AN ECONOMIC HISTORY OF MODERN EUROPE: INDUSTRY, 1700-1870

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I. INTRODUCTION

The transition to modern economic growth occurred in Europe between the mid-eighteenth and mid-nineteenth centuries. The decisive breakthrough was made in Britain, and centred on the adoption of new technologies and methods of organisation in industry. Although economic historians now see these changes as quite drawn out, and involving at first only a modest increase in the growth rate, the term "Industrial Revolution" has continued to be widely used. Though the British growth rate remained modest, the structural transformation of the economy was dramatic, with industry's share of male employment increasing from 18.5 per cent in 1700 to 47.3 per cent by 1840 (Crafts, 1985). Moreover, as de Vries (2001) argues, the changes associated with industrialisation were irreversible and became an "ideal type", like the French Revolution. Although the rest of Europe did not merely copy the British example—there were "different paths to the twentieth century"--the idea of "catching-up" remains a useful starting point for thinking about continental industrial developments between the late eighteenth and the late nineteenth centuries (O'Brien and Keyder, 1978; Gerschenkron, 1962; Fremdling, 2000). Working at the pan-European level helps to make clear the fundamental significance of the Industrial Revolution for the history of mankind, something which can be lost when focusing on national developments.

II. KEY THEMES

1. Technological progress

It is common in the literature on technological progress to make a number of distinctions between invention, innovation, diffusion and imitation (Mokyr, 1994: 13-16). An invention is defined as a new discovery, while an innovation is the commercial application of an invention. Although the distinction is blurred in practice, there are some obvious examples, such as Leonardo da Vinci's technical sketches for a helicopter, which remained dormant for centuries. The distinction between innovation and diffusion is between the first commercial application of an invention and its widespread use. This distinction may also be blurred in practice, because an innovation often requires some modification before it can become widely diffused. Similarly, the distinction between innovation and imitation can become blurred if a company or a society that sets out to imitate ends up innovating. Twentieth century Japan is a well-known example of this, but there is also an element of it in Britain during the Industrial Revolution.

Economists have recently used the idea of a General Purpose Technology (GPT) to shed light on periods of accelerating economic growth. Lipsey, Carlaw and Bekar (2005: 98) define a GPT as "a single generic technology recognisable as such over its whole lifetime, that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects". The concept was born to explain the acceleration of economic growth with the recent widespread adoption of information and communications technology (ICT), but has obvious historical parallels in earlier periods of accelerating growth, such as the Industrial Revolution. We shall examine the extent to which steam power can be seen as the first GPT, and assess its contribution to economic growth during the Industrial Revolution.

2. Wages and technology

Factor prices may be expected to affect the choice of technology. However, although this idea has received a lot of attention in explaining technological differences between Europe and America in the nineteenth century, it has received rather less attention in the context of the differences between Europe and Asia during the early stages of the Industrial Revolution. Writing about transatlantic differences in the nineteenth century, Habakkuk (1962) argued that high wages in America induced a substitution of capital for labour (more machines) and a labour-saving bias in the direction of technological progress (better machines). Broadberry and Gupta (2006) have recently pointed out that the scale of the wage gap between northwest Europe and Asia was substantially larger on the eve of the Industrial Revolution than the wage gap between Britain and the United States during the nineteenth century. This is important because the breakthrough to modern factory industry occurred in the British cotton textile industry, which displaced the Indian industry as the major producer and exporter of cotton textiles. Faced with money wages that were five or six times as high in Britain as in India, British firms could not hope to compete using labour-intensive Indian production methods.

Factor prices are also important in explaining the sometimes long delay in the adoption of the modern British technology in much of continental Europe. Whilst writers such as Landes (1969) have seen this as the result of entrepreneurial failure, this view does not do justice to the conditions actually faced by entrepreneurs who had to take account of the differences in factor prices between Britain and the rest of Europe. This often meant that the new technology, which had been developed to suit british factor prices, could not be profitably used on the continent without further technological improvement or adaptation to local circumstances (Fremdling, 2004; Broadberry, 1997).

3. Energy

Another important factor price was that of energy. With a growing shortage of wood, there was an increasing incentive to substitute coal for wood as the major source of energy. This can be seen as leading to the innovation of coke smelting (Hyde, 1977). Allen (2006) argues that the combination of high wages and cheap coal was important in explaining both the development of the key technologies of the Industrial Revolution in Britain, and the delay in their adoption in other European countries.

Wrigley (2004) sees this substitution of coal for wood as a crucial development, enabling Europe to escape from the constraints of the "organic economy" by tapping into the stored up energy of millions of years embodied in coal seams. Coal replaced wood as a source of heat energy in a growing range of industries during the eighteenth century. This occurred initially in processes such as boiling salt and sugar refining, where the source of heat and the object to be heated could be separated by a physical barrier to prevent chemical contamination. Over time, it extended to industries such as bricks, pottery, glass and brewing, where pollution could be tolerated in return for cheapness. The culmination of the process was the use of coke for smelting iron. Coal, via the steam engine, also provided the solution to the constraints on mechanical energy provided by reliance on animals and water power. Steam power played an important role in many sectors of the economy, spreading quickly from its initial role in pumping water out of mines to providing motive power in manufacturing, driving steamships and railways, and powering agricultural machinery such as threshers (Crafts, 2004).

4. Knowledge and human capital

Economists today generally place a great deal of emphasis on the contribution of knowledge and human capital to growth. Until recently, however, economic historians and historians of science have tended to be rather sceptical about their contribution to the Industrial Revolution. On the role of knowledge, although there was an attempt by Musson and Robinson (1969) to argue for a strong link between science and innovation during the Industrial Revolution, most economic historians remained sceptical. As von Tunzelmann (1981: 148-151) noted, science had not been brought into a consistent framework and much of it was simply wrong. Furthermore, the crucial innovations of the Industrial Revolution were a long way from the major areas of scientific enquiry, and anyway science was in better health in continental Europe than in Britain where the decisive breakthroughs were made. More recently, however, Mokyr (2002) has argued for a more general inter-relationship between "propositional knowledge" (science) and "prescriptive knowledge" (engineering). Interactions between these two types of knowledge are seen as important in preventing the cluster of innovations during the Industrial Revolution from petering out and running into diminishing returns, as had happened after previous burst of innovation.

Economic historians have often been quite dismissive of the role of the patent system during the Industrial Revolution, pointing more to its shortcomings than its advantages (Landes, 1969; MacLeod, 1988). However, more recently, Dutton (1984), Sullivan (1989), Mokyr (2007) and Broadberry and Gupta (2007) have suggested a more positive role for the patent system, drawing on the importance attached to intellectual property rights in the recent literature on technological change, and pointing to the large sums that inventors were prepared to pay for patent protection. Of course, much crucial knowledge was also embodied in skilled workers and passed on by doing rather than written down. Both types of knowledge can be shown to have played a role in the industries discussed below.

Although human capital has been seen as crucial to economic growth in recent times, it has rarely featured as a major factor in accounts of the Industrial Revolution. One problem is that the machinery of the Industrial Revolution is usually characterised as de-skilling, substituting relatively unskilled labour for skilled artisans, and leading to a decline in apprenticeship (Mitch, 2004: 347). A second problem is that the widespread use of child labour raised the opportunity cost of schooling (Mitch, 1993: 276). Hence Galor (2005) argues for an increase in the demand for human capital and a demographic transition only in the later stages of the Industrial Revolution.

5. The organisation of industry

Before the Industrial Revolution, much of industry was conducted on a small-scale and part-time basis in the countryside. Of course, there were exceptions, such as mining, metal smelting and grain milling, which required large fixed investments, and even in industries without such large capital requirements, there were always craftsmen working full-time in towns and cities (Clarkson, 1985: 9-10).

Mendels (1972) used the term “proto-industry” to describe this type of rural production, which he identified as the “first stage of industrialisation”. The stage approach was further developed by Kriedte et al. (1981), who tried to identify a more detailed progression. In the first stage, or *Kaufsystem*, artisanal producers retained control over production in rural workshops. In a second stage, or *Verlagsystem*, merchants took control by putting out work to rural producers working in their homes. The third stage is seen as the development of “centralised manufactories and mechanised factories” (Ogilvie and Cerman, 1996: 4). Although the specific theory of proto-industrialisation, and the dynamics of the progression between stages, has received much criticism, most economic historians have continued to see the emergence of the factory system as an important part of the Industrial Revolution.

One aspect of economic development highlighted in the proto-industrialisation framework is the importance of the region, sometimes cutting across national borders, as a unit of analysis (Pollard, 1981: 63-78). However, notice that this framework, by focusing on industrial employment in the countryside as a sign of economic dynamism, sits uneasily with work emphasising the links between urbanisation and economic development (de Vries, 1984; Persson, 1993; Bairoch, 1976). It is only with the emergence of factory employment in towns that we see the emergence of genuine “Marshallian industrial districts”, characterised by external economies of scale. As cotton mills clustered together in Lancashire towns, although each individual firm faced constant returns to scale, the industry as a whole faced increasing returns to scale. The external economies arose through learning (knowledge spillovers between firms), matching (thick markets making it easier to match employers and employees) and sharing (giving firms access to customers and suppliers in the presence of significant transport costs) (Duranton and Puga, 2004).

III. THE STRUCTURE OF EUROPEAN INDUSTRY

Tables 1 and 2 present a rough quantitative picture of European industry around 1870. Table 1, which shows the overall distribution of industry, reveals that the process of industrialisation had gone much further in some parts of the continent than in others. The share of industry in GDP was over 30 per cent in only four countries: the United Kingdom, France, Belgium and Switzerland, a contiguous area that could be seen as the industrial heartland of Europe at this time. Similarly, these were the only countries for which their share of European industrial production was greater than their share of European GDP. Germany, on the eve of its great burst of industrial development, was the only country with between 25 and 30 per cent of its GDP coming from industry, and its share of European industry was similar to its share of GDP.[1] In all other countries the share of European industry was a good deal less than the share of European GDP. A number of countries had an industrial share between 20 and 25 per cent: greater Austria, which at this time included much of what is now the Czech Republic and Slovenia; Italy, Spain, the Netherlands; Denmark and Sweden. With Germany these countries formed a contiguous ring around the heartland. Finally, there were a number of countries on the periphery of Europe—Portugal, Norway, Finland and greater Hungary (including Slovakia and parts of Poland and Romania)—that had industrial sectors accounting for less than 20 per cent of GDP. These countries are representative of the even less industrialised countries—Russia, Turkey and much of southeastern Europe—for which reliable statistical information is wanting.

[1] Although the Rhineland and Westfalian Ruhr formed part of the contiguous industrial heartland of Europe, other parts of the newly founded German Reich in 1871were much less industrialised.

Table 2 shows, in the first instance, the broad composition of Europe's industrial production in 1870. More than half, accounting for about 17 per cent of European GDP, catered to what were still the basics of life, food, clothing and shelter. The other notable manufacturing activity was metals and metal working, which took in primarily the production of iron and steel and their transformation into rails and locomotive, ships, steam engines and other machines. Mining supplied raw materials and energy for some industrial activity, but much of its output was coal for domestic heating. Around 1870, before the advent of electricity, the small utilities sector was mainly occupied with the production of gas for lighting.

Table 2 also shows the shares of Europe's three biggest economies—the United Kingdom, France and Germany—in production by sector. Together they accounted for over two-thirds of industrial output, as against about 60 per cent of European GDP. Their shares in construction and food processing, both activities in which there was little or no trade, were similar to their shares in GDP. The big three stand out in the production of textiles and clothing and metal and metalworking. Here they accounted for about three-quarters of European output. The United Kingdom was particularly in important in metals and metalworking. The most remarkable feature of this table is that the United Kingdom was responsible for over two-thirds of all mining activity in Europe.

How had European industry changed since 1700? It is possible to provide a rough quantitative picture of the scale and geographical unevenness of the expansion of European industry between the mid-eighteenth and mid-nineteenth centuries in

Table 3, based on the work of Bairoch (1982). One way of obtaining such data is to project backwards in time from the more solidly grounded picture of comparative levels of industrialisation in the late nineteenth century, using indices of industrial production. However, for many of the countries considered here, we lack reliable production indices over the relevant period. Thus a second procedure adopted by Bairoch was to assemble data on production of key products for each country at benchmark years from historical sources and weight them together by their relative importance in the value of production. The way in which Bairoch combined the procedures is not transparent, but with one important exception, the results fit well with the large secondary literature on the subject, and can at least be seen as providing a broad guide to the orders of magnitude. The exception is the case of the United Kingdom, where a major revision of the Hoffmann (1955) industrial production index used by Bairoch (1982) has been undertaken by Crafts and Harley (1992) and incorporated here. This results in a substantially slower rate of growth of UK industrial output between 1750 and 1830, and hence a much higher level of industrialisation in 1750 and 1800 than suggested by Bairoch.

Table 3 shows us that the United Kingdom was already the most industrialised country in Europe on a per capita basis in 1750, before the classic Industrial Revolution period, as emphasised by Crafts (1985). Between 1750 and 1860, per capita industrial output in the United Kingdom almost quadrupled, growing at an annual rate of 1.2 per cent. Combined with population growth, this resulted in an annual growth rate of industrial production of 2.1 per cent. Four other countries stand out as highly industrialised by 1860: Belgium and Switzerland are classified by

Bairoch as early industrialisers, while France and Germany are seen as later industrialisers.

IV. COAL AND STEAM

From the sixteenth century onwards, Britain led the way in the use and exploitation of coal as wood could no longer meet the increasing demand for energy, particularly for heating London, the largest city in Europe by 1700. A shift of relative prices in favour of coal, with which Britain was relatively well endowed, led to a process of substitution. Since the substitution between the two sources of energy was less than perfect, this process also brought about large scale technological change (Buenstorf, 2001). Coal was increasingly used in industrial processes requiring heat, culminating in the use of coke for smelting iron, as noted above. The high costs of transportation meant that industrialisation in Europe during the early nineteenth century became strongly linked to location on or near a coal field (Pollard, 1981: xiv-v). Coal was also used to create mechanical energy through the steam engine, which later played an important role in reducing transport costs through the railways, thus freeing industry from the need to locate on or near a coal field.

In the early exploitation of coal for various purposes and in the sheer size of this industry, the British Isles tremendously outstripped any other European country far into the nineteenth century. Table 4 shows the dominance of the British coal industry around 1860, when Britain alone produced more than twice the coal of all other European countries taken together. British coal mines not only supplied domestic customers but during the nineteenth century increasingly also foreign markets, including the rapidly expanding international steam navigation (Fremdling

1989; 1996). In the middle of the nineteenth century, imports of coal from Britain helped continental countries and regions poorly endowed with coal or far away from coalfields to apply the British type of coal-consuming technologies and thus catch up with the British model of industrialisation.

To a large extent, the success of early industrialising Belgium was based on the coal deposits in the Sambre-Meuse region (Pollard, 1981: 87-90). After France, Germany was the second largest importer of British coal during the nineteenth century. Nevertheless, Germany also became the second largest exporter of coal after Britain. This peculiar development reveals important features of coal production and coal markets. For hard coal, the two most important German mining districts, namely the Ruhr and Upper-Silesia, were both located far away from the coast and closer to the western or south-eastern borders than to northern, central and southern parts of Germany. All coal mining districts became major centres of industry. Above all, the Ruhr with its heavy industry developed as the most important industrial region of continental Europe (Holtfrerich, 1973).

In the long run, coal mining could only cope with the growing demand by exploring new coal deposits with layers deep beneath the surface. In order to dig deeper mining shafts, it was necessary to solve the two major problems of drainage and transporting the coal to the pit-head and on to the customer. The solutions came in the form of the steam engine and the railway, both of which became symbols of technical and economic progress during the nineteenth century.

The steam engine is conventionally associated with James Watt, who obtained his first patent on this innovation in 1769. As with many inventions, Watt's achievement has to be placed into a long process of trial and error, stretching back to Newcomen's atmospheric engine of 1712 (Mokyr, 1990: 84-90). The diffusion of the Newcomen engine, which relied on harnessing the atmosphere as a source of power by creating a vacuum, was limited because of the machine's enormous appetite for fuel. During the eighteenth century, the steam engine was almost exclusively applied to the drainage of mines, where coal was available at cheap prices. The Watt engine, with its separate condenser, raised fuel efficiency by nearly five times compared with Newcomen's design. Watt also designed a transmission mechanism which converted the up-and-down-motion of the beam engine into a rotary motion. This way, the steam engine became the prime-mover for machines in the textile industry and various other applications, such as the steam ship and the steam locomotive.

Some writers have tended to play down the role of the steam engine, since it was not widely used during the early phase of the Industrial Revolution. Kanefsky (1979) shows that water wheels generated as much power as steam engines as late as 1830. Thus the finding of von Tunzelmann (1978) that the social saving of the stationary steam engine in Britain was only 0.2 per cent of GDP in 1801 is not too surprising. However, this may understate the importance of the steam engine if what matters is the avoidance of the onset of diminishing returns and if the steam engine helped to sustain productivity improvements across a wide range of activities. Calculations of the social savings of railways later in the nineteenth century suggest a much larger impact of just this one aspect of steam technology. For 1865, Hawke (1970) estimates the social savings of the railways of England and Wales at 6.4 to

11.4 per cent of the GDP, depending on the treatment of passenger comfort. Leunig (2006), with a more sophisticated treatment of the saving of time, arrives at a similar figure. Crafts (2004) assesses the role of steam power as a general purpose technology, using the accounting framework of Oliner and Sichel (2000), which includes the effects of capital deepening as well as TFP growth. The results are shown in Table 5, with separate calculations for stationary steam engines, railways and steamships. Although the steam engine made very little contribution to economy-wide labour productivity growth in the early phase of the Industrial Revolution, its contribution increased after 1830, and accounted for around a third of economy-wide labour productivity growth after 1850. Furthermore, Crafts (2004: 348) accepts that this ignores important TFP spillovers from steam in the second half of the nineteenth century, when transport improvements permitted increased agglomeration and specialisation along lines of comparative advantage (Rosenberg and Trajtenberg, 2004).

V. TEXTILES

After agriculture and food processing, the production of textiles and clothing was the largest economic activity in Europe during the eighteenth and nineteenth centuries. Around 1870 it accounted in most countries for 4-6 per cent of GDP and 15-30 per cent of manufacturing output. Around 1700 its share in a much smaller manufacturing sector was probably higher, perhaps 40-50 per cent. Until the second half of the nineteenth century most clothing was produced in the home or by local seamstresses and tailors. Other than the increasing importance of fashion among the middle and lower strata of the income distribution (Roche, 2000: ch. 8), there was little in the way of technological or organisational change in clothing production before sewing machines became available from the 1850s. The rise of the ready-made clothing industry is largely a development of the period after 1870.

If the clothing industry remained for the most part unchanged over this period, the same was not true of the textile industry that supplied its raw materials. The locus of production for yarn and cloth shifted from the home to the factory, and increasingly from the countryside to the towns. The processes of preparing, spinning, weaving, and finishing were mechanised, making possible large increases in productivity and steeply falling prices to consumers. The mix of textile fabrics changed as cotton cloth, which in the early eighteenth century had been an exotic luxury good, became the stuff of which most underclothing, shirts, dresses, sheets and towels were made.

This transformation of the textile industry is mainly about what happened in the British Isles and secondarily about how the rest of Europe reacted to it. By the mid-nineteenth century the United Kingdom dominated the textile industries of not just Europe, but of the world. It is astonishing that in the cotton industry over half of the mechanical spindles and power looms in the world were in British factories (Farnie, 2003: 724, 727). UK linen and jute producers, mainly located in Ireland and Scotland, operated over 40 per cent of the world's mechanical spindles and over 60 per cent of the power looms (Solar, 2003: 818-819). The English woollen and worsted industry used over a quarter of the world's new wool, supplemented by large supplies of recycled wool (Sauerbeck, 1878). Only in the silk industry was the United Kingdom surpassed by other countries, notably by France and Japan (Federico, 1997: 64).

These figures for equipment and raw material use understate British dominance during much of the early nineteenth century since one reaction by other countries was to maintain their own industries by erecting tariff walls. In the mid-1850s the United Kingdom was a large net exporter of all textiles, except silk goods (Davis, 1979). During the early nineteenth century British goods had flooded markets in the Americas, Africa and Asia, as well as those in Europe which had remained open. Only in the mid-century did some European producers start to become competitive in these markets (Jenkins and Ponting, 1982: 146-8).

The United Kingdom had not always been so dominant in textile trade or in textile production. As late as the 1780s, whilst it was a large net exporter of woollens, it was only a small net exporter of cotton, linen and silk goods (Davis, 1979). Earlier in the eighteenth century, under pressure from woollen and silk producers, the British parliament had felt it necessary to prohibit imports of Indian cotton goods. It had also raised tariffs on imports of German linen cloth in order to protect Scottish and Irish producers. O’Brien, Griffiths and Hunt (1991: 418) argue that these and other “pragmatic” measures helped to “construct a benign legislative framework for the long-term development of a cotton industry”.

In the early eighteenth century the textile industry was spread across the countryside of Europe. Much of output was for local consumption, but there were rural areas where spinners and weavers were more densely settled and where goods were produced for more distant markets, either for urban centres of consumption, such as London, Paris or Amsterdam, or for colonial markets in the Americas.[2] The traditional centres of commercial textile production in Europe were in northern and central Italy and in the region around Ghent and Courtrai in the southern Netherlands (what is now Belgium) and Lille and Amiens in France. Parts of southern England were also major producers of woollens. But by the eighteenth century these areas were being challenged. In wool textiles they faced competition from producers located in the neighbourhoods of Leeds and Bradford in Britain, Montpellier in France, Chemnitz and Aachen in Germany, and Verviers in the southern Netherlands. In linens the more dynamic areas were around Belfast in Ireland, Dundee in Scotland, Landeshut in Germany (now in Poland), and Trautenau in Austria (now in the Czech Republic).

The cotton industry was quite small in the eighteenth century. In Britain as late as 1770 it accounted for less than six per cent of value-added in textile production (Crafts, 1985: 22). Some pure cotton fabrics were produced, but most output took the form of fustians, mixed fabrics made of cotton and linen. Centres of European fustian production were near Manchester in England and in the border area taking in parts of eastern France, southern Germany and northern Switzerland. The most dynamic sector of the cotton industry was printing, often in imitation of Indian calicoes. Printing works were large establishments which required the mobilisation of significant amounts of capital and labour (Chassagne, 2003).

It is interesting to note that the technological breakthrough in the mechanisation of textile production in Britain occurred in cotton, a sector where there

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[2] This overview of the main areas of commercial textile production draws on Clarkson (2003), Jenkins (2003), Solar (2003) and Van der Wee (2003).

was no local supply of the raw material. However, as Broadberry and Gupta (2007) note, wages were 5 to 6 six times higher than in India, the largest producer and exporter of cotton textiles during the early modern period. If British producers were to succeed in displacing India in world markets, it would clearly not be using the labour intensive Indian production methods. The canonical textile inventions - the spinning jenny and the water frame in the 1760s, the mule in the late 1770s, and the power loom in the early 1780s – can thus be seen as a response to the particular factor price environment faced by British producers. The fact that England had a patent system which offered protection to innovations embodied in machinery also helped to realise the potential for import and re-export substitution offered by the success of Indian cottons in English and overseas markets (Sullivan, 1989; Broadberry and Gupta, 2007).

By 1830 cottons accounted for almost half of British textile output, and their share in the textile industries of other European countries had also risen. Several factors account for the cotton industry's rapid and sustained growth. The most obvious is the mechanisation of spinning and weaving noted above. Perhaps equally important was the elasticity with which raw cotton was supplied. The invention of the cotton gin in 1793 made it possible to extend the cultivation of short-staple cotton across the American south. The availability of land on the frontier and of slaves to cultivate it led during the following half century to an enormous increase in supplies of raw cotton at the same time as its real price was falling. Cotton prices were also falling relative to the price of flax, which, along with the much slower pace of mechanisation in the linen industry, helped cotton replace linen in a wide variety of uses. Finally, it should be noted that for consumers cottons were attractive fabrics.

They were light and easy to maintain. They could also be colourful since they lent themselves well to dyeing and printing.

The early inventions were not universally applicable. Initially they worked only with cotton, often only with certain sorts of raw cotton. The new spinning technologies were quite rapidly taken up in the cotton industry in the 1770s and 1780s, but were not widely used in the UK woollen and coarse linen industries until the 1790s, in the worsted industry until the 1800s and in the fine linen industry until the late 1820s. The power loom, even though invented in the 1780s, did not start to be widely used in the UK cotton industry before the 1810s, in coarse linen and worsted industries before the 1820s, in the woollen industry before the 1840s, and in the fine linen and silk industries before the 1850s. Some finer cotton fabrics were still being woven by hand until the 1850s. These long delays in mechanisation owed much to the differing elasticities of the various textile fibres. Where the fibres broke easily, too much hand labour was needed to piece together the yarn during spinning and weaving. Better ways to prepare fibres or smoother ways to run the machines had to be found before mechanisation became economically viable.

There were also long delays in the adoption of the new spinning and weaving technologies by countries other than the United Kingdom. In 1800 there were 3.4 million mechanical spindles working cotton in the United Kingdom yet only about 100,000 elsewhere in the world (Farnie, 2003: 724). This was not for want of trying to copy the British example. French governments, both royalist and republican, provided ample subsidies to would-be cotton spinners in the 1780s and 1790s (Chassagne, 1991: ch. 3). To take another example: the wet spinning of flax, which made possible the production of fine linen yarns, was taken up rapidly in England and Ireland in the late 1820s, but did not start to be adopted in France, Belgium and Germany until the late 1830s and early 1840s (Solar, 2003). The difficulties experienced by other continental countries in successfully applying the new British textile technologies can be readily explained by the fact that wages were lower than in Britain. Hence the labour savings offered by the new technologies did not initially justify the higher capital costs (Allen, 2001; 2006).

Within Britain the various textile industries became increasingly localised during the early nineteenth century. The cotton industry became concentrated in south Lancashire and adjoining parts of Yorkshire and Cheshire. Within west Yorkshire the woollen and worsted industries were increasingly segregated, around Leeds and Bradford respectively, and both of these areas gained relative to other UK producing areas. The coarse linen industry became clustered around Dundee and the fine linen industry around Belfast.

The localisation of the UK textile industries suggests that there were advantages to firms in being located near the centre of the industry. It is difficult to get a firm quantitative grip on the value of these external economies, as Marshall called them, but they may have arisen from several sources. One would be technological. The sort of incremental technical change involved in getting machines to run faster and more efficiently was not likely to be written down. Such knowledge was embodied in the skilled workers who maintained and repaired the machines. These workers were often the vehicle through which new inventions spread to other countries, either because they left to try their hand elsewhere, like Samuel Slater, the pioneer of the American cotton industry, or because they were enticed away by foreign entrepreneurs or governments (Jeremy, 1981; Chassagne, 1991). However, once they left, they cut themselves off from the font of new technical knowledge.

Another potential source of external economies was the concentration of mercantile activity. Reliable and timely information about the state of demand and about the sorts of fabrics that were wanted was crucial in an industry where a prime cause of bankruptcy was unsold merchandise. A notable feature of the early nineteenth century was the shift in the locus of mercantile activity away from London toward the regional centres of production (Edwards, 1967: 180; Solar, 1990). During this same period the value of the United Kingdom's stock of mercantile expertise and connections probably gained from the relative isolation of continental merchants from non-European markets during the wars from 1792 to 1815. From the 1820s foreign cotton merchants setting up in Manchester reinforced its commercial status (Farnie, 2004: 33).

VI. FOOD, DRINK AND TOBACCO

The food, drink and tobacco industries grew significantly during the eighteenth and nineteenth centuries. Population growth from the mid-eighteenth century was one driving force. So, too, was urbanisation. As a greater share of the population lived in towns and cities, fewer people could bake their own bread or brew their own beer. This was also a period when the consumption of exotic goods such as sugar, tea, coffee and tobacco penetrated further down the social scale and became items of mass consumption.

Much of the growth in this sector was based on traditional techniques. There were few major breakthroughs: the most notable was continuous distilling, patented by Aeneas Coffey in 1830 (Weir, 1977). Much change was incremental and benefited from developments in other sectors. Better metals and metalworking techniques made machinery more reliable and permitted increases in the size of machines. Steam power was applied in some industries, notably in milling and brewing, though wind, water and animal power remained important right up to 1870. However, even water-powered mills became larger and more sophisticated in their exploitation of water resources and in the organisation of production. As industrial structures, the three- and four-storey mills built from the mid-eighteenth century were precursors of the early cotton spinning mills.

Perhaps the most important force for change in this sector was more rapid and reliable transportation, first by steam ships from the 1820s, then by railways from the 1830s. Whilst better transport merely facilitated the distribution of the high-value, low-volume exotic goods, it significantly widened markets for more perishable low-value, high-volume food products such as flour and beer. For example, Guinness, which had initially relied on the Dublin market, was, by the 1860s, shipping its dark stout throughout Ireland and to many cities in England. Its Dublin brewery had become one of the largest in the world.

Whilst the impact of transport changes was already apparent by 1870, it was still incomplete in the perishable goods industries (Mingay, 1989). Country mills, driven by water or wind power, still produced most of the flour used in small towns and rural areas. The beer consumed in the these places was home-brewed or made by publican-brewers or small breweries. Other perishable goods industries generally remained on a very small scale and were spread fairly evenly across space. Even in towns bakers, cheese-makers, and meat processors rarely employed more than a handful of workers unless they were working for the military or other large institutional customers.

There was more concentration in the production of non-perishable goods, though here the organisation of production was also heavily influenced by state policy. Tobacco, sugar, tea, coffee and cocoa and chocolate were all imported commodities, so processing, where necessary, often took place in the major ports. Sugar refineries, which were very capital- and fuel-intensive, were major features of the urban landscape in Amsterdam, London and other cities, not only for their size but for their smell and smoke (De Vries and van de Woude, 1997, 326-9). Because some of these exotic goods were also heavily taxed, governments tried to prevent smuggling and tax evasion by restricting the number of producers. In the extreme some countries, including France, Austria and Spain, created state-owned tobacco monopolies. These monopolies were some of the largest industrial enterprises of the eighteenth and early nineteenth centuries, though they remained highly labour-intensive (Goodman, 1993: ch.9). The production of spirits, another important source of tax revenue, was also highly regulated. In addition, the introduction of the patent still led to a highly concentrated industry. In 1860 just eight distilleries produced all of the spirits made in England (Weir, 1977: 138).

VII. THE IRON INDUSTRY

Deposits of iron ore were scattered across most of Europe and were thus widely available and in abundant supply, whereas in the most populated and thriving regions, wood had become a scarce resource. In the long run, to overcome this *Holzbremse* or "wood brake", which was binding in the seventeenth and eighteenth centuries, societies had to proceed to a new technology independent of wood (Sombart, 1928: 1137). In the meantime, there were transitory strategies, which either economised on wood consumption or drew on the resources of remote regions with still abundant supplies of wood. This is precisely what Britain did during the eighteenth century, with Sweden and later Russia delivering iron produced with charcoal technology for the increasing British iron consumption. Table 6 provides some crude estimates of annual production of wrought iron in the main iron producing countries of Europe around 1725/50, drawn mainly from assessments of contemporary travellers.

Figure 1 provides a brief overview of the production stages and processes in the iron industry, emphasising the distinction between traditional and modern methods. In the first stage of production, iron ore was smelted in the blast furnace. In the traditional method, the fuel was charcoal, derived from wood, while the modern process used coke, derived from coal. The output, "pig iron", contained a lot of impurities and a high content of carbon, which made it brittle and unsuitable for shaping. It could, however, be turned into final products by casting while in a molten state. Otherwise, the pig iron had to be further refined at the forge to produce malleable or wrought iron, which was suitable for shaping by hammering or later, by rolling. This refining largely involved reduction of the carbon content, and required re-heating, again either using charcoal in the traditional process or coal in the modern puddling process. Distinguishing between the two stages of production is essential, because smelting on the one hand and refining/shaping on the other were not necessarily integrated in one production unit or even at the same location.

1. Sweden: The advanced charcoal-based iron industry

Iron-making in Sweden during the seventeenth and eighteenth centuries was a highly advanced activity closely connected with traditional agriculture (Hildebrand, 1992). Cheap peasant labour was available for burning charcoal, mining the iron ore and smelting it in blast furnaces. Water-driven wheels provided the mechanical power for the bellows of the blast furnace and the hammers of the forge. Bar iron, manufactured by specialist forge-men, was the major product, much of which was exported. Iron-making was heavily regulated by state authorities. From the middle of the eighteenth century, production and thus exports were deliberately limited in order to protect the forests against over-felling. High prices on the international market, as a result of growing demand from Britain and supply restrictions in Sweden, created a favourable environment for a new competitor, namely bar iron from Russia (Agren, 1998: 6). Russian iron production also depended on wood as fuel and on the intensive use of peasant labour. (Florén, 1998).

2. Britain: the first coal-based iron industry

At the beginning of the eighteenth century, the British iron industry was small and unable to meet domestic demand, with imports exceeding domestic production (Hyde, 1977). British costs of production were high, largely because of the high cost of charcoal. The transition from charcoal to mineral fuel techniques, which made possible a process of import substitution, was a long drawn-out affair, lasting the whole of the eighteenth century, as can be seen from Figure 2. As late as 1755, only

20 per cent of pig iron produced in England and Wales was being smelted using coke, and the proportion did not reach 90 per cent until 1790.

Abraham Darby is usually credited with being the first successfully to operate blast furnaces using coke from 1709 onwards. The diffusion of coke smelting gained momentum in the 1750s or even 1760s, which was mainly due to the increasing use of the coke pig iron for castings. New casting techniques had been developed to use coke pig iron made molten again in reverberatory or cupola furnaces fired by coal (Beck, 1897: 380-385, 753-756).

In 1784, Henry Cort obtained a patent for his famous puddling and rolling process. Very quickly this method of refining pig iron came to prevail in the production of wrought or bar iron (Figure 1). The large increases in production turned Britain from one of the foremost importers of iron products in the eighteenth century into a net exporter by the early nineteenth century (Fremdling, 2004: 151-152). Within a century, the British iron industry had transformed itself from a small high-cost producer into the leading supplier of iron products for the world market. Using the new technology, its disadvantage (the “wood brake”) had been turned into a competitive advantage in a long drawn-out process of innovation, diffusion and improvement.

3. The Continent: partial adoption of the new techniques

Despite Landes’ (1969: 126) statement that the process innovations of the coke-using blast furnace, the puddling furnace and the rolling mill were vastly superior to the traditional procedures both technically and economically, traditional or partly modernised processes could survive very well within their native districts and in their traditional markets. Moreover, as they diffused in continental Europe, the new techniques did not follow the British model strictly. Rather, there was a co-existence of techniques adapted to local circumstances, particularly different factor prices (Fremdling, 2004; Broadberry, 1997).

Wallonia, the southern part of Belgium, was the first and nearly only continental region to follow the British model in its entirety. In the middle of the 1820s, numerous works comprising coke blast furnaces as well as puddling and rolling mills were built in the coal mining areas around Liège and Charleroi (Reuss et al., 1960). As in Britain, iron ore and coal were situated closely together. Transportation costs and moderate protective duties screened Wallonia from British competition, while an ambitious government programme for industrial development was framed on the British model (Fremdling and Gales, 1994). In a favourable economic environment, with proximity to customers and the relatively high cost level of the traditional iron industry, the technology transplanted from Britain could prosper. Whilst by the 1840s the old-fashioned way of smelting iron ore with charcoal still dominated in Germany and France, it had already retreated into niches of the market in Wallonia, as can be seen in Figure 2.

In France, as well, imports from Britain had shown that there was a demand for coal-smelted iron. With customs policy fending off British competition from 1822 onwards, a guaranteed high price level and large profits seemed to be in prospect for establishing British type ironworks. Large establishments were actually set up in the coal districts of the Loire valley and the Massif Central, but had no economic success until well into the 1830s. This was largely because of the high costs of shipping ores to the production sites and the final products back to the centres of consumption, where they had to compete with the products of the traditional or partly-modernised iron industry. Thus for a long time, traditional iron production based on charcoal technology remained viable (Roy, 1962; Vial, 1967; Gille, 1968; Belhoste, 1994). Before railway demand created a new situation, a similar story could be told for Germany (Fremdling, 1986: 117-75; Banken, 2000: 210-386; Banken, 2005).

4. The Continent: adaptations in the traditional sector

Some German and French regions managed to compete with the British iron industry for a transitional period, covering several decades. Total factor productivity in smelting iron ore with charcoal increased considerably in the Siegerland, Württemberg and Sweden between 1820 and 1855, particularly as a result of some remarkable economies in the use of charcoal (Fremdling, 1986: 155-160). Furthermore, elements of the new coal-based technology were integrated into the traditional iron production. Small forges could for instance substitute the new puddling furnace for the old refining furnace without changing the rest of the operations. As puddling furnaces were fuelled with coal, the effects of rising charcoal prices were mitigated. These partial modernisations were widespread in the most important regions of the traditional iron industry in Germany and France, namely the Siegerland and the Champagne region. Nevertheless, during the 1860s, German and French charcoal using iron works retreated into niches and in the end sank into insignificance beside the large-scale technology coming from Britain (Figure 2).

In Sweden, however, charcoal iron production did remain viable, but not without adaptation (Rydén, 2005). Around 1830, a Swede came across in Lancashire a refining technique very similar to that of puddling, but using charcoal. This highly productive British charcoal technique became the dominant process of Swedish iron making in the 1840s. Austria also persisted in the use of charcoal technology (Paulinyi, 2005). Only with the coming, from the 1860s, of the new liquid steel Bessemer and Thomas/Gilchrist processes and the open-hearth (Siemens-Martin) method, did technological convergence occur across Europe’s iron and steel industries.

Table 7 shows output of pig iron and steel in the major producing countries around 1860. Britain was heavily dominant, with the next largest country, France, producing less than a quarter of the British output. The other large producers were Belgium and Germany in western Europe, and Austria-Hungary and Russia in central and eastern Europe.

VIII. CONCLUSION

Industry was a relatively small part of the European economy at the beginning of the eighteenth century, with economic activity dominated by agriculture and services. By 1870, much of Europe had undergone an Industrial Revolution, with the development of modern technology leading to an acceleration in the growth rate of industrial output and productivity, accompanied by a dramatic structural shift of economic activity towards industry. Unlike earlier, pre-industrial episodes of economic expansion, this burst of economic growth did not peter out, but ushered in a new era of continuously rising living standards, which has continued to the present.

The process began in Britain and spread to the rest of Europe. However, the process of technology transfer from Britain to the continent should not be seen as a process of slavish copying. Rather, it was a long drawn out affair, involving the adaptation of technology to local circumstances. This process has been illustrated here with examples drawn from the classic industries of the Industrial Revolution, including iron making and textiles. We have also pointed to the importance of steam power as the first general purpose technology in sustaining the process of growth.

TABLE 1: Industry in Europe, c.1870: Overall distribution (%)

	Industry share in country GDP	Country share in European industry	Country share in European GDP
Northwestern Europe			
Belgium	30	3.9	3.4
Denmark	20	0.6	0.8
Finland	17	0.3	0.6
Netherlands	24	1.8	2.1
Norway	12		
Sweden	21	1.0	1.3
United Kingdom	34	30.3	25.5
Southern Europe			
France	34	18.9	15.8
Italy	24	10.0	11.6
Spain	22	3.6	4.7
Portugal	17	0.7	1.1
Central & eastern Europe			
Austria-Hungary	19	9.0	13.1
Austria	*23*	*7.2*	*8.8*
Hungary	*12*	*1.8*	*4.4*
Germany	28	19.8	20.0
Switzerland	36		

Sources: GDP in 1870 boundaries: Broadberry and Klein (2007); Belgium: personal communication from Antoon Soete; Denmark: Hansen (1970: 11, 18, 71-73); Finland: Hjerppe (1989: 78, 218): Netherlands: Smits, Horlings and van Zanden (2000: 130-141); Norway: personal communication from Ola Grytten; Sweden: Schön (1988: 208-17); United Kingdom: Feinstein (1972: Table 51); Broadberry (1997); France: Lévy-Leboyer and Bourguignon (1990: 272, 314); Lévy-Leboyer (1968: 806); Italy: Fenoaltea (2003: 1084); Spain: Prados de la Escosura (2003: 259-274); Portugal: Lains (2003: 138); Lains (2006: 152); Austria-Hungary: Schulze (2000: 316, 339-40); Germany: Hoffmann (1965: 390-391, 451); Switzerland: personal communication from Thomas David.

TABLE 2: Industry in Europe, c.1870: Major branches and countries (%)

	Share of European GDP	Share of European production			
		UK	France	Germany	Big 3
Food, drink, tobacco	5.7	21	16	19	57
Textiles, clothing	7.6	29	24	22	75
Metals	3.4	45	5	24	74
Other manufacturing	4.5	16	23	25	64
Construction	3.7	17	32	13	62
Mining	3.0	70	5	12	87
Utilities	0.3	43	20	11	74
Total industry	28.0	30	19	20	69
GDP		26	16	21	63

Sources: Same as Table 1.

TABLE 3: Per capita levels of industrialisation, 1750-1860 (UK in 1900 = 100)

	1750	1800	1830	1860
Northwestern Europe				
Belgium	9	10	14	28
Denmark	--	8	8	10
Finland	--	8	8	11
Netherlands	--	9	9	11
Norway	--	9	9	11
Sweden	7	8	9	15
United Kingdom	18	19	25	64
Southern Europe				
France	9	9	12	20
Greece	--	5	5	6
Italy	8	8	8	10
Portugal	--	7	7	8
Spain	7	7	8	11
Central & eastern Europe				
Austria-Hungary	7	7	8	11
Bulgaria	--	5	5	5
Germany	8	8	9	15
Romania	--	5	5	6
Russia	6	6	7	8
Serbia	--	5	5	6
Switzerland	7	10	16	26
EUROPE	8	8	11	17
WORLD	7	6	7	7

Sources and notes: Derived from Bairoch (1982), but with UK data before 1830 amended using the industrial production index from Crafts and Harley (1992).

TABLE 4: Output of Coal in 1860, 1000 metric tons

	1000 t	% of GB
Austria	3,189	3.9
Belgium	9,611	11.8
France	8,304	10.2
Germany	16,731	20.6
Great Britain	81,327	100.0
Hungary	475	0.6
Italy (1861)	34	0.0
Russia	300	0.4
Spain	340	0.4
Sweden	26	0.0

Note: Hard coal and brown coal (lignite) are lumped together
Source: Mitchell (2003).

TABLE 5: British labour productivity growth and the contribution of steam technology (% per annum)

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

Source: Derived from Crafts (2004).

TABLE 6: Wrought iron production in Europe, 1725/50

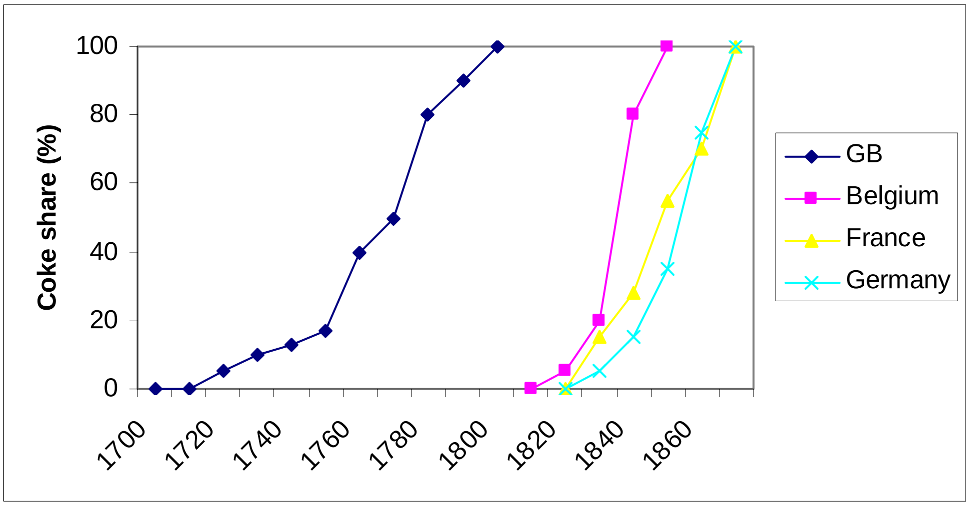
	1000 tonnes
England and Wales	16
France	40 – 70
Sweden	50
Germany	15 – 20
Spain	14 – 18
Habsburg Monarchy	15 – 20
Italy	5
Russia	10 – 15
Europe	200

Sources: King (2005: 23); Wertime (1962: 101); Paulinyi (2005: 97); Hildebrand (1992: 22).

FIGURE 1: Primary wrought-iron industry

Stage of Production	Process		Product
	traditional	modern	
First Stage	Smelting in the blast furnace		pig iron
	with charcoal	with coke	
Second Stage	Refining		wrought iron (steel)
	in a hearth with charcoal	in a puddling furnace with coal	
	Shaping		bar iron (rails)
	by the hammer	by a rolling mill	

FIGURE 2: Share of coke pig iron



Sources: King (2005: 3, 7); King (2006: 264); Fremdling (1986: 342); Fremdling (2005: 49, 51-52); Banken (2005: 56).

TABLE 7: Production of iron and steel in 1860 (1000 tonnes)

Country	Pig Iron	Bar Iron and Rails
France	898	532
Belgium	320	218
Germany	530	335
Great Britain	3888	?
(Exports)	348	741

Sources: Fremdling (1986: 260, 262, 285-6, 324-5, 385); Mitchell (1988).

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