second rank – tells its own story, of the population in the four most industrial counties (the West Riding of Yorkshire, Staffordshire, Warwickshire, and – above all – Lancashire) increasing from 17 pre cent of the population in 1781 to 26 per cent in 1861 (Deane and Cole 1967: 103, column for 1781; Mitchell and Deane 1962: 22).

The increase and redistribution of the population was accompanied by its enrichment, contrary to all reasonable expectations: this is the conclusion of the second piece of counting, the counting of national income. The work of Deane and Cole and others implies that the amounts of bread, beer, trousers, shoes, trips to London, warmth in winter, and protection against conquest increased from £11 per head in 1780 to £28 in 1860 (Feinstein 1978: 84, col. 5; Deane and Cole 1967: 78, last column). This is a real increase, no monetary trick: the money income is measured in the prices of one time (the decade of the 1850s here). Because he produced two and a half times more than his great grandfather produced in 1780, the average person in 1860 could buy and use two and a half times more goods and services. If the wheat grown per farm hand or houses cleaned per maid did not increase by two and a half times (they did not) the output of cotton yarn per spinner or tons of freight shipped per sailor would increase by more than two and a half times (they did). The average worker was a great deal more productive than he had been before.

The halving of the population in fourteenth-century England had increased income per worker by a third; in the other direction the doubling of the population in sixteenth-century England had halved income per worker. The expectation warranted by the experience of earlier centuries, then, would have been a fall, not a rise, in income per head after 1780 as the number of heads increased, an expectation confirmed by economic reasoning. The reasoning is not that a fixed income of the nation was in 1860 to be divided among nearly three times more people than it had been in 1780. Pleasing as such arithmetic may seem, it is incorrect, for it involves the elementary (if common) fallacy of supposing that a nation's output is unrelated to the number of people producing it. The correct reasoning, embodied in the dismal predictions by Ricardo and Malthus of the immiseration to come, is that more people produce more (not the same amount, as in the arithmetical reasoning), but less in proportion to their increase if the tools and land they work with do not increase as well. This proposition is known as the law of diminishing returns: growth bumps against inputs that are not reproducible.

Land, in particular, was not reproducible. True, landlords could and did increase the effective amount of land by fertilising and hedging it, and freeing it of ancient customs – or, for that matter, by creating new land from swamps or the sea, as on the Somerset Levels and the Fens. But the source of much of the value of the land was irreproducible and unaugmentable. An owner of the 'original and indestructible powers of the soil', as Ricardo (who first made the point) described them, earned from them 'pure rents', and the very fact that the owner's tenant farmers were willing to pay him the rents indicate that these powers of the soil were useful in production. How useful is measured by the share of pure rents in national income – before 1815 some 17 per cent. Unlike ploughs and engines, the 'free gifts of nature' could not grow in proportion to population: strictly speaking they could not grow at all. In other words, Britain was agricultural (albeit less so at the time than any other country except perhaps Holland), pure rent was a large part of agricultural income (albeit diminishing), and, therefore, a large share of national output depended on a factor that could not grow.

In the eighty years after 1780 the tools with which Englishmen worked did, in fact, grow. By setting aside each year a portion of the nation's resources to invest in repairing old shovels, ships, roads, spindles, and docks and in making new ones Britain increased her panoply from 1780 to 1860 by about 1.6 per cent per year. The number of workers using these tools increased somewhat slower (at 1.3 per cent per year), which is to say that Britain somewhat increased the value of tools per worker. On this count she offset diminishing returns a little.

She offset them much more by using inputs better. What was extraordinary about the industrial revoution 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 (see the final table in appendix 6.1 below). The larger quantities of capital did make a difference. Had the effort of investment in new capital from 1780 to 1860 not been made – that is, if the Englishman's tools in 1860 had been the same in quantity as well as quality as they had been in 1780 – income per head would have falled to £6.4. The possibility was remote, for the rate of savings to be used for new capital changed little in the period, and there is no reason to suppose that it would have fallen to zero. The larger part of the difference between this dismal possibility and the £28 per head actually achieved by 1860 was attributable to better technology. In short – and this is the main point – ingenuity rather than abstention governed the industrial revolution.

The location of ingenuity

Great Inventions have usually symbolised this ingenuity. In textiles, first in cotton and with a lag of one or two decades in linen and wool, the inventions harnessed non-human power, initially the power of falling water and later steam, as a team of horses is harnessed to a plough. In the 1770s and 1780s water-driven spindles allowing one factory worker to produce rapidly and simultaneously many strands of cotton yarn initiated the obsolescence of the root meaning of the word 'spinster'. Steam power applied to the weaving of the yarn into cotton cloth began in the early years of the new century (although its massive application awaited the 1820s and later). If cotton cloth is the symbolic consumers' good of the industrial revolution, iron is the symbolic producers' good, and was similarly transformed: in the last two decades of the eighteenth century steam and water power were applied to the bellows in the furnace that melted ore into iron and to mills that rolled out useful shapes as a cook rolls out a pie-crust. The culinary metaphor applies also to the premier innovation in iron, 'puddling', in which, from the 1780s on, a hand process of stirring a soup of iron and boiling off carbon (which weakens the metal) replaced the smith's way of making 'wrought' iron, i.e. hammering it in little pieces (or large pieces: power had been applied to the hammering as well). With the introduction in the 1830s of preheating the air from the bellows the iron industry took the technical form it retained until the introduction of cheap steel (steel is purified and lower-carbon iron) in the 1860s. Cheap iron gradually replaced wood in the construction of bridges, ships, and, eventually, buildings; with the adaptation of wood drills and lathes to iron – no easy task – it replaced wood in machinery as well, allowing machines to run faster and with more precision. The steam engine, of course, was the characteristic iron machine: the steam pump, the steam locomotive, the steam factory, the steam ship, the steam tractor, the steam this and that made it possible for Britain to substitute her large endowment of coal for men, horses, wind and water.

The list of inventions could be extended without limit; clay drainage pipes made by machine and chemical fertiliser in farming from the 1840s on; lathes for making metal bolts and screws from the 1800s; the safety lamp in mining from the 1810s and the wire rope (permitting very deep working) from the 1840s; and scores of others. Few of these ideas were entirely novel, for scientific history is not the same as technological history. Steam engines had existed as toys in classical times, and 'atmospheric engines' (in which condensing steam created a vacuum against which atmospheric pressure pushed) were raising water from mines from the early eighteenth century. Agricultural crops that came to prominence in the industrial revolution, most notably the potato, were novelties only in their new extent. Rails carried coal from the face to the ship long before they carried passengers behind a locomotive.

A list of inventions, furthermore, is not a list of adoptions, for technological history is not the same as economic history. The contrary view was expressed to the historian of the industrial revolution, T. S. Ashton, with unconscious brilliance by a student: 'About 1760 a wave of gadgets swept over England' (Ashton, 1948: 59). 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. Looms run by hand and factories run by water survived in the cotton textile industry in 1860, as in wool, linen and silk. Around 1860 more shipping capacity was built of wood than of iron, and new sailing ship capacity was two and a half times larger than new steamship capacity, not to speak of existing ships – overwhelmingly wood under sail.

The rain left much of the ground untouched. Down to 1860 the places in the economy that the new techniques could touch were manufacturing, mining, and building – what usually spring to mind when one thinks of 'industry' – and trade and transport. From 1801 to 1861 about half of the economy's resources were allocated to these sectors, but within them many of the old ways persisted. The allocation of one resource, labour, is known from the decennial census in greater detail and permits a more illuminating calculation. In 1861, at the end of the customary dating of the industrial revolution, only about 30 per cent of the labour force was employed in activities that had been radically transformed in technique since 1780, railways, ships, mining, metal and machines, chemicals and textiles, and a handful of smaller industries (such as pottery). Britain was not in 1861 a cotton mill. By 1911, by contrast, it is easier to list the classes of employment that had not been transformed: public administration, the professions, commerce (but consider the typewriter), roads, fishing, and (the largest of these) domestic service, taking together the same percentage of the labour force as had in 1861 been taken by partially modernised industries – namely, 30 per cent (Mitchell and Deane 1962: 60, removing from the denominator the unclassified 'All others occupied'). Agriculture acquired its reapers, clothing its sewing machines, food its steam flour mills and refrigerators, building its steam shovels well after the novelty of an accelerated pace of economic life had worn off.

If so much remained to be done in 1860 the great rise in productivity during the 80 preceding years would seem to be a puzzle. The puzzle is merely superficial, however, because the history of the adoption of new techniques is not the history of their economic impact. A stream locomotive pulling coal trucks over rails is from the technological point of view radically different from a horse pulling a coal barge in a canal. The adoption of the new technique, however, may or may not have had a large impact in reducing the cost of transporting coal: that the new technology was revolutionary in form and was adopted is consistent with both a trivial and a significant advantage over the old technology. The advantage must be measured directly, not inferred from the outlandishness of new machines or the rapidity with which they superseded old machines.

And, in fact, many of the few novelties adopted between 1780 and 1860 had great advantages. The most spectacular case is cotton cloth. A piece of cloth that sold in the 1780s for 70 or 80 shillings was selling in the 1850s for around 5 shillings. Some of this decline was attributable to declines in the prices of the inputs to cloths, especially raw cotton after the introduction of the cotton gin (picking out the seeds in the raw cotton) and the consequent extension of cotton growing in the United States. But most of the decline was attributable to innovations in preparing, spinning, and weaving the cotton which enormously decreased the cost of the resources to produce a piece of cloth. From 1780 to 1860 on average these technological changes appear to have reduced the materials, labour, and capital per piece by over 2.5 per cent each year, or, to put it in alternative but equivalent words, they raised by over 2.5 per cent per year the amount of cloth producible from a given bundle of resources. A number rising at over 2.5 per cent a year reaches nearly eight times its initial level in eighty years. By 1860 the new techniques permitted cloth to be produced at a cost about one eighth what it would have cost in 1760: that is, a given bundle of cotton, labour, and machines in 1860 produced eight times more cotton cloth than it did in 1780.

Most of this accomplishment (and all of it before 1812–15) can be attributed to the mechanisation of combing out (carding) the raw cotton and twisting (spinning) it into yarn rather than to the mechanisation of weaving. By 1860, as table 6.1 indicates, the price of cloth would have fallen to a quarter of its

Table 6.1. *The fall in the real cost of cotton cloth* 1780–1860

	Real cost Index	Percentage rate of growth of productivity
c. 1780	100	
		3.4 (3.4)
c. 1812–15	32 (32)	
		2.0 (0.65)
c. 1860	13 (24)	

( ) = without weaving productivity growth
Source: See table 6.2

level in 1780 even had weaving not moved out of the weavers cottages and into factories. Although the power loom was invented in the 1780s, its application awaited later improvements in design and materials, and only after the Napoleonic War did it contribute to productivity change (albeit for a decade or two massively: nearly all the 50 per cent decline in real costs 1815–40 is accounted for by innovations in weaving, concentrated in the late 1820s and 1830s). The same point applies to carding and spinning machinery, and, indeed, to innovations in most industries. The heroic age of invention in cotton had ended by the late 1780s, yet the bulk of the resource savings promised by the inventions of Hargreaves, Arkwright, Kay, Crompton, and Cartwright required the ingenuity of later, lesser men – lesser, at least, in glory. By 1799, which may be taken as the end of the first harvest of inventions, the real price of cloth compared to its level in 1780 has halved; but it was to halve twice more by 1860.

Other industries, such as other textiles, had a similar experience of slow perfection of bright ideas. The devices applied to cotton were applicable to any fibre, but between this obvious conception and the actual creation fell a long shadow of adaptation, adapting machinery to silk, flax, and, most important, wool. Wool weavers in Scotland with their hand looms could still sing in the 1840s:

There's folk independent of other trademen's wark,
For women need no barbers and the dyker's need no clerk;
But none of them can do without a coat or a sark...
So the weaving's a trade that never can fail,
While we aye need a clout to hold another hale.

Though they would very soon join their Lancashire colleagues:

Come all you cotton weavers, your looms you may pull down,
You must get employed in factories, in country or in town,
For our cotton masters have found out a wonderful scheme,

These calico goods now wove by hand they're going to weave by steam.
(Dallas 1974: 97, 119)

The railway is another case among many. The dates of opening of the first railway, the Stockton and Darlington (1825) and of the Liverpool and Manchester (1830) stick in the mind as emblems of the dawn, but in the perspective of what followed the charming little engines and trucks were mere experments. Further developments reduced the resource cost of railways by at least half by 1860.

The impact of the novelties, then, was spread through many years. Their significance depended on the sizes of the industries they transformed. If cotton was used only for kerchiefs and iron only for nails the speed with which their productivity grew would perhaps be interesting in itself (as is the cheapening of clay cups and plates in this period) but not vital to the history of the nation. The appropriate measure of size must be a money measure, for the brute fact that in 1800 Britain produced about 50 million pounds of cotton yarn to be woven into cloth and about 200000 tons of pig iron to be made into castings and wrought iron is uninterpretable. The cloth and the iron must be brought into a unit of account – pounds sterling – that allows them to be compared. And the money measure must be compared with national income as a whole. That the cloth sold for about £17 million and the products of iron for about £2.7 million makes the important point that the characteristic consumers' good of the industrial revolution in fact dwarfed the characteristic producers' good, but beyond this the figures are by themselves unintelligible. The ratio of cotton output to national income in 1800 was about 0.07, the ratio of iron about 0.01. In other words, even very great changes in the productivity of ironmaking would have had little effect on national productivity in 1800 (although more by 1860, when the ratio for iron reached about 0.03).

Cotton is quite another story. The 2.6 per cent of the resources it (had) used that were freed by technical change each year for alternative uses in the economy amounted nationally to (0.07) (2.6 per cent) = 0.18 per cent per year. The calculation can stand for the whole period, because the size of the industry was smaller when (1780 to 1800) its rate of productivity growth was larger and its size larger when (1800 to 1860) its growth was smaller. Now the rate of growth of productivity in the economy as a whole 1780 to 1860 was about 1.2 per cent per year. Cotton alone, therefore, accounted each year on average for 0.18/1.2 per cent or 15 per cent of the total. Five or six more such industries as Lancashire cotton would have made Britain's fortune.

The location of ingenuity was not in fact so concentrated as this. Nonetheless, a relative handful of other industries with large and easily measurable changes in 'productivity' account for a good deal of the fortune's history. Productivity, recall, means the efficiency with which inputs of *all* kinds, not only the labour, are used. Statistics of the prices of products and of the human inputs and materials used to make them can be employed to measure productivity in this sense. The reasoning involved, which has already been used in describing the innovations in cotton, is simple and is at this point worth making explicit. To put it in a sentence, the reasoning is that better ways of making things will result in those things becoming cheaper. To put it more fully, in the absence of changes in productivity the price of, say, cotton cloth will move with the prices of raw cotton, labour and capital employed, with each input carrying a fixed weight in the total change equal to its share in the costs of cloth. If we calculate a weighted average in this way of the prices for the inputs to the manufacture of cloth, we then have a measure of changes in the price of the output, cotton cloth, which would have occurred in the absence of productivity change. Such a measure of the productivity-absent price of cloth might rise or fall; to be concrete, the prices of inputs, and thus of this 'productivity-absent' price was falling rapidly, for example, in most of the twenty years after the Napoleonic wars. If the actual price of cloth was falling even faster, as it was, then the relative fall is evidence that savings in the costs of inputs were being achieved over and above those from the fall in their prices. That is, cloth was being made with fewer and fewer inputs: productivity was increasing. The difference between the rate of fall in the cloth price and the rate of fall in the input prices is the measure of the increase of productivity.

For the history of national income the industry's productivity change measured in this way is to be multiplied (and was above) by the value of the industry's output divided by national income: 0.07 in the case of cotton. This measure of the importance of cotton (and of other industries) to the nation can be understood as follows. In the four years from 1826 to 1830, at the height of the introduction of power looms, the industry saved through productivity change 13 per cent of its costs. If all its costs (equal, of course, to the value of its output) were, in 1828, £V, then it released over the next four years £$0.13V$ worth of resources to serve other demands in the economy. The value of its output in 1828 expressed as a ratio to national income (called £I) is £V/£I, and multiplying this ratio by the percentage productivity change in the industry (i.e. £$0.13V$/£V) will give £$0.13V$/£I, that is, the resources saved in cotton as a percentage of all resources in the economy. In other words, applying the ratio to the industry's rate of productivity change will give the contribution of that productivity change to national productivity change. And this is what is wanted: a way of gauging the significance of power looms, potteries, and puddling to British economic growth.

The measure here of an industry's importance is not the usual one, although it is the correct one. Happily, the correct measure is typically easy to calculate. National income is here divided into the whole value of the industry's output (output multiplied by its price), not merely (to give the more usual measure of

Table 6.2. *Crude approximations to annual productivity change by sector* 1780–1860

	(1) Rates of growth of productivity (per cent per year)	(2) Value of output divided by national income (1780–1860 on average)	(3) Contribution to the national growth of productivity = (1) × (2) (per cent per year)
1 Cotton	2.6	0.07	0.18
2 Worsteds	1.8	0.035	0.06
3 Woollens	0.9	0.035	0.03
4 Iron	0.9	0.02	0.018
5 Canals and railways	1.3	0.07	0.09
6 Coastal and foreign shipping	2.3	0.06	0.14
Sum of these modernised sectors	1.8 (Average weighted by share in Col. 2)	0.29	0.52
7 Agriculture	0.45	0.27	0.12
8 All other sectors	0.65	0.85	0.55
Total		1.41	1.19

Sources: For sources and methods of calculation see Appendix 6.1.

importance) into its value *added.* Value added is the portion of the whole value paid directly to labour and capital in the industry, as distinct from payments for material or services from other sectors of the economy (for example, the importing of raw cotton for the material or the mining of coal for the powered machines). It is customary to think of the size of incomes earned *directly* in an industry such as cotton as the appropriate measure of the 'contribution' of the industry to national income, and therefore as the appropriate measure of its importance. The arithmetic of this custom seems plausible, for the sum of all direct earnings (values added) is indeed national income. But for present and most other purposes the raw materials cannot be left out: for measuring productivity change it matters that prices of raw materials are often known with fair precision when prices of value added (labour, capital, and land) are not; for understanding and assessing the productivity change it matters that an industry's innovations often save materials and thereby save the nation's labour and machinery and land indirectly: and for applying the understanding to the history of the industry itself it matters that the cost of materials as well as of labour and the rest determine the supply price of its product.

Applying such thoughts to what is now known of the prices and outputs of Britain's economy during the industrial revolution yields a table (table 6.2) of 'contributions' of each of eight parts of the economy to national productivity change. The figures are very crude approximations, and are to be viewed as first attempts. Nonetheless, they provide a useful framework for the narrative.

The statistics of 'All other sectors' (Row 8) are calculated from what is left over from the whole (1.41) ratio value of output to value added and from the whole (1.19%) national growth in productivity per year. The other seven parts of the whole are based on evidence about the part in question, though it should be emphasised again that the evidence is sparse. The best way to appreciate the sparseness is to read the footnotes to the table. Differences in detail between estimates here and estimates in other chapters result from different choices of how to leap over gaps in the data. The leaps are necessary, but each student of the subject makes them in a personal style: the statistical and the literary approaches to history are not so very far apart.

The result can be looked at in two ways, depending on whether one sees the glass as half full or half empty. The half full way of looking at it is to note with wonderment how very rapid productivity change was in the six 'modernised sectors' distinguished in the table, and how large a share of national productivity change these sectors can explain – 0.52 per cent per year for them alone out of a total of 1.19 per cent per year for the nation. The half empty way of looking at it is to note with equal or greater wonderment how much was left over for sectors unaffected by steam and iron before 1860 to contribute. Their productivity change was slower but their importance was larger, with the result that their contribution to the explanation of national productivity change was larger than that of the modernised sectors. Ingenuity in the industrial revolution was either wonderfully concentrated or wonderfully dispersed, depending on what excites one's sense of wonder.

The wonder of cotton textiles (row 1) has been discussed in detail already. The industry of row 2, worsteds – long-staple wool spun into thin, compact yarn and woven flat, with no nap to the cloth – was similar to cotton in technique, and was quick to adopt the advantageous novelties invented in cotton. The productivity change given in row 3 for the other wool product, wollens, is a mere guess, but probably of the right order of magnitude. Its relative lowness fits at any rate the narrative evidence. That iron's productivity (row 4) grew at about the same rate, high nationally but low by comparison with the other modernised sectors, does not fit the narrative evidence. So much the worse for the narrative evidence. Spectacular though they were in a technical sense, puddling and the hot blast were able to cut the price of bar iron (and its raw material, pig iron) only in half from the 1780s to the 1850s, in the face of little change in the prices of raw materials, especially coal. Coal itself is not included in the table because it is difficult at present to know even the few facts the method requires: the pithead price of coal, wages, owner's royalties, and their shares in costs at the beginning and end of the period. In view of the stable price of coal shipped to London it would be surprising if its productivity change were great, though apparently sufficient to offset the higher costs of deeper mines. The large factor of multiplication from the 1780s to 1860 in the output of coal – 11, when national income was increased by a factor of seven (Clapham 1926–38: vol. 1, 431; Mitchell and Deane 1962: 115) – and the truly stupendous one for iron – 56 (Mitchell and Deane 1972: 131) – were achieved not by producing a great deal more output from the same inputs but by drawing inputs from other industries and setting them to work in mine and furnace.

Transport, on the other hand (rows 5 and 6), had rapid productivity change. Transport rates fell to a third of their former levels on the routes of canals, and if the railway had a less spectacular immediate effect it was less confined by the need for water in its choice of routes and continued to cheapen down to 1860 and beyond. Productivity change in ocean transport was still more rapid. Especially on long hauls the improvement is attributable not to the application of iron and steam to shipping (which came on a large scale later) but to bigger sailing ships with smaller crews per ton of cargo (North 1968). Textiles and transport figure heavily in the explanation of national productivity change, 1780 to 1860; together they account for over two-fifths of it.

Agriculture is more typical of the other sectors of the economy. Productivity change did occur, but at a modest 0.45 per cent per year instead of the 1.8 per cent per year average in cotton and the rest. All the other sectors – commerce as distinct from transportation, the making of clothes as distinct from the making of cloth, food processing (bread-making, beer, canning and so forth) as distinct from food growing, machinery and implements as distinct from the iron raw material, together with domestic service, building and the professsions (having little or no technical change) and chemicals, pottery, glass, gasworks, tanning, furniture (having a good deal of technical change) – experienced productivity change at 0.65 per cent per year on average.

Small though it is by comparison with textiles or transport, 0.65 per cent per year is no trivial achievement. Had agricultural productivity grown as it did (i.e. at 0.45 per cent per year) and had all other sectors grown at this 0.65 per cent per year (instead of some at 1.8 per cent per year), national income per head would still have grown substantially: it would have doubled from 1780 to 1860, rising from £11 to £22 per head (rather than from £11 to £28). The Great Inventions – mule spinning, power weaving, steam traction, and behind these the steam engine – deserve special attention, for their effects were indeed out of proportion to the sizes of the industries in which they flourished. But the doubling of income that would have occurred even had they been Ordinary Inventions serves as a warning: ordinary inventiveness was widespread in the British economy 1780 to 1860.

Explanations: supply

The chronology of growth so far established sets limits on explanations of it. There is something to be explained, something unexpected, namely substantial growth of income per head in the face of a sharp rise in the number of heads. British growth from 1780 to 1860 was not uniquely fast. The rate of growth of income per head was equal or greater in later periods of comparable length. And by comparison with countries industrialising after Britain and having therefore the benefit of techniques perfected in Britain the rate was not spectacular. Yet these very facts are notable. That Britain's experience from 1780 to 1860 was the prelude to modern economic growth at home and abroad, with real incomes per head routinely doubling every half century, demands explanation.

The explanation cannot, it would appear, rely on the accumulation of capital. True, there was a new enthusiasm for projects such as canals and enclosures involving large investments and large but distant returns, whether from a fall in the interest rate (Ashton 1948) or, more fundamentally, from a rise in the national propensity to save (Rostow 1960). As was shown above, however, rises in income that are not explicable as more machines per man dominate the story. This is a bitter disappointment to economists. The scientists of scarcity delight in the thought that more consumption later can come only from abstinence now. As it is put in the mildly comical jargon of the discipline, there is no such thing as a free lunch. Yet indubitably Britain from 1780 to 1860 ate a massive free lunch. The normal return on investment was 10 or 15 per cent per year, the return that would bring the benefits from investment into that equality with costs so pleasing to economists. Yet in fact the nation was earning 12 per cent or so in addition to this on the investments with no corresponding costs, if one attributes all a year's productivity gain to capital. The story that might be called vulgar capitalism – more savings produces more capital which produces more income which produces savings and so again in a 'self-sustained virtuous spiral' (the usual tired witticism) – lacks force for this reason, among others. The higher income was attributable largely to something outside the spiral, namely, technological change.

The significance of capital accumulation for British economic growth can be rescued in various ways, none wholly persuasive. It can be argued that better technology was embodied in new capital equipment, and therefore that the nation could not have had the advantage of the better technology without the new investment. Old spindles and ships, it is said, could not simply be sped up or enlarged or redesigned as the knowledge of how to do so became available.

The persuasive sound of the argument, however, springs from the element of tautology embedded (not to say embodied) in it rather than from any great logical or empirical power. Of course better weaving technology, say, required new looms. But this does not imply that productivity change in weaving required a rise in the nation's savings. Replacement investment provided an occasion, a frequent one, for introducing the better technique. And were this not fast enough to suit businessmen they could divert saving from sectors with low rates of embodied technical change (building and agriculture, for example) to those with high rates (textiles and transport), as did early cotton manufacturers who set up business in disused warehouses rather than spend on buildings money better spent on primitive machines (Crouzet 1972: 38), or as did landlords investing agricultural incomes in canals.

A deeper argument is that investment is under-measured. Knowledge is not free, as Faust could testify, and apprenticeship, schooling, and inventive effort might be viewed as payments to the devil of scarcity. The educational portion of the argument, the only portion that is easily measurable, is not strong on the face of it: although literacy at marriage did increase from 1780 to 1860, especially women's literacy (from an appalling 38 per cent to 65 per cent), the increase was no revolution and the low (and sometimes falling) rates that persisted in industrial areas down to the end of the period confirm the natural supposition that the ability to read was unimportant to a factory hand (Schofield 1973). Still, it has been estimated tentatively that the cost of maintaining the literacy there was – literacy, alas, is not inherited – was as high as 1 per cent of national income in the 1830s (West 1970, but see Hurt 1971a and West 1971), or 7 per cent of total investment in more conventional forms of capital. Admitting the desirability of counting all the costs of achieving higher income, however, the size, and what is more to the point the rate of increase, of non-measured capital would have to have been impossibly large from 1780 to 1860 to account fully for the change in productivity (Deane 1973).

The rejection of capital accumulation makes it necessary to search the menu of the free lunch. If great inventions were most of the story the search could narrow to great inventors, proceeding by a reduction to individual biography. This is the style of much industrial history, still more of business history, and for the task of explaining a handful of definite innovations it has merit. But it was shown earlier that contrary to much thinking on the matter innovation was widespread. The industrial revolution was not the Age of Cotton or of Railways or even of Steam entirely; it was an age of improvement.

Although widespread consequences do not invariably have widespread causes, the betting would have to be on that side. Resources were being allocated better in many places. A favourite locus of improved allocation, for example, is the capital market, for the notion that accumulation governed the industrial revolution dies hard. In the simplest form it is believed that if merchants or landlords can be shown to have invested heavily in railways or coal mines (as they can be), then the original accumulation of industrial capital, in Marx's phrase, will have been identified. Reallocations of capital, however, are ill-matched to the task of explaining a doubling of income per head. The reasoning is simple and distressingly decisive, applying with equal force to reallocations of labour: it can be shown that the potential gains from eliminating misallocation were small. Too much capital is applied to, say, agriculture if capital earns less in agriculture than elsewhere, perhaps 5 per cent a year rather than (to take a generously high figure) the 15 per cent to be earned in manufacturing or transport or other projects. The net gain to the nation of moving £1-worth of agricultural capital into the other projects is clearly $(0.15-0.05)(£1) = £0.1$ per year. As more £1-worth are so moved, however, the differential return narrows (capital become relatively less abundant and therefore more valuable in agriculture and more abundant and less valuable elsewhere), being zero when capital is allocated correctly. The total gain to national income is the area, as it were, of a triangle with a height equal to the amount of capital (in pounds) to be reallocated, a base of 0.15–0.05, and an apex at the point of zero differential. If the percentage allocation of the nation's capital to agriculture in 1860 (25 per cent) is taken as the correct allocation in 1780 (when it was in fact 50 per cent), the correct allocation would require the movement of a quarter of the nation's total capital stock of £670 million. The height of the triangle of gain to reallocation is therefore $(\frac{1}{4}) \times (£670) = £168$m. and the area of gain is $(\frac{1}{2}) \times (£168\text{m})(0.10) = £8.4$ million. This is only $8\frac{1}{2}$ per cent of British national income in 1780, as against an increase to be explained of 150 per cent per capita down to 1860. No doubt this argument and its conclusion will appear strange at first, but on second thought they can be seen to be in accord with common sense: were differentials in returns to labour or capital very large the labourers or capitalists could be expected in so developed an economy as Britain in 1780 to have exploited them already; and the reallocations that in fact took place between 1780 and 1860 involved no very large portion of the nation's labour and capital. The upshot is a moderate gain on a moderate portion of the nation's resources, not the stuff of revolutions in economic life.

The explanation of the revolution must be sought in less definite reallocations, of human effort and spirit, and in the luck of invention. These are old and obvious notions, although they have not been tested persuasively. Studies of individual enterprise and invention are less conclusive than they are numerous, for what is wanted is general evidence rather than doubtfully representative cases in point. A much-travelled path to general evidence is by way of comparisons, most fruitfully between successful and unsuccessful parts of the country (for example, the vigorous industrial North *versus* the sleepy agricultural South), although more usually between Britain and France. There is growing evidence that the contrast with France has been overdrawn, that if France was for much of the period a country with less freedom for enterprise and more rigid social stratification, this did not long retard the development of new techniques in industry and agriculture (O'Brien and Keyder 1978; Roehl 1976). The industrialization of northern England was merely a little earlier and a little faster than the industrialisation of northern France, Belgium, and the Prussian Rhineland.

Whatever the seed, the ground in these places was fertile. Farmers do not debate whether it is the seed or the soil that causes their crops, nor perhaps should historians, though recognising that both were present. Nothing very definite can be said about the 'preconditions' for British growth, which leaves room for unrestrained speculation on what they were. Security of property, peace, an acquisitive and inquisitive mentality among the people, a hostility to monopolies propped up by government, the ability of the occasional ploughboy to rise to a seat in Parliament are all candidates, and for each an opposing candidate can be found: as to peace, the first half of the period consisted largely of French wars, albeit not on British soil; as to laissez faire and security of property against government, the new interventionism of factory acts replaced the old interventionism of wage regulation (though both were at this time ineffective), and the same French wars left taxes high (though smaller than they were to become in the twentieth century). Fixed backgrounds, by definition, do not move, making it difficult to detect their contribution to the play. Moving them in the imagination is delicate work. One is free to imagine a Britain of lazy businessmen, say, but it is hazardous to infer from the mental comparisons that vigorous businessmen were a prerequisite for British growth. The most that economic reasoning can offer at present is the valuable thought that one condition for growth can substitute for the lack of another. To return to the comical jargon of the field, there is more than one way to skin a cat, and more than one way to grow in wealth (Gerschenkron 1962). How exactly the cat was skinned in Britain from 1780 to 1860 remains uncertain: we know less what it was than what it was not.

Explanations: demand

One thing it probably was not was a response to demand. It is proper to treat demand symmetrically with supply in explaining the growth of iron output or wheat output, but for the nation as a whole it is improper. The demand for things-in-general is income itself, which is determined by the resources and technology supplied to the nation. In the aggregate (with some exceptions to be mentioned below) demand is not an independent factor causing income to grow (Mokyr 1977).

Judging from the frequency with which it has eluded writers on the industrial revolution the point is an elusive one. The simplest way to grasp it is to think of Britain as that favourite of economic exposition, Robinson Crusoe (before

Friday). Obviously, if Crusoe decides to demand more wheat – from himself – his total product, taking wheat and fish together, does not *ipso facto* grow, for he must give up fish to acquire the time to grow more wheat. Still more obviously, if he decides to eat more with his left hand than with his right his total product does not grow, for what goes into one hand must come from the other. Britain, likewise, could (and did) demand more iron for itself, but only at the expense of other things, the factors of supply being given. An expansion of the iron industry caused by a rise in the demand for iron did not 'generate' income, either in the iron industry itself or, though what are wisely known as 'backward linkages' and 'multipliers', in the mines and factories that supplied inputs to the iron industry: it merely redistributed the income. Similarly, like left and right hands, an enrichment of one group (say producers of grain during the Napoleonic Wars) and the consequent increase in their demands for manufactured goods comes at the expense of impoverishment of another (consumers of grain) and a decrease in their demands (Hueckel 1973).

There are two conditions under which demand in the aggregate can nonetheless have an effect on the size of national income. Neither was important. The first is foreign trade, which can again be made clear by reference to Crusoe. If Crusoe trades with someone, say Friday, demand – Friday's demand, not his own – does affect his income. The increase in population and wealth abroad undoubtedly did increase British national income, but the increase attributable to this cause was small. The second condition under which aggregate demand would have a role of its own is mass unemployment. If Crusoe behaved like another shipwrecked sailor

> ...my grandfather knew
> Who had so many things which he wanted to do
> That, whenever he thought it was time to begin,
> He couldn't because of the state he was in.
>
> (Milne 1927: 36)

he would be behaving like a modern economy in depression. For reasons that are still unclear, the business cycle in virulent form appears to have begun during the industrial revolution (Gayer, Rostow, and Schwartz 1953a). Crop failures in an agricultural economy evoked prayerful resignation: business failures in an industrial economy, man-made as they were, evoked social criticism. The social disease at which the diagnoses and cures were directed, however, was an episodic one, not chronic. This is the critical and frequently overlooked point for the role of aggregate demand in British economic growth. Crusoe can overcome his indecision and end his involuntary idleness, raising his income by the amount of the increase in demand, but from one episode of full employment to another his income is constrained by supply, not demand. And at the peaks of the business cycles Britain was near full employment. The force of the argument can be made plain in a simple calculation. The increase in income to be explained is an increase from £11 per head in 1780 to £28 in 1860. Suppose, to take the most favourable case, that 1780 to 1860 was one long secular boom, with previously unemployed resources set to work by a rise in aggregate demand – it does not matter whether the rise was itself a consequence of external demand (more foreign trade) or internal demand (less hoarding of money or more creation of money by the govenment). To sustain the interpretation, unemployment in 1780 would have to have been at least $(28-1)/28 = 61$ per cent. The figure is absurd – the most enthusiastic believer in open or disguised unemployment as a factor in economic life would not advance a figure above, say, 20 per cent at this time – and therefore the premise that aggregate demand dominated the industrial revolution is absurd as well.

Demand is a more plausible cause of growth if its effects are constrained to work through the composition of output. Here, again, the verdict is not decided, but possibilities may be offered. The oldest argument, a neglected fruit of Adam Smith's thinking, is that the division of labour is limited by the extent of the market. Put in more general language, it could well be that a rise in the demand for, say, cotton allowed the industry to exploit economies of scale, to train a highly differentiated and specialised work-force, for example, or to support specialised sub-industries, such as cotton marketing or machinery-making.

There is a version of this thought with a special air of economic precision that must be rejected at once. It is commonly said that the expansion of the textile or iron industry led to larger firms which could, as it is put, spread fixed costs over a larger output, and therefore produce textiles or iron at lower total cost. But if the size of firms did increase during the industrial revolution (frequently, in fact, the size decreased, by the very specialisation being discussed) it is not because the industries in which they were worked were larger. The size of a single small firm is determined by the size best suited to the money-making purposes of the firm, not by the size of the industry. To supose otherwise is to suppose that market demand is shared out to firms in a centralised and egalitarian fashion, one *N*th share to each of *N* firms. The truth is the opposite: each of the *N* firms decides what it will supply independently, adjusting its independent decision to the prevailing price. A larger total demand for cotton or iron will encourage more firms of the optimal size to enter these industries, not increase the size of existing firms, and certainly not induce the existing firms to move down along their separate cost curves: each firm will already have exploited economies of scale within its walls, for each wishes, naturally, to produce for sale at the lowest possible cost.

Any economies of scale initiated by increases in demand, therefore, would have been economies of a whole industry's scale. In this form the argument is cogent. But whether it is true and significant in the industrial revolution remains to be seen. The increase in one demand, to repeat, must be achieved at the expense of a decrease in another. If potential economies of scale were scattered about the economy at random then what was gained on the swings might be lost on the roundabouts. If they were located in the sectors made relatively larger by demand then there may have been a net gain to the nation. We do not know.

Nor do we know the significance of another and related argument from demand, that disproportionate rises in the demand for one or another product induced technological change, although ignorance has not forestalled confident assertions that it was or was not significant. To return to an earlier line of argument, if technological change is costly then one can expect technological change to occur in those industries in which demand is rising rather than falling, just as any costly factor of production is allocated to expanding industries. Like economies of scale, however, the effect must be asymmetrical to lend significance to demand. It is entirely plausible that the textile industries were ripe for technological revolution from the middle of the eighteenth century on, but it must be shown that some other industry – furniture, say – whose demand languished because textiles grew (a foolish premise, but adequate for the point) was not thereby robbed of its own technological revolution. In any case, the notion of technological ripeness turns attention back to supply, to the initial supply of technological knowledge and the supply of vigour to exploit it.

A more mechanical argument capturing the effects of demand is available, and has the great merit of being testable. Suppose that technological change descended on industries for reasons unconnected with their sizes. In that case the national rate of technological change would depend on the importance of the various industries, that is, on the composition of demand. A smaller cotton industry would have the same rate of technological change but would contribute less to national growth than a larger one. The argument has in fact already been tested: it was found earlier that had the modernised industries mentioned in table 6.2 experienced productivity growth at 0.65 rather than 1.8 per cent per year (which is equivalent to reducing their size to about 40 per cent of their actual size), income per head would nonetheless have doubled between 1780 and 1860, not far short of its actual increase. And so the circle is complete. The pursuit of effects on income related to demand has come back to supply, that extraordinary flowering of ingenuity in many sectors of the British economy known as the industrial revolution.

The causes of the industrial revolution are uncertain, to be sure, but not therefore mysteries beyond knowledge. If many of the explanations proposed can be shown to fail the tests of economic fact, the failures themselves are increments to knowledge. Later chapters examine the intellectual successes and failures in more detail. Chapters 7, 8 and 11 describe the histories of the two major resources of the nation, accumulated capital and human effort, showing how exactly machines and men were brought to the factory. Chapters 10 and 12 describe two great sectors, agriculture and transport, each of whose links with the industrial revolution have been considered vital. Chapters 9 and 14 describe the consequence of the revolution for the distribution of income and for the social and political life of the nation. As will become clear, the explanation and evaluation of the industrial revolution is not the only task of British economic history for the period 1780–1860. To repeat an earlier theme, much of Britain's economic life was only lightly touched by it. But it was, in more ways than one, the primary event.

Appendix 6.1
Sources and methods of calculation for table 6.2

Except for row 8 (which is discussed below), the sources are arranged by rows. Column 1 is the estimate of productivity, usually estimated by subtracting the rate of growth of output price (e.g. cotton cloth) from the rate of growth of input price (e.g. spinning labour and raw cotton). Column 2 is the ratio of the industry's value of output to national income averaged over 1780–1860.

As explained in the text, column 3 is the product of these two, i.e. the industry's productivity growth per year weighted by the industry's importance in national product.

Row 1 (cotton): column 1

Because raw cotton is an import its price is well known (Mitchell and Deane 1962: 490–1). As as such things go, the wage of labour in cotton is also well known (Wood 1910 can be extrapolated back to 1780 by Gilboy's Lancashire wages in Gilboy 1934: 282). The crucial and difficult statistic is the price of the output, i.e. yarn and cloth of average quality. The sources were Sandberg 1974: 239–48; Edwards 1967: 240–2; Ellison 1886: 55, 61. The calculations in the text of productivity change in spinning and weaving separately use cost shares of the two processes in the final product.

Row 1 (cotton): column 2

Deane and Cole (1967: 185, 187) estimate the gross value of cottons produced; and on p. 166 estimate British national income from 1801 on by decades. The estimate of 0.07 is if anything an understatement of the ratio of the two 1780–1860 (making due allowance for the low ratio likely before 1800).

Rows 2 and 3 (worsted and woollens): column 1

The best estimates, so to speak, are the worsteds. The essential fact is that, around 1805, a worsted piece cost four times the value of the raw wool, around 1857 only two times (Deane and Cole 1967: 198). In the meantime the price of raw wool had fallen at 0.7 per cent per year (Deane and Cole 1967: 196, column 2 divided by column 1). These two facts together imply that the price of a worsted piece fell 1805–57 at 2.0 per cent per year. Labour's wage did not change much (Mitchell and Deane 1962: 348, note 3 to table). The fall in the output price minus the fall in the price of raw wool weighted by its share in costs (the latter being the average of 0.25 and 0.50) yields 1.77 per cent per year, or about 1.8. The woollens productivity is a mere guess – half the worsted, on the grounds that the mechanisation begun in cotton came next to worsteds and only tardily to woollens.

Rows 2 and 3 (worsteds and woollens): column 2
Deane and Cole (1967: 196, 198) estimate woollens and worsted as roughly equal in size, and some 7 per cent of national income together (e.g. p. 196, col 4 for 1805 divided by p. 166, last column, for 1801–11 averaged equals 8.4 per cent; likewise for 1855–64 and 1861 equals 6.4 per cent).

Row 4 (iron): column 1
Pig iron prices (coke made) for 1780 are from Charles K. Hyde 1973: 401–14: For 1860 they are from Mitchell and Deane 1962: 493. Prices for wrought iron are from Ashton (1924: 101), which is a mere remark on the fall in price from £20 to £12 down to 1812. Birch (1967: 42) reports a price of £16 a ton in 1787, which lends credence to the estimate of £20 in 1780. The price for 1860 is taken to be the £8 a ton figure for the 1850s given in Mitchell and Deane (1962: 493). With equal weights on cast and wrought iron the price falls at about 1.0 per cent per year 1780–1860. Coal prices fell somewhat in the period, making 1.0 per cent an overestimate. The estimate of 0.9 per cent allows for a modest fall in the prices of inputs into iron.

Row 4 (iron): column 2
Average of 1 per cent around 1800 and 3 per cent around 1860. Numerators are tons of pig iron Mitchell and Deane (1962: 131), in the two years multipied by its price (ibid: 492f) multiplied by 2 to allow for fabrication into wrought (much fabrication) and cast (little fabrication) products.

Row 5 (canals and railways): column 1
The railway estimate of 2.2 per cent per year is Hawke's (1970: 302, col. 10), assumed to apply back to 1830. Before 1830 the source of productivity change is assumed to be canals, cutting overland transport costs by perhaps two-thirds on the perhaps half of the transport experiencing improvement down to 1860. The implication of these guesses is a rate of 0.8 per cent per year from 1780 to 1830, the end of substantial canal building. The entire productivity-experiencing sector, them, had productivity growth at (50/80) (0.8) + (30/80) (2.2) = 1.3 per cent per year over the entire period 1780 to 1860.

Row 5 (canals and railways): column 2
Railway receipts were only about 4 per cent of British national income in 1861 (Mitchell and Deane 1962: 225; Deane and Cole 1967; 166). The rest of the productivity-experiencing portion of transport might add another 3 per cent for 7 in all.

Row 5 (coastal and foreign shipping): column 1
D. C. North (1968) estimates productivity change in Atlantic ocean shipping 1814 to 1860 at 3.30 per cent per year. He estimates it at 0.45 per cent per year from 1600 to 1784: a guess of 1.0 per cent per year 1780–1814 is perhaps reasonable. The resulting average for the entire period would be (35/80) (1.0) + (45/80) (3.3) = 2.3 per cent per year.

Row 6 (coastal and foreign shipping): column 2
Imlah's estimates for the balance of international payments of Net Credits from Shipping (1958: 70–2, col. F) divided by British national income (Mitchell and Deane 1962: 366) give 3.2 per cent for 1820 and 4.5 for 1860. Foreign earnings, which these are, were probably growing faster than coastal shipping. The figure of 6.0 per cent for both makes a crude allowance for this fact.

Row 7 (agriculture): column 1
The rate of change of labour and land prices (weighted 0.75 for labour, 0.25 for land) minus the rate of change of output prices. Labour's wage (England and Wales) from Mitchell and Deane (1962: 348f); land's rent from Norton, Trist and Gilbert, 'A Century of Land Values: England and Wales' (1891), reprinted in E. M. Carus-Wilson, ed. (1962: vol. III, 128f). Output price is the Gayer, Rostow and Schwartz index of 'Domestic Commodities' (largely agricultural) in Mitchell and Deane (1962: 470), extrapolated to 1860 by relation to Rousseaux's index of total agricultural products (Mitchell and Deane 1962: 471f) 1840–50. The resulting productivity change was assumed to apply to the 1780–95 period as well.

Row 7 (agriculture): column 2
Deane and Cole (1967: 166), average share 1780–1861 of agriculture in national income (agriculture has very few purchased inputs), with 1780 and 1790 assumed to be the same as 1801.

Row 9 (total)
The total requires estimates of national productivity, which in turn requires estimates of national outputs and inputs. The basic source is Feinstein (1978). The initial date used here is 1780 instead of 1760, which necessitates some interpolation. The principle in the interpolation is that 1760–80 was a time of war, in which income and capital per man could be expected to remain constant. Therefore, Feinstein's estimate (based on those in Deane and Cole) of gross British domestic product per head of population in 1760 (i.e. £11 – Feinstein's table 25, col. 5) is used for 1780 as well; so too is his 1760 estimate in constant prices of domestic reproducible capital capital (place cited, col. 1, 1760 level blown up by change in number of workers 1760–80). The number of workers in 1780 is derived by applying the 1801 participation rate (0.44) to the 1780 population of Britain (as Feinstein did for 1760). The 1780 population is derived by calculating the Scotland/England and Wales ratio for 1761 and 1791 (Deane and Cole, 1967: 6) using Feinstein's implied figure for Scotland in 1761 of 1.3 million; then interpolating this ratio by a straight line to 1780; then applying the interpolated rate to the (allegedly known) population of England and Wales in 1781 to get Scottish population. Interpolating the Scottish growth rate 1761–91 gives very similar results.

Basic statistics of income, labour and capital

	Income per head	Labour	Capital	Capital labourer
1780	£11	3.93m.	£670	£170
1860	£28	10.8m.	£2770	£256

To do productivity calculations one needs shares.
Land's share: This is meant to comprise pure rents alone, not returns on capital. Feinstein gives (1978: part V, section 5, p. 72, 'Farm land') estimates of the unimproved value of farm land at his four benchmark dates and also the year's purchase applied to all rents (not only pure rents). Dividing the years' purchase into the unimproved value should give

annual pure rent; 1760 = £15.2 m., 1800 = £22.5 m., 1830 = £29.3 m., 1860 = £45.0 m. These appear to be reasonable in relation to agricultural income. Feinstein uses 20 years' purchase to capitalise urban rents (p. 73). Applying this, as with farm land, to his estimates of the capital value of urban land rent (1978: table 15, p. 68, line 6) and then removing his deflation to 1851–60 prices (table 5, p. 38, col. 1) yields annual urban rents of 1760 = (15.2 + 0.9)/90 = 0.18; 1800 = (22.5 + 1.0)/140 = 0.17; 1830 = (29.3 + 1.9)/310 = 0.10; 1860 = (34.0 = 21)/650 = 0.085. The arithmetic average, presumably typical of 1780–1860, is 0.13.

Labour's share: The estimate by Deane and Cole of wages and salaries in 1801, 1831 and 1861 (1967: 152) was divided by their estimate of gross national income minus income from abroad (p. 166):

	1801	1831	1861
Wages and salaries	104	148	315
GDI	232	336	648
Share	0.45	0.44	0.49

The 1780 share was supposed to be equal to the 1801 share. The average is [2(0.45) + 0.44 + 0.49]/4 = 0.46.

Capital's share: As usual, a residual. The simplest calculation is: 1.00 − 0.46 − 0.13 = 0.41. The result is:

	Growth rate (per cent per year)	Share	Contribution to 'Explaining' change in income per head (per cent per year)
Income/head	1.17	—	—
Capital/labour	0.35	0.41	+0.14
Land/labour	−1.26	0.13	−0.16
Residual	1.19	—	+1.19

The assertions earlier in the text about diminishing returns derive from recombinations of these facts.