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**RESEARCH MEMORANDUM**

# European Industry, 1700 - 1870[1]

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**Summary**

This paper offers an overview of the development of European industry between 1700 and 1870, drawing in particular on the recent literature that has emerged following the formation of the European Historical Economics Society in 1991. The approach thus makes use of economic analysis and quantitative methods where appropriate. There are a number of important revisions, compared with previous accounts of Europe's Industrial Revolution, particularly as embodied in the major existing textbooks on European economic history. First, the Industrial Revolution now emerges as a more gradual process than was once implied by the use of the "take-off" metaphor. Nevertheless, the scale of the structural transformation that occurred during the process of industrialisation continues to justify the use of the term "Industrial Revolution". Second, although the emphasis on the central role of technological change is not new, we use economic analysis to shed new light on the process. Drawing on a model of technological choice first introduced by Paul David, we emphasise the importance of factor prices for the initial switch to modern capital intensive production methods in Britain, the rate of diffusion of these methods to other countries and path dependent technological change. In the cotton industry, particular emphasis is placed on the role of high wages, while in the iron industry, the price of coal is seen to pay an important part. We also draw on the idea of a General Purpose Technology to evaluate the role of steam power.

[1] This is an extended version of a chapter for *Unifying the European Experience: An Economic History of Modern Europe, Volume 1: 1700-1870*, edited by Stephen Broadberry and Kevin O'Rourke. To be published by Cambridge University Press 2009. This version will be published in Jahrbuch für Wirtschaftsgeschichte – Economic History Yearbook, Berlin: Akademie Verlag 2008.
For references, please quote **Economic History Yearbook 2008/2**.

## 1. 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, building on already high shares of economic activity in industry and involving at first only a modest increase in the growth rate, the term "Industrial Revolution" has continued to be widely used (Crafts, 1985; Shaw-Taylor and Wrigley, 2007). 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.

## 2. Key Themes

### *2.1. 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.

## 2.2 *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).

## 2.3 *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, as a result of technical developments which prevented pollution from ruining the product. 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).

## *2.4 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 (2008) 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.

## *2.5 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).

### *2.6 A framework for comparative analysis*

We will draw on a framework of comparative analysis which encompasses many of the above themes. The general framework was developed by David (1975) and has been applied in the context of the Industrial Revolution by Broadberry (1997) and Fremdling (2004). Figure 1A characterises the initial different technical choices in Britain and Continental Europe at the beginning of the eighteenth century. There are two available technologies, which differ in the proportions of capital (K) and labour (L). Once the technique has been chosen, substitution possibilities are very limited, so that to all intents and purposes fixed coefficient technology can be assumed. The convex combination of these alternative techniques determines the available process frontier (APF), since in principle, a combination of both processes could be used. If we assume a further set of latent techniques spanning the range of factor proportions, then joining up the points of minimum input combinations we obtain a continuously differentiable isoquant of the fundamental production function (FPF).

In Figure 1B we add in relative factor prices. If, as in eighteenth century Continental Europe, labour is relatively cheap, the relevant factor price line is $P_0$ and producers locate at B, using the relatively labour intensive technique. On the other hand, if labour is relatively expensive, as in eighteenth century Britain, the relevant factor price line is $P_1$ and British producers locate at A. Note that although Continental and British producers use different techniques, they nevertheless have access to the same fundamental production function.

In Figure 2 we move from the initial choice of technique to technological progress, which can be represented as a movement around a ray through the origin. David (1975), following Atkinson and Stiglitz (1969), uses a model of endogenous technological change through learning, which results in locally neutral technological progress. In fact, there is no guarantee that the technological progress has to be neutral, constrained by "elastic barriers" surrounding the process ray $\alpha$ in Figure 2, but in practice such neutrality does seem to have occurred in Britain before the mid-nineteenth century (von Tunzelmann, 1994: 289-290). David (1975: 81) argues that the elastic barriers can be seen as representing non-convexities in micro-engineering designs, but they could also be seen as arising from the fact that before the mid-nineteenth century, patents were not examined, and therefore did not have the same need to avoid similarity to previous designs that characterised the later patent system. In Figure 2, technological progress occurs as a stochastic process between the elastic barriers around the α-ray and shifts the available process frontier from APF to APF'.

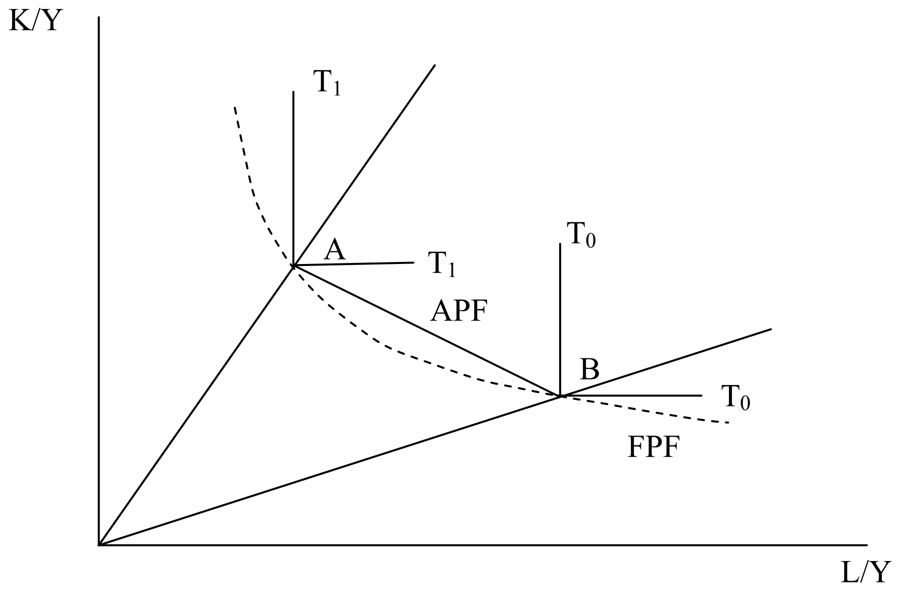
Figure 3 illustrates the process of competition between new and old technologies. In Figure 3A, the new and old technologies co-exist, with technological progress in Britain along the α–ray, being matched by improvements to the old technology in Continental Europe along the β-ray. Continental producers, faced with relatively cheap labour continued to produce using the evolving Continental technology, while British firms, faced with relatively expensive labour, continued to produce using the evolving British technology.

Note in Figure 3B that with continued improvement to the British technology along the α-ray, but without any improvement to the Continental technology, a point was bound to be reached where the old Continental technology became uncompetitive at any set of factor prices. This occurs at point A' in Figure 3B. Of course, this may not be the end of the story, since producers with the old technology cold always press for protection and thus hang on in business for some time.

The model has been developed in terms of substitution possibilities between capital and labour. However, as noted by Fremdling (2004: 169), it may be adapted to the substitution between coal and wood to shed light on the iron industry. With wood in short supply in Britain, and coal in relative abundance, the British developed a coal-using technology. Although Continental European producers had access to this technology, they continued to utilise wood-using technology to a much greater extent than in Britain.

**Figure 1: Choice of Technique**

*A. The available process frontier and the fundamental production function*



*B. The role of factor prices*

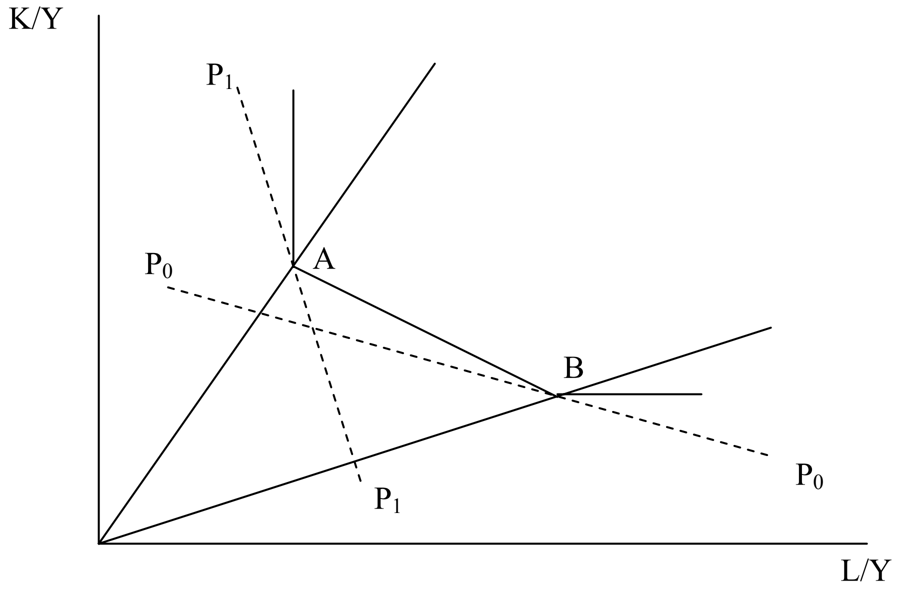



**Figure 2: Localised technological progress**

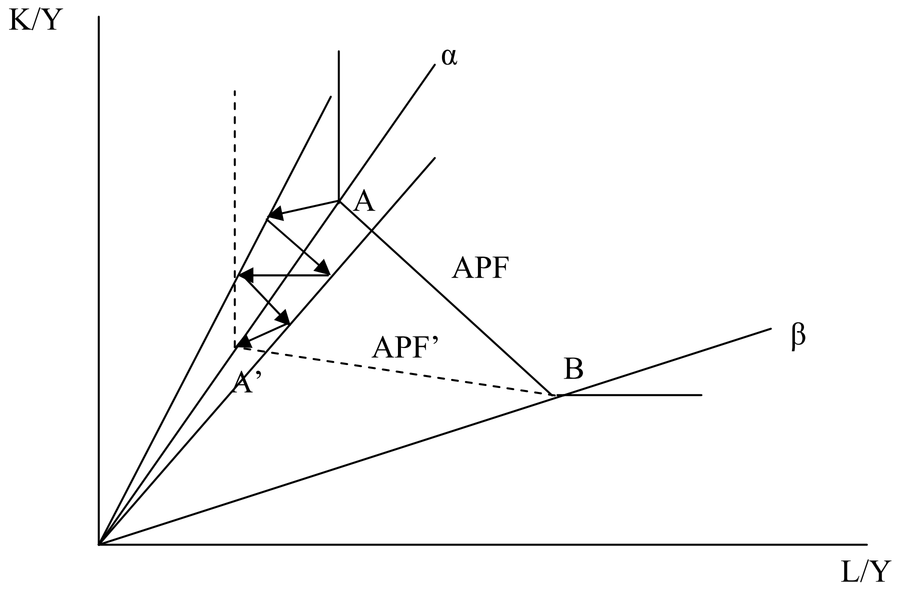
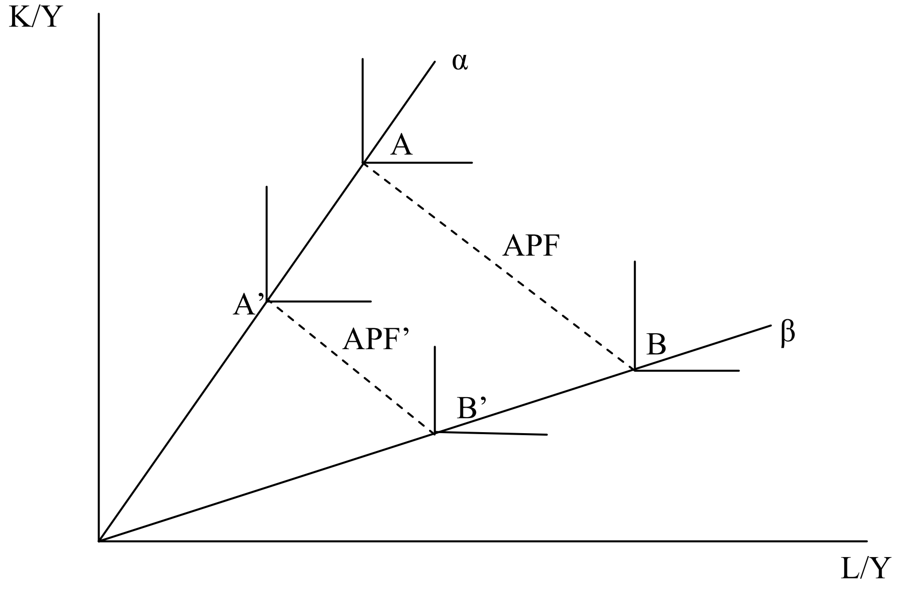
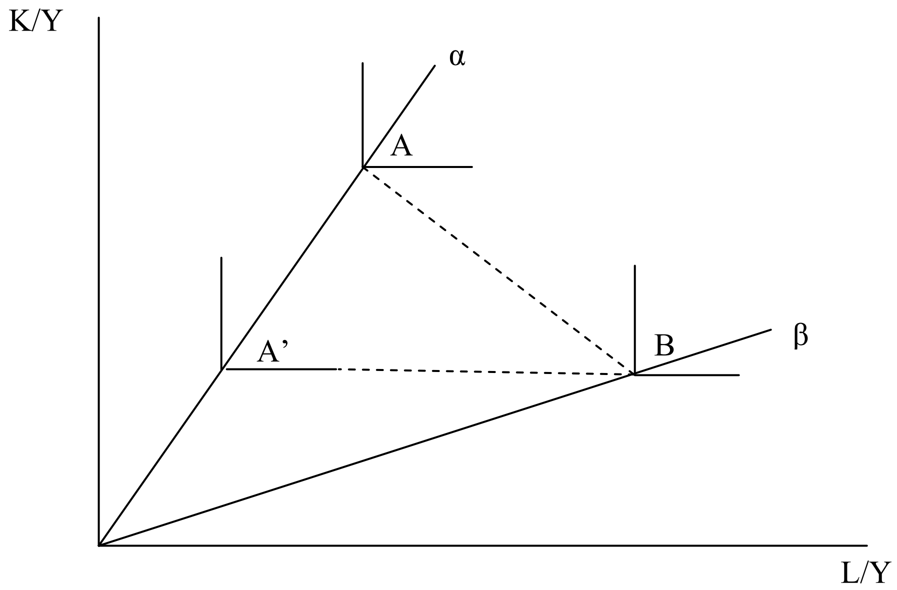


**Figure 3: Competition between technologies**

*A. Co-existence between technologies*




*B. β–technology redundant*




## 3. 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.[2] 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.

**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 (2008); Belgium: personal communication from Antoon Soete; Denmark: Hansen (1970, pp. 11, 18, 71-73); Finland: Hjerppe (1989, pp. 78, 218): Netherlands: Smits et al. (2000, pp. 130-141); Norway: personal communication from Ola Grytten; Sweden: Schön (1988, pp. 208-217); United Kingdom: Feinstein (1972, Table 51); Broadberry (1997); France: Lévy-Leboyer and Bourguignon (1990, pp. 272, 314); Lévy-Leboyer (1968, p. 806); Italy: Fenoaltea (2003, p. 1084); Spain: Prados de la Escosura (2003, pp. 259-274); Portugal: Lains (2003, p. 138); Lains (2006, p. 152); Austria-Hungary: Schulze (2000, pp. 316, 339-340); Germany: Hoffmann (1965, pp. 390-391, 451); Switzerland: personal communication from Thomas David.

[2] 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: 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 1860 = 100)**

| | 1750 | 1800 | 1830 | 1860 |
|---|---|---|---|---|
| *Northwestern Europe* | | | | |
| Belgium | 14 | 16 | 22 | 44 |
| Denmark | -- | 13 | 13 | 16 |
| Finland | -- | 13 | 13 | 17 |
| Netherlands | -- | 14 | 14 | 17 |
| Norway | -- | 14 | 14 | 17 |
| Sweden | 11 | 13 | 14 | 23 |
| United Kingdom | 28 | 30 | 39 | 100 |
| *Southern Europe* | | | | |
| France | 14 | 14 | 19 | 31 |
| Greece | -- | 8 | 8 | 9 |
| Italy | 13 | 13 | 13 | 16 |
| Portugal | -- | 11 | 11 | 13 |
| Spain | 11 | 11 | 13 | 17 |
| *Central & eastern Europe* | | | | |
| Austria-Hungary | 11 | 11 | 13 | 17 |
| Bulgaria | -- | 8 | 8 | 8 |
| Germany | 13 | 13 | 14 | 23 |
| Romania | -- | 8 | 8 | 9 |
| Russia | 9 | 9 | 11 | 13 |
| Serbia | -- | 8 | 8 | 9 |
| Switzerland | 11 | 16 | 25 | 41 |
| EUROPE | 13 | 13 | 17 | 27 |
| WORLD | 11 | 9 | 11 | 11 |

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 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 wholly 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.

## 4. 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.

**Table 4: Output of Coal in 1860, 1000 metric tons**

| | 1000 t | % of Europe |
|---|---|---|
| Austria | 3,189 | 2.7 |
| Belgium | 9,611 | 8.0 |
| France | 8,304 | 6.9 |
| Germany | 16,731 | 13.9 |
| Great Britain | 81,327 | 67.6 |
| Hungary | 475 | 0.4 |
| Italy (1861) | 34 | 0.0 |
| Russia | 300 | 0.2 |
| Spain | 340 | 0.3 |
| Sweden | 26 | 0.0 |

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

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).

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

| | Economy-wide labour productivity growth | Contribution of steam technology: 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).

## 5. 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. In the eighteenth century its share in a much smaller manufacturing sector was probably higher, perhaps 40-50 per cent. Crafts and Harley (1992, p. 728) put the textile industries at 48% of industrial value-added in the mid-eighteenth century. Estimates for France in the 1780s put the textile share at much the same level (Daudin, 2004, p. 29)

The production of clothing remained largely traditional. 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 all 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, pp. 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, pp. 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 Germany (Federico, 1997, p. 64).

These figures for equipment and raw material use understate British dominance during much of the early nineteenth century since one reaction by other European 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, notably in light woollen goods (Jenkins and Ponting, 1982, pp. 146-148).

The United Kingdom had not always been so dominant in textile trade and production. As late as the 1780s, whilst it was a large net exporter of woollens, the U.K. was still quite 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 et al. (1991, p. 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 European countryside (Clarkson, 2003; Jenkins, 2003; Solar, 2003; van der Wee, 2003). 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 distant markets, either for urban centres of consumption, such as London, Paris or Amsterdam, or for colonial markets in the Americas. 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 among the major producers of woollen cloth. But by the eighteenth century these traditional 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, p. 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 the Manchester area in the U.K. and the border area taking in parts of eastern France, southern Germany and northern Switzerland. The most dynamic sector of the cotton industry for much of the eighteenth century 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 breakthroughs in the mechanisation of textile production in Britain occurred in cotton, a sector where there was no local supply of the raw material. That they took place in cotton production, as against that of woollens or linens, owes much to the relative elasticity of the cotton fibre. The early machines were quite jerky, so repairing breakages in the yarn, which was often the job of child labour, was a major problem. That the breakthroughs took place in Britain where, as Broadberry and Gupta (2008) 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, is another issue. 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. Allen (2007) shows that the spinning jenny was highly profitable at British factor prices, but not at French or Indian factor prices. 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 European overseas markets (Sullivan, 1989; Broadberry and Gupta, 2008).

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. Ways to prepare fibres better and to run the machines more smoothly 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 100,000 or so elsewhere in the world (Farnie, 2003, p. 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). But as the machines were being continuously improved, they eventually became more economical than hand-spinning and weaving.

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, Derbyshire 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 wool textile producing areas in the U.K. 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 in various markets 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, p. 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, p. 33).

During the early to mid-nineteenth century the development of textile industries on the continent depended in large part on the extent to which they were protected from British competition. The case of Belgium is illustrative (Scholliers, 2001; Solar, 1992). Its mechanized cotton industry developed rapidly during the Napoleonic wars, when what would become Belgium was part of imperial France. When the country became part of the Netherlands, in 1815, the loss of the French market meant that the cotton industry languished until the mid-1820s when the Dutch government reserved its colonial markets for domestic producers. The industry then lost this market when Belgium gained independence in 1830 (and an indigenous Dutch industry got its start). In the 1830s and 1840s the Belgian industry received protection sufficient to reserve it its domestic market. The story of the Belgian linen industry is similar. In the late 1830s and early 1840s the development of mechanical flax spinning benefited from protection for the domestic market and preferential access to the French market, though the latter was eliminated by the French government in 1842 under pressure from its own producers.

The Belgian textile producers, condemned to a small domestic market, eventually succeeded in competing with their U.K. rivals. They did so by investing in up-to-date machinery and by concentrating on certain niches in the market. By the 1850s the Belgian cotton spinners were starting to export a significant share of their production, mostly in coarse and medium grade of yarn. The flax spinners worked almost exclusively at middle grades of yarn and were also able to export successfully from the 1850s, though they faced continually shifting markets as other countries changed their commercial policies.

By the middle of the nineteenth century other continental producers were also starting to compete with U.K. producers in third markets. From the 1840s the French, Germans and Belgians were beginning to challenge Britsh dominance of the important U.K market for woollen (as against worsted) cloth (Jenkins and Ponting, 1982, ch. 6). In addition to the Belgians, Austrian (actually Czech) flax spinners were exporting yarn.

The big exception to the story of U.K dominance in textiles was the silk industry (Federico, 1997). In the eighteenth and early nineteenth centuries the U.K. did have a large silk industry, centred in London and Macclesfield, but it had been built behind import prohibitions and high tariffs and did not figure in international markets. When Britain started reducing tariffs from the 1840s its domestic industry quickly lost ground to continental manufacturers. The French industry, centred on Lyon for cloth and St Etienne for ribbons, produced an entire range of silk products and was particularly strongin finer fabrics. The other continental centres were more specialized. The Germans around Krefeld made medium-quality velvets and plushes. The Swiss around Zurick and the Italians around Como made plain cloths.

## 6. Food, Drink and Tobacco

The food, drink and tobacco industries grew significantly during the eighteenth and nineteenth centuries, though it is difficult to be precise about the pace and patterns of growth. Flour-milling, brewing, distilling, and meat- and fish-processing were, for most of the period, characterized by small-scale, dispersed production that, except where the state taxed inputs or outputs, did not lend itself to easy measurement. Even where the state did levy taxes, evasion could render the returns misleading. In the more remote parts of Ireland and Scotland, for example, illicit distillation had almost driven out legal spirits in some periods (Connell, 1968). Another problem in measuring the growth of food processing is its often close connection with agriculture. In this period butter- and cheese-making typically took place on the farm. Wine-making is still largely done in conjunction with growing the grapes. Such activities are often classified as agricultural production until they start to take place in separate establishments.

Nonetheless, there were several forces making for growth in these industries. One was the acceleration in European population growth from the mid-eighteenth century. Perhaps as important 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. There were also changes in tastes. 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). Other developments included the van Houten press (1828) in cocoa processing, the production of evaporated or condensed milk (1856), the beginnings of roller milling of grain from the 1830s and 1840s and, more controversially, Liebig's meat extracts from the late 1840s (Horrocks, 2003). But in this period, by contrast with the late nineteenth century, which saw major developments such as pasteurization, refrigeration and cigarette machines, most technical change was incremental and drew on innovations in other sectors. Better metals and metalworking techniques made machinery more reliable and permitted increases in its size. Steam power was applied in some industries, notably milling and brewing, though even in these activities wind, water and animal power remained important right up to 1870. However, even water-powered flour mills became larger and more sophisticated in their use of power and in their organisation of production. As industrial structures, the three- and four-storey flour mills built in the United Kingdom from the mid-eighteenth century onward were precursors of the early cotton spinning mills (Cullen, 1977).

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 (Bielenberg, 1998).

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 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.

Large-scale food processing was initially often associated with demand from the military or other large customers. Navies, as well as merchant shippers and plantation owners, gave rise to the trade in heavily salted beef and pork, the centres of production for which were in Cork and Hamburg. They bought large quantities of biscuit (crackers baked several times) from commercial bakers in the ports. Military demand also stimulated technological change. During the Napoleonic wars the Frenchman Nicolas Appert discovered that food could be preserved by sealing it in glass bottles, then heating it. Shortly thereafter two Englishman, John Hall and Bryan Donkin, made the first canned foods. However, given the relatively high costs of both the containers and the processing, bottled and canned foods remained the province of the military and the rich until later in the nineteenth century.

The production of non-perishable goods was more concentrated, 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. During the eighteenth century 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, pp. 326-329). 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 Europe's largest industrial enterprises in 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 most countries. In addition, the introduction of the patent still led to a highly concentrated industry. By 1860 just eight distilleries produced all of the spirits made in England (Weir, 1977, p. 138).

War and state policy changed the nature of the sugar industry during the nineteenth century. Shortages of cane sugar imports during the Napoleonic wars stimulated the cultivation of sugar beets. By the end of the wars, in 1815, over 300 processing plants were operating in France and central Europe. Lobbying by this new industry, as well as by agriculturalists, for whom the sugar beet was an attractive new cash crop, led many countries to raise tariffs on cane sugar imports over the course of the century, with the result that by the late nineteenth century most of the sugar consumed in Europe was made from beet. Given the high cost of transporting sugar beets, initial processing became dispersed in plants scattered across the countryside of northern Europe.

## 7. 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 wrought iron production in the main iron producing countries of Europe around 1725/50, drawn mainly from assessments of contemporary travellers.

**Figure 4: Primary wrought-iron industry**

<table>
<tr><td rowspan="2">Stage of Production</td><td colspan="2">Process</td><td rowspan="2">Product</td></tr>
<tr><td>Traditional</td><td>modern</td></tr>
<tr><td rowspan="2">First Stage</td><td colspan="2">Smelting in the blast furnace</td><td rowspan="2">pig iron</td></tr>
<tr><td>with charcoal</td><td>with coke</td></tr>
<tr><td rowspan="2">Second Stage</td><td colspan="2">Refining</td><td rowspan="2">wrought iron (steel)</td></tr>
<tr><td>in a hearth with charcoal</td><td>in a puddling furnace with coal</td></tr>
<tr><td rowspan="2"></td><td colspan="2">Shaping</td><td rowspan="2">bar iron (rails)</td></tr>
<tr><td>by the hammer</td><td>by a rolling mill</td></tr>
</table>

Figure 4 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.

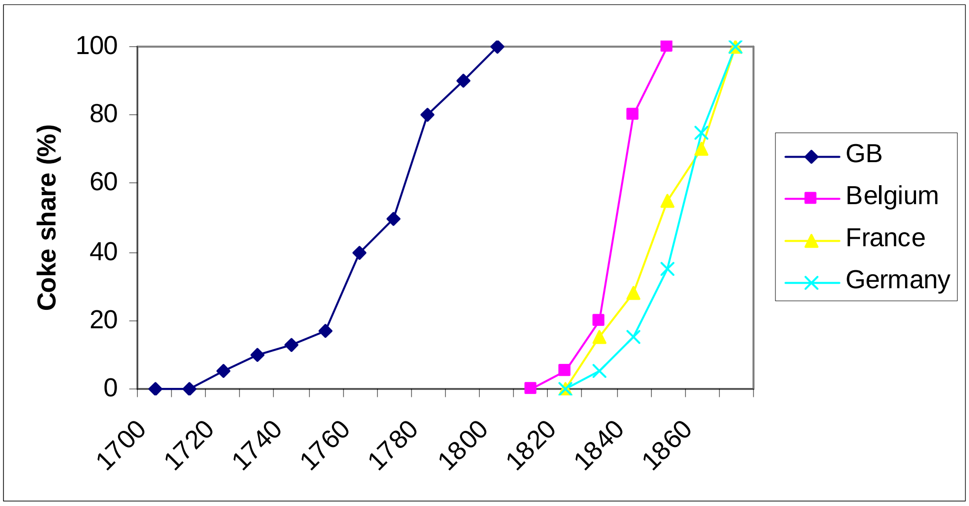
### *7.1 Sweden: the advanced charcoal-based iron industry*

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. Even the wood supply was balanced to the needs of the iron industry by a static regime of regenerating fast growing woods. 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).

### *7.2 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; for production figures in see Table 6). 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 5. 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.

**Figure 5: Share of coke pig iron**




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

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 4). 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.

### *7.3 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 5.

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 et al., 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).

### *7.4 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 5).

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 6 shows output of pig iron 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.

**Table 6: National shares of iron production in Europe, 1725/50 and 1860/1 (%)**

| | Wrought Iron 1725/50 | Pig Iron 1860/61 |
|---|---|---|
| United Kingdom | 8.1 | 59.5 |
| France | 27.0 | 13.7 |
| Sweden | 25.4 | 2.6 |
| Germany | 8.7 | 8.1 |
| Spain | 8.0 | 0.6 |
| Austria/Hungary | 8.7 | 4.8 |
| Italy | 2.5 | 0.4 |
| Russia | 6.2 | 4.9 |
| Belgium | ? | 4.9 |
| Rest of Europe | 5.3 | 0.5 |
| Europe (1000 tonnes) | 165-214 | 6,539 |

Sources: 1725/50: King (2005, p. 23); Wertime (1962, p. 101); Paulinyi (2005, p. 97); Hildebrand (1992, p. 22); 1860/1: Fremdling (1986, pp. 260, 262, 285-286, 324-325, 385); Mitchell (1988).

## *7.5 Heavy industry and the railways*

During the 1960s, the prominent New Economic historians Fogel (1964) and Fishlow (1965) challenged the traditional view of considering railways as "…the most powerful single initiator of take-offs". Rostow had used the metaphor of "take-off" to characterise his concept of the Industrial Revolution in which he maintained that "… the development of railways has led on to the development of modern coal, iron, and engineering industries" (Rostow, 1962: 302-3). Fogel and Fishlow then tried to quantify the impact the railroad had made on American economic growth during the nineteenth century and thus on the American industrial revolution. Besides calculating costs and benefits of railroads in their "Social Saving" approach they measured railroads' effects on other sectors by applying the concept of forward and backward linkages.

Analysing backward linkages to the iron industry, both authors concluded that railroad derived demand had not initiated a modern, thus mineral-fuel-consuming, iron industry in the United States during the 1840s and 1850s. Due to the peculiar set-up of import duties, the rails for the construction of American railroads were rather imported from Britain than produced by indigenous iron and rolling mills (Fremdling, 1977). Hawke (1970), who in turn measured the impact of railways on the British economy, did not take into account the backward linkage effects of foreign, e.g. American, railway construction on the British iron industry. Hawke´s judgement, however, that backward linkages were not "essential to the existence of an iron industry" in Britain should at least be complemented by considering exports of railway iron as well. Unfortunately, until 1855 British export statistics subsumed rails under the category of bar iron. In subsequent years, when railway iron was registered separately, it constituted more than 50 per cent of bar iron, and presumably this was also the case in the 1840s. In addition, enormous amounts of pig iron leaving the British isles were worked up to railway iron in foreign iron works. The growing dependence of the British iron industry on export markets was thus more and more supported by the increasing railway construction abroad (Fremdling, 2000: 202).

**Table 7** **Input-Output Coefficients for Railway and Heavy Industry in Germany (Zollverein or Prussia), 1840s - 1860s**
**(coefficients in per cent of domestic consumption)**

| Delivery (including foreign trade) to / from | I railway | II coal mining | III iron processin | IV blast furnace | V agriculture | VI consumption (100) = output + (imports - exports) |
|---|---|---|---|---|---|---|
| I railway | | | | | | |
| 1840s | | 0 | | | | 100 |
| 1850s | | 1 | | | | 100 |
| 1860s | | 25 | | | | 100 |
| II coal mining | | | III and IV | | | |
| 1840s | 0 | 7 | 5 | | | 100 = 106 - 6 |
| 1850s | 2 | 7 | 12 | | | 100 = 102 - 2 |
| 1860s | 3 | 7 | 30 | | | 100 = 109 - 9 |
| III iron processing (rails, wrought iron) | | | | | | |
| 1840s | 32 | | | | 30 | 100 = 70 + 30 |
| 1850s | 36 | | | | 26 | 100 = 96 + 4 |
| 1860s | 27 | | | | 20 | 100 = 113 - 13 |
| IV blast furnace (pig iron) | | | | | | |
| 1840s | | | 84 | | | 100 = 72 + 28 |
| 1850s | | | 88 | | | 100 = 72 + 28 |
| 1860s | | | 92 | | | 100 = 85 + 15 |

**Source:** **Fremdling, 1979: 224-6**

The German case is depicted here in some detail. From the viewpoint of unbalanced growth theory, the interplay between the railways and heavy industry formed a leading sector complex of German industrialisation from the 1840s to the late 1860s (Holtfrerich, 1973). In order to reveal the close interconnections within this complex over time the changing input-output coefficients between these sectors and foreign trade quotas were estimated (Fremdling, 1979). For three different periods (in each case related to the early years of the respective decade), the coefficients or percentages indicate how much of domestic consumption (output plus imports minus exports) was delivered to the sector named at the top of a given column in Table 7. Row I shows that 0 per cent of the railway´s output went to coal mining in the early 1840s, i.e. to the transportation of coal; in the early 1850s, it was 1 per cent; but during the early 1860s, due to decreasing freight rates for coal, it rose to 25 per cent. Row II indicates that railways (locomotives) consumed rather low shares of coal output whereas the iron industry increased its share from a modest five per cent to nearly one third of overall consumption of coal. Field III/I demonstrates the close connection between railway construction and iron works. In field III/VI, import substitution on the level of iron processing (rails) becomes visible whereas constantly high imports of pig iron (field IV/VI) indicate the peculiar way in which the iron industry of the emerging industrial agglomeration of the Ruhr modernised. Initially, puddling and rolling mills had been erected there on the basis of imported pig iron from Belgium and Scotland. These figures prove how closely railways, iron and coal were connected through backward and forward linkages. They also reveal an important agricultural demand for iron products from the 1840s to the 1860s (field III/V). Finally, the rapidly changing magnitude of most of the coefficients reflects structural changes occurring in the German economy during these years. Whereas the increase both of domestic coal mining and of the domestic iron industry depended heavily on the linkage effects of the other two leading sectors, the growth of the railway was determined mostly exogenously and thus depended far less on the growth of the other two sectors. Especially in its beginning, railway construction had been induced by the traditionally existing demand for the transportation of passengers and goods of high value which were hauled among existing cities (Fremdling, 1975).

Beyond the German case, the connection between railways and industrialisation was ambiguous with the impact of backward linkages varying from country to country. Like in Germany, the initial construction of other European railways was chiefly not induced by the needs of economic branches typically associated with the industrial revolution proper.[3] Most countries imported the capital goods, required to establish the main network and its rolling stock. In Belgium, however, the further expansion of the coal-consuming iron industry depended on state railway construction and on export markets for railway iron. And in France, the modern iron works embodying British technology for the first time sold their product with profits by supplying rolled rails to railway companies (Fremdling, 1986). Based on the evaluation of nearly all European country studies O´Brien (1983: 15-17) summarised the linkage effects to heavy industry as follows: “At the outset almost every country except Britain and Belgium laid down imported rails and hauled freight with foreign locomotives. But in some countries the process of import substitution quickly redirected demand towards domestic industry [France, Germany]. In others [the Netherlands, Spain, Italy, Tsarist Russia] the lags … were long, and the establishment of the initial networks exercised almost no impact upon local metallurgy,

[3] The early coal trains were important for the technical breakthrough but not for the commercial success of the railway nationally.

coal and engineering but contributed to the continued development of British, French and Belgian export industries."

## 8. 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..

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