Foreign trade-transfer-adaptation

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1 Introduction

This article aims at disclosing general features of the transfer pattern to the Continent, exemplified for some particular countries. Special attention is given to the international trade flows in iron producs as they form an integal part of this transfer. The composition and contents of the present book make it superfluous to give a thorough account of the transition process in the UK (for this see the chapter by Evans). As a background for my description and analysis of the transfer of these mineral techniques to some selected Continental countries during the second half of the 18th century and the first decades of the 19th century some typical features in the UK herself will be highlighted, though. The period dealt with is confined to the time before the crucial demand of railway construction made iron industries in France, Belgium and Germany completely switch to the economically successful British model. For a brief summary account of the railway age see Fremdling (2002, pp. 216-219). The developments in France and Belgium will be put into front here but I will refer to other countries as Germany as well.

Both for Britain and most countries on the Continent following later, the transition from an organic / wood economy towards a mineral-fuel / coal economy (Wrigley 1988) raises the question of 'Why the delay?'(Landes 1972, p. 126). Landes asked this question when comparing the Continental achievements in industrial performance with those of Britain around the Crystal Palace World Exhibition in 1851. At bottom, the question can even be turned against Britain, though. Going beyond Landes' linear retrospective view on British accomplishments and Continental failures one might see Britain's transition to a coal-based technology as a rather long-drawn desperate attempt to overcome the scarce endowment with the most important natural resource of the organic economy, namely wood. In this view, Great Britain was the first country to resort to an Industrial Revolution in order to overcome the bottleneck of running short of wood. This limit to growth had hit Britain earlier than most parts of the Continent. Within a sketch of a broader framework at the end of my essay, I will try to explain, why the differences between the British and Continental technologies persisted for such a long time or even held on (e.g. Sweden). But before that, a brief introduction into the primary iron industry is given with a simplified model of the production stages and processes. Figure 1 distinguishes between traditional and modern methods of producing and processing wrought iron.

Figure 1
Primary wrought iron industry

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

In the pre-industrial or traditional method, the iron was smelted in the blast furnace by using charcoal as a fuel. Charcoal (which is derived from wood) was then substituted for by mineral fuel (mainly coke derived from coal). The output, 'pig iron', contained a lot of impurities and a high content of carbon. Therefore it was brittle and could not be shaped in a cold or warm state. The only way to use it directly for final products was to cast it in a molten state into forms for cast iron products. To some extent, this was done directly with the molten pig iron flowing out from the blast furnace. Indirectly it was done by reheating the pig iron again before the casting. In order to produce wrought iron the pig iron had to be refined, which in essence meant a reduction of carbon. By refining (the second stage of the primary iron production), wrought iron was obtained, which could be shaped into the desired bars or rails. These were elastic enough, not brittle any more and could endure mechanical shocks without breaking easily. 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. This rough outline of the production process in the primary iron industry is necessary to comprehend the specific transition from an iron industry based on wood-fuel to an iron industry based on mineral-fuel. On the Continent, some traditional and some modern methods were combined in the two stages of production, which were often performed in different independent locations. Within the history of technology, such interplay of 'old' and 'new' is still too neglected an issue.

In the UK, it took the iron industry almost one century to proceed from charcoal to mineral fuel. The British model of smelting, refining and shaping iron (see Figure 2) was framed by two benchmark innovations, namely Abraham Darby's coke-fired blast furnace of 1709 and Cort's puddling and rolling process of 1784. Within the 18th century, the British iron industry transformed itself from a small producer at high cost to the leading supplier of iron products for the world market. With the new technology, her disadvantage turned to a competitive advantage in a long-drawn process of innovation, diffusion and improvement.[1]

Figure 2

The British model (wrought iron)

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

After the end of the Napoleonic Wars, the British iron industry was not only free from any real competition in her domestic market, but was increasingly able to export much of her output abroad. From 1815 to 1830, 'exports usually amounted to between one-quarter and one-third of total output' (Hyde 1977, pp. 144, 172). From 1830 to 1870, exports jumped from one-quarter to roughly 60 per cent of total pig iron production. From a British point of view, on the basis of available aggregate figures, it seems quite appropriate to conclude that British ironmasters ‘maintained and perhaps strengthened the strong international competitive position they had established in the early part of the century’ (Hyde 1977, p. 173). This conclusion is supported by rather crude evidence, using aggregate export figures in relation to aggregate output figures. They inevitably conceal the considerable structural changes affecting Britain’s competitive position in foreign markets, which took place from the 1820s onwards.

[1] There are numerous books and articles on the development of the British iron industry. I mainly draw on the standard work by Hyde (1977). Concerning output, see Riden (1977), the summary account by Harris (1988) and the classical articles edited by Church (1994). Furthermore, see Fremdling (2000) and Evans (in this book).

Table 1

British iron exports, 1821-1870, thousands of metric tonnes, percentages and ratios, annual averages.

Years	Pig iron total tonnes	Germany/ Holland[a] per cent	France per cent	USA per cent	Bar iron (including rails) total tonnes	Germany/ Holland[a] per cent	France per cent	US per cent	Ratio total tonnes[b]
1821/25	4.5	4.6	56.3	28.4	30.5	7.2	12.6	11.4	8.5
1826/30	8.5	14.3	43.5	23.4	49.3	11.7	4.4	14.9	7.3
1831/35	21.6	13.0	22.5	44.9	76.4	12.1	2.0	27.8	4.4
1836/40	44.5	23.2	26.5	24.8	112.8	13.3	1.3	37.6	3.2
1841/45	103.7	43.7	17.7	17.4	183.0	28.6	1.8	22.8	2.2
1846/50	165.0	26.5	13.4	38.0	304.3	11.9	0.5	49.9	2.3
1851/55	276.4	26.1	12.9	37.8	575.7	7.1	2.4	56.8	2.6
1856/60	366.1	37.2	20.6	18.0	266.2[c] (475.9)[d]	10.2[c] (7.7)[d]	3.8[c] (3.9)[d]	28.5[c] (26.3)[d]	2.5
1861/65	470.0	33.4	29.9	10.2	256.7[c] (370.8)[d]	9.0[c] (6.9)[d]	5.4[c] (3.6)[d]	16.2[c] (15.1)[d]	1.7
1966/70	626.5	30.0	17.0	17.8	269.2[c] (605.4)[d]	6.3[c] (5.0)[d]	2.0[c] (-)[d]	16.5[c] (41.5)[d]	1.7

Notes: a) Holland is included because exports to Dutch ports were very often transit trade to Germany.
b) For bar iron a multiplier of 1.25 was used to obtain pig iron equivalents. Bar iron divided through pig iron.
c) Without railway iron.
d) Railway iron.

Source: See Appendix.

The bulk of British iron exports were made up of pig iron, bar iron and rails. Unfortunately, British export statistics subsumed rails under the category of bar iron, until 1855. In subsequent years, when railway iron was registered separately, it constituted more than 50 per cent of bar iron. The growth of these exports between 1821 and 1870 is shown in Table 1. To analyse the pace of this growth, I calculated average yearly growth rates. Whereas pig iron exports grew by a remarkable 11 per cent, bar iron, including rails still achieved the impressive growth rate of nearly 7.5 per cent. Both figures are well above the average yearly growth rate of British pig iron production, which amounted to 5.6 per cent (Riden 1977). They demonstrate quite patently the increasing dependency of the British iron industry on export markets. Not only did the product mix of British iron exports shift towards the lower stages of production (from bar iron to pig iron, as shown by the ratio in Table 1), but above all, Britain could only enlarge her export markets, especially after 1850, by diverting her incremental deliveries from her closest Continental competitors, namely Belgium, France and Germany - constituting the European core - to the periphery and to the developing world.

2 Transfer patterns to the Continent: Coke smelting and castings

In Britain, the diffusion of coke-smelting did not get momentum before the 1750s, or even 1760s, although in Coalbrookdale it had been a viable commercial process of producing cast iron products directly from the molten coke pig iron, from 1709 onwards. The now classical explanation for the rather belated diffusion of coke smelting origins from Hyde (1977), who maintains that charcoal prices had not increased sharply before the 1750s / 60s. Evans (see his chapter in this book) however challenged this view by pointing out that Hyde had not presented any convincing quantitative evidence: According to Hyde's own data, variable costs of charcoal smelting during the 1720s even were as high as in the 1750s / 60s. For Evans himself it remains rather a mystery, what iron masters had convinced to increasingly apply coke smelting from then on. Without yet being able to substantiate his supposition, Evans states that there must have been a major technological breakthrough. The only example of such a breakthrough he mentions is that of the cast iron blowing cylinders for the blast furnace. Isaac Wilkinson received a patent on this innovation in 1757. I basically concur with Evans' supposition, although I rather believe in the power of various minor innovations than in <u>the</u> major technological breakthrough. My hypothetical explanation is based on the fact that the technology of producing cast iron products improved considerably during that period. Whereas in the time from the 1750s to the 1780s the production of pig iron increased threefold, bar iron production just doubled (Fremdling 1986, pp. 30 f.). New casting techniques had been developed with the coke pig iron being molten again in a reverberatory or cupola furnace fired by coal. The rather homogeneous molten pig iron could be cast into complicated forms and high quality cast iron products resulted.[2] The best known example is the still existing Iron Bridge crossing the Severn near Coalbrookdale, built between 1777 and 1781. Moreover, much of the machinery of the industrial revolution including the cylinders of steam engines was made from cast iron. Cast iron products served various purposes. As they were cheap they even replaced goods hitherto made from wrought iron (details in Hyde 1977, p. 128; Beck 1897, p. 755 ff.). And last but not least: 'The cannon and shot, as well as the small arms used against Napoleon, were cast in British foundries' (Hyde 1977, p. 128). In order to produce accurate cylinders for steam engines or cannons, new drilling techniques had been developed. Best known for this achievement is John

2 For technical details, see Beck 1897, pp. 380-385; 753-756.

Wilkinson, Isaac's son. There is a lot of evidence that foreign metallurgists visiting British iron works during the second half of the 18th century were highly interested in precisely these casting techniques, which allowed the production of superior and cheaper cast iron goods for civil and above all military purposes (cannons).[3] I agree, however, with Broadberry's (1997, p. 78) principal notion, that all countries or entrepreneurs have access to a common pool of knowledge. Thus concepts of 'industrial espionage' (Harris 1988), which are very common with technical historians, divert from the principle economic problem of technology transfer or diffusion.

On his travels through Europe during the 1760s, the French metallurgist Jars also visited British iron works. He neither got acquainted with the then modern processes of stamping and potting for making wrought iron from coke pig iron, though, nor did he even believe that this type of pig iron would be a useful input for wrought iron at all. Jars' description of the new British casting techniques, however, attracted the curiosity of several experts from the Continent. Besides Jars and other Frenchmen as De la Houlière, Swedish metallurgists, who throughout the 18th century knew and described the state of the art minutely, regularly visited Britain. Furthermore, Prussian civil servants as Heynitz and von Reden made their technological travels to this country (Weber 1976). Although these visitors did get acquainted with the new British methods of producing wrought iron with coal (stamping and potting and even Cort's puddling) they were not impressed by the outcome of these processes. They obviously considered the coal-based products as inferior to bar iron produced by means of charcoal pig iron. The new casting techniques with coke pig iron taken as an input, however, convinced the French and Prussian governments to introduce these techniques into their countries. Together with the Frenchman Wendel, John Wilkinson's brother William in 1776 got a contract for establishing these techniques at the coalfields of Creuzot (Woronoff 1984). Already before its total collapse in 1814, this enterprise failed both economically and technically. For instance, the cannons produced between 1788 and 1793 were too brittle. In my opinion, it is short-sighted to blame the quality of the inputs for this failure (Harris 1978, pp. 258 f.); for from 1836 onwards, based on the same local raw materials as at the end of 18th century (Roy 1962) the brothers Schneider set out to make Le Creusot one of the most successful engineering and iron works of France.

The Prussian government tried to introduce the coke blast furnace early in Upper Silesia and eventually they planned the adoption of British cast iron techniques for producing cylinders and cannons from this input. In 1788, William Wilkinson spent four months as a Prussian adviser (Weber 1976, p. 227). In contrast to Le Creusot, the Prussian civil servants von Reden and Heynitz opted for a stepwise introduction of the coal techniques. And at a very early date indeed, ironworks in Upper Silesia did succeed in smelting iron ore in a coke blast furnace. The state-owned ironworks of Malapane, Gleiwitz and Königshütte (Krolewska Huta) were the very first on the Continent to continuously use coke for smelting pig iron.

The meanwhile prevailing view (including my earlier writings on the subject) namely the reproach that Prussian technocrats modernised only an enclave of the iron industry has to be modified considerably, however. Although von Reden in 1789/90 and other experts clearly got acquainted with e.g. Cort's innovations, they obviously did not intend to introduce British methods of producing wrought

[3] In the following, I mainly draw on Harris 1988.

iron altogether. Why should they, if their region did not suffer from a serious shortage of wood yet and Continental observers during the second half of the 18th century generally regarded coke pig iron as an inferior input for wrought iron and the refining methods of stamping/potting (and later puddling) as inferior to Continental forge practises? The term of 'inferior' refers both to prices and quality.

It was otherwise with cast iron: On (British) coke pig iron in combination with new casting techniques Continental observers very well conferred the superiority (or at least a viable alternative or complementarity) to Continental practises. Hence the endeavour, to solely transfer casting techniques to the Continent during the second half of the 18th century.

As a provisional result, the attitude of contemporary observers, might be summed up as follows: In most respects, the British iron industry of the 18th century was regarded as different, unique and in parts even as backward. This in any case in comparison towards Swedish best practises.

3 Transfer patterns to the Continent: Coke smelting and puddling / rolling

What consequences did the process innovations of the coke-using blast furnace, the puddling furnace and the rolling mill entail on the iron industries in continental Europe during the 19th century? According to David Landes' statement that these innovations were highly superior to the traditional procedures both technically and economically, the new techniques ought to have spread over continental Europe rapidly.[4] This implies that the old-fashioned iron industry based on charcoal should have perished fast and instead of, as formerly, being spread all over the country the modern iron industry should have clustered round the coalfields. This did not occur for quite a long time, though. So David Landes' statement does not prove to be correct. He mixed up technical with economic superiority and thus - unjustly - blamed Continental entrepreneurs for not quickly adopting the seemingly 'superior' technology.[5] In Great Britain, the new techniques had indeed surpassed the old ones as well economically by the end of the eighteenth century, but such a supplantation does not hold in most regions on the Continent. Here, traditional or partly modernised procedures could endure very well within their innate districts and with their markets of old. Moreover, when spreading over continental Europe the new techniques did not follow the British model strictly. Great Britain as the cheapest supplier worldwide (on the world market and on regional markets) created conditions to which Continental regions reacted in different ways.[6]

3.1 Indirect, embodied transfer

A process innovation may provoke adaptations in other economic regions by being transmitted there directly and also by any trade in the new products that embody the new technology. At the beginning of the 19th century, British producers were undoubtedly the cheapest suppliers of iron internationally, but foreign ironmasters were protected from imports, firstly by tariff barriers, secondly by transportation

[4] 'Why the delay? Surely, the hardest task would seem to have been the original creative acts that produced coke smelting, the mule, and the steam engine. In view of the enormous economic superiority of these innovations, one would expect the rest to have followed automatically.' Landes (1972, p. 126).
[5] On this very common fallacy, see Rosenberg (1976, pp. 189-210).

costs and thirdly by differences in the quality of the iron, which meant a price threshold. The French, Belgian and German iron industries based on charcoal, which despite increasing productivity were finally doomed to extinction, could thus survive and even expand well until the the 1850s. In the long run, however, these artificial, natural and quality barriers were turned down or disappeared completely, and British iron definitely became competitive on Continental markets for a long time. On the other hand, protection allowed the emergence of iron industries based on mineral fuel even where the natural resource endowment was less favourable than in Britain. This became evident when railway construction led to a sharp increase in demand for mass-produced iron and a modern iron industry emerged within a relatively short period. Britain herself helped her foreign competitors to accelerate the catching-up process by delivering vast amounts of cheap coke pig iron, which was worked up in foundries and rolling mills abroad (e.g. the Ruhr).

British growing iron exports showed fluctuating market shares for different customers.Even the long-term development of demand for British iron was uneven, both in relation to the prominence of individual importing countries and the balance between pig iron and bar iron. The main clue to the fluctuations and shifts in the composition of British iron exports must therefore be found outside Britain, as her position as lowest cost producer was already established at the beginning of this period. It is the internal development of the importing countries that has to be scrutinised for an appropriate explanation of these changes. Here I concentrate on France and Belgium with brief references to some German states.

The French example during the first years of peace in the 19th century illustrates how powerfully British exports of bar iron produced with coal threatened the indigenous iron industry. The protective tariff France levied on bar iron had been adjusted according to Swedish prices in 1814. That was founded on the fact that Sweden had become the price leader and the most important exporter of bar iron beside Russia during the 18th century. For bar iron imports from Sweden this protective tariff might have sufficed indeed. Apparently unexpectedly, however, a new competitor gained against French ironmasters in their indigenous market, namely rolled iron, produced with coal, from Great Britain. In spite of the tariffs of 1814 it had a marked price advantage in several regional markets, in particular in places accessible by waterway such as Paris. (The ratio of imports to production accounted for around 16 per cent in 1821). Urged by their ironmasters, the French government raised the tariffs to keep off this perceptible competition. Doubling the price of British bar iron in the Channel ports, this new tariff was practically prohibitive. In Table 2 the decline of British bar iron exports to France after 1822 is clearly seen.[7] Only in the 1850s was the tariff reduced enduringly. Thus the tariff of 1822 artificially lengthened the proper geographical distance between Great Britain and France. The defence against an import of the new technology as it was embodied in the new iron products suppressed any import competition that would have forced the French iron making regions into adaptations. The tariff policy succeeded in shielding the new products from France indeed, but the process innovations still made their way into the country.

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[6] For detailed data, see Fremdling (1986) or the article published in English (1991a).

[7] British pig iron kept a considerable market share in France, because of the demand from foundries. For an extended discussion, see my English publication on the French case (1998).

During the 1820s, Belgium was part of the Kingdom of the United Netherlands. British exports of bar iron hardly penetrated into the markets and production centres of the old-established iron industry of Wallonia. In the free trade tradition of Holland rather moderate duties prevailed thus preventing import duties as in France. The huge iron and machinery work of Cockerill at Seraing near Liège tried to get supply of British iron. As it received nothing but incidental deliveries in the end Cockerill rather relied on cheaper or qualitatively better procurements; that is: his own production, local supplies and still deliveries from traditional German producers of high quality bar iron, e.g. Remy in Neuwied at the banks of the Rhine (Fremdling 1986, pp. 67-80).

After the separation of Belgium from the United Netherlands, iron masters enforced considerably higher import duties on iron deliveries from Britain. At the beginning of the 1830s, duties on pig iron imports increases fourfold while those on bar iron augmented by mere 40 % at valorem. This recourse to higher duties changed in the late 1850s, and finally stopped, when Belgium joined the free trade area of the Cobden-Chevalier-Treaty in 1861. Overlooking the entire period from the 1830s to the 1860s, British iron exports never ingrained deeply in the Belgian market. Only in extreme cyclical downturns with low prices in Britain, e.g. 1837 and 1838, did British exports enter the Belgian domestic market. In the long run, Belgian ironmasters not only secured their domestic markets but succeeded in exporting their products to neighbouring countries such as France, Germany and the Netherlands. Above all, they competed with British suppliers on remote markets as Italy and in the 1860s, they even penetrated into the British domestic market (Fremdling 1986, pp. 234-248).

Table 2

French Iron Imports, 1815-1828, thousands of metric tons and percentages

Year	Bar Iron (fer en barres) tons	from Great Britain %	Belgium %	Sweden/Norway %
1815	6.9			
1816	4.0			
1817	13.8			
1818	10.1			
1819	10.7			
1820	8.9	76.8	10.1	?
1821	13.8	79.2	4.9	?
1822	5.1	48.5	8.1	37.1
1823	4.5	33.7	6.7	53.9
1824	5.8	17.7	3.0	67.1
1825	6.1	?	?	?
1826	9.6	?	?	?
1827	7.3	6.7	0.7	74.3
1828	6.6	15.9	0.3	72.3
	Pig Iron (fonte brute)			
1815	0.9			
1816	2.3			
1817	2.8			
1818	3.4			
1819	2.7			
1820	5.4			
1821	7.7	35.6	42.0	-
1822	8.3	30.7	41.5	-
1823	7.8	41.7	39.0	-
1824	7.2	24.9	47.4	-
1825	7.4	?	?	-
1826	11.4	?	?	-
1827	7.8	28.6	46.1	-
1828	8.8	29.9	44.2	-

All figures are related to the "commerce spécial", i.e. imports entering the French market for consumption.
Sources: See Appendix.

Table 3

French Iron Production, Imports and Exports, 1825-1870, thousands of metric tons and ratios, annual averages

Years	Pig Iron Production (P)	Imports (M)	Exports (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1824/30	220.9	8.8	0.9	-0.81	0.04
1831/40	293.6	13.4	0.4	-0.94	0.04
1841/50	447.2	49.9	0.4	-0.98	0.11
1851/60	780.0	70.7 (+19.4)[a]	0.8	-0.98 (-0.98)[a]	0.09 (0.11)[a]
1861/70	1191.5	79.1 (+73.1)[a]	0.7	-0.98 (-0.99)[a]	0.07 (0.13)[a]
Years	Bar Iron[1] Production (P)	Imports (M)	Exports (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1825/30	148.6	6.9	0.5	-0.86	0.04
1831/40	195.2	5.6	0.5	-0.84	0.03
1841/50	301.7	6.7	0.8	-0.80	0.02
1851/60	480.0	18.1 (+1.9)[a]	2.1 (+5.1)[a]	-0.79 (-0.47)[a]	0.03 (0.03)[a]
1861/70	767.0	12.2 (+16.4)[a]	2.5 (+28.9)[a]	-0.66 (0.05)[a]	0.01 (-0.004)[a]

1 Including rails

a The “commerce spécial” is a category in which imports allowed under the system of “admission temporaire” are not included. It can be corrected by means of following formula: S = commerce spécial; G = commerce général (MG – MS) – (XG – XS).

Sources: See Appendix.

Table 4

German[1] Iron Production, Imports and Exports, 1825-1870, thousands of metric tons and ratios, annual averages

Years	Pig Iron Production (P)	Imports (M)	Exports (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1825/30	56.8	3.8	3.5	-0.03	0.004
1831/33	71.0	5.0	1.9	-0.45	0.04
1834/40	149.0	14.2	1.8	-0.77	0.08
1841/50	196.4	75.2	1.8	-0.95	0.37
1851/60	411.5	150.5	5.3	-0.93	0.35
1861/70	1022.5	154.0	41.5	-0.58	0.11
Years	Bar Iron[2] Production (P)	Imports (M)	Exports (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1825/30	34.1	3.7	1.8	-0.35	0.06
1831/33	40.7	5.3	3.4	-0.22	0.05
1834/40	66.0	13.1	2.3	-0.71	0.16
1841/50	128.4	35.2	2.2	-0.88	0.26
1851/60	257.6	20.1	6.1	-0.53	0.05
1861/70	528.5	13.9	28.8	0.35	-0.03

1 Until 1833 Prussia; from then on the Zollverein
2 Including rails
Sources: See Appendix.

Table 5

Belgian Iron Production, Imports and Exports, 1841-1870, thousands of metric tons and ratios, annual averages

Years	Pig Iron Production (P)	Imports (M)	Exports (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1841/45	105.3[a]	1.4	37.4	0.93	-0.34
1846/50	178.5	0.3	74.9	0.99	-0.42
1851/55	231.1	0.1	78.6	1.00	-0.34
1856/60	317.4	2.8	53.4	0.90	-0.16
1861/65	396.2	10.4	28.2	0.46	-0.04
1866/70	488.7	55.1	17.5	-0.52	0.08
Years	Wrought Iron Production (P)	Imports of Bar Iron and Rails (M)	Exports of Bar Iron and Rails (X)	$\frac{X-M}{X+M}$	$\frac{M-X}{P}$
1841/45	62.3[b]	0.4	3.5	0.79	-0.10[b]
1846/50	69.1	0.2	3.1	0.88	-0.04
1851/55	104.2	0.2	12.3	0.97	-0.12
1856/60	182.1	0.6	35.5	0.97	-0.19
1861/65	294.2	1.0[c]	68.5[c]	0.97[c]	-0.24[c]
1866/70	423.4	3.0	162.9	0.96	-0.38

a 1841-1844 estimated by Fremdling (1986, p. 78)
b 1845 only
c 1861-1864
Sources: See Appendix.

The competitive position of the three Continental countries is revealed in Tables 3 to 5. Exports and imports are compared by using the Balassa Index. It ranges from + 1 to -1, where a positive value reveals a comparative advantage and a negative one the opposite. Furthermore, net foreign trade in pig and bar iron is expressed in relation to domestic production (see the last two columns of the respective tables).

French ironmasters clearly had a comparative disadvantage in foreign trade during the entire time span from the 1820s to the 1850s. With the system of 'admission temporaire' in the 1850s and moderate free trade in the 1860s this improved to some extent for bar iron. In general, however, foreign trade never gained very high proportions compared with production (Table 3).
In Germany, the ironmasters revealed an increasing comparative disadvantage concerning pig iron from the 1820s to the 1850s. Extremely high shares of net imports accompanied this in the 1840s and 1850s. Concerning bar iron and rails, this dependence on imports was even more pronounced during the same decades. The last two columns of Table 4, however, also show the process of import substitution in the 1850s and 1860s. In the last decade, Germany even became a net exporter of bar iron and rails.

Belgian ironmasters revealed a comparative advantage in foreign trade throughout from the 1840s to the 1860s. Concerning pig iron, this changed from the late 1850s to the 1860s. The export quotas showed high values for pig iron mainly in the 1840s and early 1850s, which were due to preferential tariff rates to France and Germany. The significant growth of the export quotas for bar iron and railway iron in the 1850s and 1860s reveals the increasing comparative advantage in the segment internationally (Table 5).

3.2 Direct transfer

So far, I have concentrated on the British innovations as they were embodied in products, the import of which changed the regional economic pattern in the importing countries. Before railway construction on the Continent demanded huge quantities of wrought iron mainly for rails, for which low quality iron sufficed, Wallonia was the only Continental region to follow the British model successfully (Reuss et al. 1960). Since the middle of the 1820s, numerous works comprising coke blast furnaces as well as puddling and rolling mills were built there in the coal mining areas around Liège and Charleroi. Excelling the others, John Cockerill's factory at Seraing integrated all stages of production, from engineering to the supply of raw materials, as early as 1825. The natural locational factors of Wallonia were similar to those in British iron producing regions with ore and coal situated closely together. Transportation costs and moderate protective duties screened Wallonia from the British competition while an ambitious government programme for industrial development was established on the British model (Fremdling and Gales 1994). There were mainly two additional factors that favoured the Walloon iron industry: firstly, its vicinity to its customers, and secondly, the relatively high cost level of the traditional iron industry. In such an economic environment the technology transplanted from Britain could prosper. In the long tradition of processing wrought iron (for nails and

Rhineland, in the 1820s. Thus the establishment of the new technology there was not confined from the first by sales problems, as it was the case with most of the modern ironworks in France. In Wallonia as well, it took the modern iron industry more than 20 years to push aside the traditional competition. While the old-fashioned way of smelting iron with charcoal in the 1840s still dominated in Germany and France, it had already retreated into niches of the market in Wallonia. During the 1840s, roughly 90 per cent of the pig iron was smelted by the use of coke (Fremdling 2000, p. 212). Table 6 shows the development of the Belgian pig iron production. As early as during the middle of the 1830s, the mineral-fuel technique had surpassed pig iron produced with the use of charcoal. For the production of bar iron, it is not possible to produce figures that delimit both techniques (Table 7). The sheer number of puddling furnaces indicates a higher production in the modern segment of the market. One should not forget, however, that to some extent puddling furnaces refined pig iron, which originated from charcoal blast furnaces. This mixing of old and new techniques became highly important in France and played a role Germany as well.

Table 6

Pig Iron Output in Belgium, 1811-1870 in 1000 metric tons

Year	with charcoal	with coke	total output
1811	39.1		39.1
1822	30		30
1825	35		35
1828	?	?	47.0
1830	40.7	12.0	52.7
1831	31.5	13.5	45.0
1832	22.2	15.1	37.3
1833	25.7	19.7	45.4
1834	29.9	28.3	58.2
1835	34.6	45.5	80.2
1836	39.6	68.4	108.0
1837	39.6	85.1	124.7
1838	46.8	72.2	119.0
1839	31.2	66.3	97.5
1840	30.6	74.2	104.8
1841	30.0	82.0	112.0
1842	9.0	75.6	84.6
1843	19.8	86.0	105.8
1844	15.6	101.2	116.8
1845	13.5	121.1	134.6
1846	19.9	169.4	189.3
1847	26.1	222.3	248.4
1848	19.1	142.5	161.6
1849	14.0	134.5	148.5

1850	13.3	131.1	144.5
1851	13.8	153.9	167.7
1852	10.8	168.0	178.8
1853	9.7	220.4	230.1
1854	11.7	273.2	284.8
1855	14.1	280.1	294.3
1856	15.9	306.0	321.9
1857	14.5	287.8	302.2
1858	11.5	312.7	324.2
1859	9.6	309.2	318.8
1860	5.3	314.9	319.9
1861	5.9	305.9	311.8
1862	3.6	352.9	356.5
1863	6.1	386.0	392.1
1864	5.5	444.3	449.8
1865	4.6	466.2	470.8
1866	0.6	481.8	482.4
1867	1.3	421.7	423.0
1868	0.9	434.9	435.8
1869	2.2	532.2	534.3
1870	1.8	563.5	565.3

Notes and Sources: See Appendix.

Table 7

Wrought Iron Output and Number of Refinery Furnaces in Belgium, 1845-1870

Year	Output 1000 metric tons	Refinery with charcoal	Furnaces with coal (puddling)
1845	62.3	137	161
1846	67.1	130	164
1847	80.9	124	206
1848	57.8	124	196
1849	67.1	125	204
1850	72.7	131	192
1851	74.6	131	201
1852	76.6	124	210
1853	110.8	118	257
1854	114.2	116	270
1855	144.6	113	282
1856	180.0	110	298
1857	176.2	99	309
1858	161.3	85	285

1859	174.8	92	295
1860	218.3	85	314
1861	236.9	79	339
1862	260.5	65	390
1863	279.8	59	417
1864	343.9	56	525
1865	349.7	51	558
1866	388.3	33	518
1867	362.0	34	495
1868	350.1	22	528
1869	494.1	16	670
1870	522.6	15	714

Sources: See Appendix.

In France, the conditions after 1822 seemed to favour establishing British type ironworks (Figure 2: The British model). By then, imports from Britain had shown that there was a demand for coal iron. With the customs policy guaranteeing a high price level, a big profit seemed to be in prospect. In expectation of this, ironworks shot up in the coal districts of the Loire valley and the Massif Central, from 1822 onwards. Following the British model, they were originally built as big ironworks comprising several stages of production. These new establishments, however, had no economic success until far into the 1830s. Technical problems at the outset were solved little by little but the new locations presented serious shortcomings. Other than in Britain, iron ore had to be transported from afar, which raised the costs of production enormously. Moreover, the sites of the new iron industry were located far away from the centres of consumption, which made the sale dearer. To make matters worse, in these centres the new products had to compete with those the traditional or partly modernised iron industry offered in a superior quality .The newcomers could not undercut the prices of the old-established firms low enough for them to enter the markets permanently. Thus for a long time, the changing economic structure of the coal mining areas did not entail the decline of the traditional iron producing regions (See Tables 8 and 9; Roy 1962, Vial 1967, Gille 1968, Belhoste 1994). The same holds true for German regions.

Table 8

Pig Iron Output in France, 1819-1870 in 1000 metric tons

Year	with charcoal		with coke or mixed fuel		total production
	pig iron[a]	products[b] directly casted from pig iron	pig iron[a]	products[b] directly casted from pig iron	
1819	110.5		2.0		112.5
1822	107.8		3.0		110.8
1824	192.3		5.3		197.6
1825	194.2		4.4		198.6
1826	200.3		5.6		205.8
1827	209.1		7.4		216.4
1828	199.3		21.8		220.9
1829	190.0		27.1		217.1
1830	239.3		27.1		266.4
1831	197.2		27.6		224.8
1832	194.7		30.3		225.0
1833	196.8		39.3		236.1
1834	185.8	36.1	43.3	3.8	269.1
1835	208.3	38.2	46.0	2.3	294.8
1836	223.3	38.8	43.1	3.2	308.4
1837	223.1	45.8	59.3	3.5	331.7
1838	235.1	43.2	65.2	4.2	347.8
1839	239.2	44.5	62.7	3.8	350.2

1840	223.5	47.2	69.1	8.0	347.8
1841	219.9	72.0	61.3	23.9	377.1
1842	223.5	73.7	77.4	24.9	399.5
1843	232.1	59.7	104.6	26.3	422.6
1844	217.5	63.1	109.8	36.8	427.2
1845	205.8	59.1	133.1	41.0	439.0
1846	209.7	73.0	182.8	56.9	522.4
1847	287.7	51.7	225.3	26.8	591.6
1848	240.8	41.5	170.0	20.1	472.4
1849	214.7	36.7	144.8	18.1	414.2
1850	190.6	38.9	155.8	20.3	405.7
1851	202.9	44.3	169.5	29.2	445.8
1852	220.1	43.2	217.4	41.9	522.6
1853	242.5	49.9	326.9	41.6	660.9
1854	293.4	50.5	374.7	52.5	771.1
1855	306.1	54.7	433.8	54.7	849.3
1856	316.5	58.5	485.6	62.6	923.1
1857	318.7	54.6	554.8	64.2	992.3
1858	278.1	48.2	494.0	51.2	871.6
1859	291.4	42.1	481.7	49.3	864.4
1860	274.7	41.8	526.5	55.3	898.4
1861	237.1	38.9	620.8	70.1	966.9
1862	239.5	34.4	736.6	80.3	1,090.8
1863	223.4	32.7	813.2	87.5	1,156.9
1864	211.0	13.5	908.7	79.5	1,212.8
1865	180.7	13.2	936.3	73.5	1,203.7
1866	168.8	15.4	984.7	91.5	1,260.3
1867	141.4	13.8	989.7	84.2	1,229.0
1868	120.7	10.6	1,029.4	74.6	1,235.3
1869	98.9	13.8	1,193.3	75.0	1,381.0
1870	77.8	12.1	1,022.1	66.1	1,178.1

[a] 1819-1833 including [b]
Sources: See Appendix.

Table 9

Bar Iron Output in France, 1819-1870 in 1000 metric tons

Year	with charcoal or mixed fuel	with hard coal total	of this rails[a]	total of bar iron
1819	73.2	1.0		74.2
1822	71.2	15.0		86.2
1824	99.6	42.1		141.7
1825	102.5	41.1		143.5
1826	104.9	40.6		145.5
1827	104.5	44.4		148.9
1828	102.8	48.6		151.4
1829	108.0	45.7		153.6
1830	101.6	46.9		148.5
1831	101.3	39.8		141.1
1832	99.2	44.3		143.5
1833	99.2	53.1		152.3
1834	102.1	75.1		177.2
1835	108.2	101.4		209.5
1836	110.9	99.7		210.6
1837	110.0	114.6		224.6
1838	109.1	115.1		224.2
1839	101.8	130.0		231.8
1840	103.3	134.1		237.4
1841	110.4	153.4		263.7
1842	109.8	175.0	27.8	284.8
1843	114.7	193.7	28.5	308.4
1844	108.5	206.5	36.9	315.0
1845	108.5	233.8	46.5	342.3
1846	105.9	254.3	53.7	360.2
1847	97.0	279.7	88.7	376.7
1848	72.4	203.8	72.8	276.3
1849	73.2	170.3	41.2	243.5
1850	73.5	172.7	23.1	246.2
1851	82.0	172.1	27.1	254.2
1852	74.1	227.1	60.5	301.8
1853	101.0	350.0	94.7	451.0
1854	93.9	417.2	135.8	511.1
1855	100.3	456.9	147.9	557.2
1856	105.0	463.7	163.1	568.7
1857	103.3	456.6	153.7	560.0
1858	102.5	427.6	141.1	530.1

1859	105.8	427.6	101.4	533.4
1860	96.4	435.8	121.3	532.2
1861	83.3	547.9	164.4	631.2
1862	87.8	646.4	216.2	734.3
1863	95.8	674.4	226.9	770.2
1864	86.0	706.0	216.0	792.1
1865	73.7	695.5	208.8	769.2
1866	74.5	744.9	171.0	819.4
1867	68.8	707.5	172.5	776.3
1868	52.8	760.9	186.0	813.7
1869	55.2	848.5	216.6	903.7
1870	45.9	613.8	171.0	659.7

a before 1842 not seperately documented.
Sources: see Appendix.

3.3 Adaptations of the traditional sector

Whereas Sweden succeeded in developing a completely alternative model traditional German and French regions, well endowed with iron ore and wood, could compete with the British iron technology only for a transitional period, covering several decades, though. In the following, I concentrate on adaptations of the traditional charcoal industry in France and touch upon Germany and Sweden, all of which formed their particular response to the British challenge of iron producing.

Beyond imitation, the British model obtruded various strategies of adaptation onto the traditional iron industry. Hence this sector did not remain passive at all, but it underwent a development known from other sectors of industry as well, for instance from sailing ships: a technique becoming obsolete reaches its highest technical and productive level shortly before it disappears. Accordingly, calculations made for the Siegerland and Württemberg show that smelting iron with charcoal increased its productivity considerably in the decades from the 1820s to the 1850s, which is exactly the crucial period here.[8] This was achieved through extraordinary retrenchments on charcoal having the highest shares in the costs of smelting iron. In some traditional iron producing areas, even the output grew enormously during the crucial period. Only in the 1850s did this growth reveal itself as a short-lived success.

And even then, several contemporary experts did not see it as certain at all, whether or not the traditional iron producing areas that used nothing but wood and iron ore would more or less sink into insignificance by the side of the large-scale technology coming from Britain.[9]

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8 See the calculations in Fremdling (1986, pp. 155-160). This statement is confirmed by using detailed Swedish data on the development of input and output prices: Whereas prices for charcoal, iron ore and labour increased between 1820 and 1855, the price for pig iron remained constant or increased only slightly. See Jörberg (1972), vol. I, pp. 197, 697 f., 702 f., 721 f.

9 On this, see the results of an enquête, which was conducted in connection with the Cobden-Chevalier-treaty between France and United Kingdom. Gille (1968), pp. 211-32; 'Rapport sur les droits spécifiques à établir sur les produits de manufactures Anglaises, en vertu du traité de commerce avec la Grande-Bretagne'. Archives Nationales F. 12 2483. See furthermore the failure of the charcoal iron producing 'Société des Hauts Fourneaux et Forges de la Côte-d'Or', in Jobert (1979).

The traditional iron industry struggled for survival by both increasing the productivity of smelting iron with charcoal and by elaborately integrating parts of the new technique. The small forges could for instance substitute the new puddling furnace for the old refining furnace without changing the rest of the operations (Figure 3: The Champagne model). Detached from the other modern techniques from Britain, the craft of puddling began spreading over many regions of the traditional iron industry, as early as the 1820s. As puddling furnaces were fuelled with coal, the charcoal was left only for the blast furnaces and the rise in charcoal prices was slowed down. These partial modernisations were widely spread over the most important regions with a traditional iron industry in Germany and France, namely the Siegerland and the Champagne. This holds partly true for Wallonia as well. The bar iron produced by mixing old and new techniques was of as good a quality as the traditional iron but much cheaper. At the beginning, the iron made by use of coal through and through had been of inferior quality and thus had to compete hard against both the traditional iron and the new products of the technique combination (Fremdling 1991b).

Figure 3

The Champagne model

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

The hot blast was a further means to render the coexistence of the traditional and the new technology possible for a long time. It was the most efficient single innovation at that time, increasing the productivity of both smelting with charcoal and with coke. Instead of taking cold air, heated air was blown into the blast furnace. In 1828, the Scot James Beaumont Neilson got a patent for this invention. The hot blast raised the temperature in the blast furnace, which thus made better use of the fuel. It soon turned out that Neilson’s innovation was of greatest advantage in regions with the highest fuel prices. Within Great Britain this holds for Scotland, which speedily proceeded to install the hot blast. During the short period from 1829 to 1833, Scotland took the place of South Wales in being the cheapest supplier of pig iron. Concerning Britain’s ability to compete against the Continental iron industry, however, Neilson’s innovation soon proved to be a disadvantage. With the high fuel prices on the Continent it was logical that Neilson’s hot blast spread very fast there. As early as the middle of the 1830s, numerous blast furnaces in Belgium, France and Germany worked with the hot blast. And in France, this innovation spread even faster than in Britain (Fremdling 2000, p. 216, and Table 10). It could also be applied to charcoal blast furnaces with advantage, thereby extending their survival. In addition, a highly important supplementary innovation was introduced there. For a long time, the gases generated with smelting had been uselessly burnt off. In the 1830s, devices were installed to utilise the blast furnace gases for heating the air of the blower. The small iron industry of Württemberg based on charcoal was on top of this development (Plumpe 1982). Soon the modern coke blast furnace proceeded to utilise the blast furnace gases as well. This is a clear case of cross-fertilisation between traditional and modern methods. Economising on fuel like this both protected the traditional iron sector from the rising coal iron industry and also shielded the more cost-intensive coal districts from the less expensive. Nevertheless, during the 1860s, charcoal using iron works retreated into niches and barely covered 10 per cent of the production of pig iron both in Germany and France (Fremdling 2000, p. 212).

Table 10

The diffusion of the Hot Blast in France, 1837-1844

Year	*3.4 Blast Furnaces fueled*								
	with coke or coal			with coke or charcoal			with wood or charcoal		
	total number	in blast	using the hot blast	total number	in blast	using the hot blast	total number	in blast	using the hot blast
1837	30	23	14	11	11	8	502	433	38
1838	33	22	15	11	11	5	514	432	55
1839	33	23	15	10	10	4	526	445	71
1840	40	28	19	14	13	9	527	421	74
1841	43	32	24	11	10	10	519	426	78
1842	45	35	30	16	16	9	530	418	78
1843	45	37	31	26	25	8	526	409	108
1844	50	38	31	26	23	8	518	369	115

Sources: See Appendix.

Sweden boasted of abundant iron ore, wood and sufficient waterpower for driving rolling mills. It did not dispose of coal resources, though. And the large Swedish iron industry based on charcoal was located too far from the coast or navigable rivers to allow the import of coal.

Given these conditions, Sweden found her particular way of responding to the challenge of the new British iron production (see Rydén's chapter in this book). Rydén concludes 'that we should perhaps give more weight to a more developed machine-making technology and industrial organisation than to the actual use of mineral coal. A charcoal response to coal technology implicates that industrial production was possible even when no coal was available.'

The persistent differences of technology between Britain and the Continent in iron making - either permanently [as in Sweden and similarly in Austria (Paulinyi, 1974)] or for a long transitional period [in France and Germany] - demonstrate, that Britain was not merely the first but furthermore (nearly) the only country, that completely proceeded to coal-based techniques before the coming of the railway. (Belgium has to be seen as an exception to the other Continental iron industries.) Britain thus went her own, unique path to the Industrial Revolution. At least for the 18th century and for long periods before the coming of the new liquid steel processes in the second half of the 19th century [Bessemer, Thomas/Gilchrist and the open-hearth method (Siemens-Martin)], her exceptionalism holds true.

4 A sketch of an explanatory framework

Placing the case of the iron industry in a somewhat broader theoretical framework makes the British uniqueness even more palpable.

The iron industry – and probably other technological breakthroughs in Britain as well – could be seen as examples of leapfrogging, which has gained prominence in the recent literature on growth processes (Brezis et al. 1993). The rather slow transfer of the modern iron techniques to continental Europe certainly fits this theoretical concept of comparing countries catching up and forging ahead. But the competitors did not have the same 'buck-horses', which were not placed in one row and one direction, at that. For we witness the persistence of technological differences with an alternative sequence or path of productivity development in certain regions of the Continent. For these deviating paths of development Broadberry's approach to technological differences between the United States of America and Great Britain in the 20th century could probably be used analogously. Broadberry (1997, chapter 6) explains the productivity gap between the US and the UK by applying an evolutionary model of technical change, which integrates David's concept of path dependency with Mokyr's distinction between macro- and micro-inventions.

To illuminate the British-Continental dichotomy (thereby neglecting differences among the Continentals countries), I 'translated' a part of Broadberry's text (1997, pp. 77f.) to the case of the former iron production by merely replacing a few words: ***'Great Britain'*** is substituted for 'New World', ***'coal'*** for 'land/resource abundance' and ***'wood'*** for 'skilled labour'. The substitutes are written in cursive fat letters, followed by the originals in brackets.

> The starting point is the Rothbarth-Habbakuk thesis, which traces the origin of ***trans-channel*** (transatlantic) technological differences to ***coal abundance*** (land and resource abundance) in ***Britain*** (the New World). … ***British*** (American) manufacturing substituted ***coal*** (resource-using machinery) for ***wood*** (skilled labour), which was in short supply in ***Britain*** (the New World). ***In some Continental countries*** (Europe), however, ***wood*** (skilled labour) was abundant and ***coal*** (resources) scarce, so the ***Continental*** (European) technology remained ***wood-intensive*** (skilled labour-intensive). … However, whereas ***Landes*** (Chandler) sees a uniqe best technology and assesses ***Continental*** (French and German) industry according to how quickly they adopted ***British*** (American) methods, I follow the … literature in noting that competitive advantage requires developing distinctive capabilities rather than slavishly copying. Technical change within each country is therefore best seen as a path dependent process, with all countries able to draw on a common pool of knowledge but developing distinctive capabilities and adapting innovations to local circumstances. Finally, some common trends in the development of technology in all countries are noted.'

Most of Broadberry's argumentation and even figures on the further pages in chapter 6 can be applied to the case study on the iron industry, similarly modified. In analogy to Broadberry's figures (on pp. 85 ff.), the point ‘A’ in figure 6.3 was reached in Belgium, France and Germany at least around 1860. Hence, the wood-intensive technology had by then become obsolete there, but definitely not in Sweden.

Touching upon the implicit comparison between the iron industry then and other technological transfers in another space and time, places the persistence of technological differences between Great Britain and successful Continental countries until far into the 19th century theoretically into the tradition of the Rothbarth-Habbakuk-thesis. This provides an explanation of why there were different paths leading to modern economic growth into the 20th century.

Literature

Ågren, M. (Ed.) (1998), Iron-Making Societies. Early Industrial Development In Sweden And Russia, 1600-1900, Providence: Berghahn Books.

Banken, R. (2000), Die Industrialisierung Der Saarregion 1815-1914, Vol. 1, Stuttgart: Franz Steiner.

Beck, L. (1897), Die Geschichte Des Eisens. Dritte Abteilung, Das Xviii. Jahrhundert, Braunschweig: Friedrich Vieweg.

Belhoste, J.-F. Et Al. (1994), La Métallurgie Comtoise Xve-Xixe Siècles, Besançon: Asprodic.

Blanchard, I. (2000), Russian Railway Construction And The Urals Charcoal Iron And Steel Industry, 1851-1914, Economic History Review. 53, Pp., 107-126.

Boëthius, B. (1957), Swedish Iron And Steel, 1600-1955, Scandinavian Economic History Review. 5, Pp. 144-75.

Brezis, E.S., Krugman, P.R. And Tsiddon, D.C. (1993), Leapfrogging In International Competition: A Theory Of Cycles In National Technological Leadership, American Economic Review 83, pp. 1211-18.

O' Brien, P. (2000), Mercantilism And Imperialism In The Rise And Decline Of The Dutch And British Economies 1585-1815. De Economist 148, Pp. 469-501.

Broadberry, S.N. (1997), The Productivity Race: British Manufacturing In International Perspective, 1850-1990. Cambridge: Cambridge University Press.

Church, R.A. (Ed.) (1994), The Coal And Iron Industries. Oxford: Blackwell.

D/Dg D.H. = Glamorgan Record Office, Cardiff. Records Of The Dowlais Iron Company, Incoming Letters.

Evans, Ch., Rydén, G. (1998), Kinship And The Transmission Of Skills: Bar Iron Production In Britain And Sweden, 1500-1860, In: M. Berg, K. Bruland (Eds.), Technological Revolutions In Europe. Cheltenham: Edward Elgar, Pp. 188-206.

Evans, Ch. (2000), Coal, Iron And The Industrial Revolution In Britain. Unpublished Paper. University Of Glamorgan.

Florén, A. Et.Al. (1998), The Social Organisation Of Work At Mines, Furnaces And Forges. In Ågren, M. (Ed.), Iron-Making Societies. Providence: Berghahn Books, Pp. 61-138.

Fremdling, R. (1986), Technologischer Wandel Und Internationaler Handel Im 18. Und 19. Jahrhundert: Die Eisenindustrien In Großbritannien, Belgien, Frankreich Und Deutschland. Berlin: Duncker & Humblot.

Fremdling, R. (1991), Foreign Competition And Technological Change: British Exports And The Modernisation Of The German Iron Industry From The 1820s To The 1860s. In: W.R. Lee (Ed.), German Industry And German Industrialisation. London: Routledge, Pp. 47-76. Reprinted (1994) In: R.A. Church (Ed.), The Coal And Iron Industry. Oxford: Blackwell,
Pp. 345-374.

Fremdling, R. (1998), The French Iron Industry, 1820-1860. The Change From Charcoal To Mineral-Fuel Based Technology. In: M. Merger, D. Barjot And M-N. Polino (Eds.), Les Entreprises Et Leur Réseaux: Hommes, Capitaux, Techniques Et Pouvoirs Xixe-Xxe Siècles. Paris: Presses De L'université De Paris-Sorbonne, Pp. 712-24.

Fremdling, R. (1991), The Puddler. A Craftsman's Skill And The Spread Of A New Technology In Belgium, France And Germany. Journal Of European Economic History. 20, Pp. 529-567.

Fremdling, R. And Gales, B.P.A. (1994), Iron Masters And Iron Production During The Belgian Industrial Revolution: The "Enquete" Of 1828. In: P. Klep And E. Van Cauwenberghe (Eds.), Entrepreneurship And The Transformation Of The Economy. Leuven: Leuven University Press.

Fremdling, R. (2000), Transfer Patterns Of British Technology To The Continent: The Case Of The Iron Industry. European Review Of Economic History. 4. Pp. 195-222.

Gales, B. And Fremdling. R. (1994), Ijzerfabrikanten En Industriepolitiek Onder Koning Willem I: De Enquête Van 1828. Neha-Jaarboek 57, Pp., 287 – 347.

Gille, B. (1968), La Sidérugie Française Au Xixe Siècle. Genève: Libraire Droz.

Griffiths, S. (1873), Griffiths' Guide To The Iron Trade Of Great Britain. Newtown Abbot.

Harris, J.R. (1988), The British Iron Industry 1700-1850. Houndmills: Macmillan Education.

Harris, J.R. (1998), Industrial Espionage And Technology Transfer: Britain And France In The Eighteenth Century. Aldershot: Ashgate.

Hildebrand, K.-G. (1958), Markets For Swedish Iron In The 18th Century. Scandinavic Economic History Review. 6. Pp. 3-52.

Hildebrand, K.-G. (1992), Swedish Iron In The Seventeenth And Eighteenth Centuries. Export Industry Before The Industrialization. Södertälje: Bröderna Ljungsbergs Trykerei.

Hyde, C.K. (1977), Technological Change And The British Iron Industry, 1700-1870. Princeton: Princeton University Press.

Jobert, P. (1979), Paul Thoureau: Echec D'une Concentration Métallurgique En Côte-D'or 1840-1861. Annales De Bourgogne. 51, Pp. 5-30.

Jörberg, L. (1972), A History Of Prices In Sweden 1732-1914. Lund.

Landes, D. (1972), The Unbound Prometheus: Technological Change And Industrial Development In Western Europe From 1750 To The Present. Cambridge: Cambridge University Press.

Paulinyi, A. (1974), Der Technische Fortschritt Im Eisenhüttenwesen Der Alpenländer Und Seine Betriebwirtschaftlichen Auswirkungen (1600-1860), In: M. Mitterauer (Ed.), Österreichischer Montanwesen. Wien: Verlag Für Geschichte Und Politik.

Paulinyi, A. (1987), Das Puddeln. München: Oldenbourg.

Pierenkemper, T. (1994), Strukturwandlungen Im System Deutscher Motanregionen Im 19. Jahrhundert- Saarregion, Oberschlesien Und Das Ruhrgebiet Im Wachstumprozeß. In:
J. Wysocki (Ed.), Wirtschaftliche Integration Und Wandel Von Raumstrukturen Im 19. Und 20. Jahrhundert. Berlin: Duncker & Humblot.

Pierenkemper, T. (1992), Das Wachstum Der Oberschlesischen Eisenindustrie Bis Zur Mitte Des 19. Jahrhunderts-Entwicklungsmodell Oder Spielwiese Der Staatsbürokratie? In:
T. Pierenkemper (Ed.), Industriegeschichte Oberschlesiens Im 19. Jahrhundert. Wiesbaden: Steiner.

Plumpe, G. (1982), Die Württembergische Eisenindustrie Im 19. Jahrhundert. Wiesbaden: Franz Steiner Verlag.

Pluymers, B. (1992), De Belgische Industriële Produktie 1811 – 1846. Leuven: Research Paper: 92.01.

Pluymers, B. (1993), De Produktie Van De Belgische Metallurgie (1810 – 1850), In Aerts, E. Et Al. Studia Historica Aeconomica. Liber Alumnorum Herman Van Der Wee. Leuven: Up. Pp. 325 – 333.

Reuss, C. Et Al. (1960), Le Progrès Économique En Sidérurgie, Belgique, Luxembourg, Pays-Bas 1830-1955. Louvain: Editions E. Nauwelaerts.

Riden, P. (1977), The Output Of The British Iron Industry Before 1870. Economic History Review. 30, Pp. 442-59.

Rosenberg, N. (1976), Perspectives On Technology. Cambridge: Cambridge University Press.

Roy, J.-A. (1962), Histoire De La Familie Schneider Et Du Creusot. Paris: Marcel Rivière Et Cie.

Rydén, G. (2002), Responses To Coal Technology Without Any Coal Resources. Swedish Ironmaking In The First Half Of The Nineteenth Century. Unpublished Paper: University Of Uppsala.

Sombart, W. (1928), Der Moderne Kapitalismus. Vol. 22. München: Duncker & Humblot.

Vial, J. (1967), L'industrialisation De La Sidérurgie Française 1814-1864. Paris: Mouton.

Weber, W. (1976), Innovationen Im Frühindustriellen Deutschen Bergbau Und Hüttenwesen, Friedrich Anton Von Heynitz. Göttingen: Vandenhoeck & Ruprecht.

Woronoff, D. (1984), L'industrie Sidérurgique En France Pendant La Révolution Et L'empire. Paris: Éd. De L'ecole Des Hautes Edtudes En Sciences Sociales.

Wrigley, E.A. (1988), Continuity, Chance And Change: The Character Of The Industrial Revolution In England. Cambridge: Cambridge University Press.

Appendix: Data Sources

Table 1

The iron export data are to be found in the respective yearly volume of the Parliamentary Papers. For the years from 1821 to 1870 the following issues were used to compile the time series; 1825 XXI; 1829 XVII; 1830-31 X; 1831-32 XXXIV; 1833 XXXIII; 1835 XLVIII; 1839 XLVI; 1840 XLIV; 1842 XXXIX; 1843 LII; 1844 XLV; 1845 LXVI; 1846 XLIV; 1847-48 LVIII; 1849 L; 1851 LIII; 1854 LXVI; 1854-55 LI; 1856 LVI; 1857 XXXV; 1857-58 LIV; 1859 XXVIII; 1860 LXIV; 1861 LX; 1862 LVI; 1863 LXV; 1864 LVII; 1865 LII; 1866 LXVIII: 1867 LXVI; 1867-68 LXVII; 1868-69 LVIII; 1870 LXIII; 1871 LXIII p. ii.

British export statistics classify countries according to the sea port a cargo was sent to. For example iron imports of the Rhineland from Britain, which were sent to the Rhine, therefore appear in the British statistics as exports to Holland. That is why Holland is always included to assess British exports to Germany.

British iron exports to Ireland, the Channel Island and the Isle of Man were subtracted from the total, and thereby counted as home consumption.

Table 2

Ministère du Commerce et des Manufactures, Enquête sur les fers, Paris 1829, pp. 21, 23; Douanes Royales de France, Tableau des quantités et de la valeur approximative des marchandises étrangères importées en France pour la consommation pendant l'année...., Paris..., Years 1820-1824; Administration des Douanes, Tableau général du commerce de la France avec ses colonies et les puissances étrangères, pendant l'année..., Paris..., Years 1825-1828; Archives Nationales, F 12 2513.

Table 3

On the production figures see various issues of the French mineral statistics which were published under different headings from 1834 onwards. Direction générale des Ponts et Chaussées et des Mines, Compte rendu des travaux des ingenieurs des mines pendant l'année... (1833-1835), Paris, 1834-1836; ministère du Commerce et des Travaux publics, direction générale des Ponts et Chaussées et des Mines, Résumé des travaux statistiques... (1835-1836), Paris, 1836-1837; ministère des Travaux publics et des Commerce, Résumé des travaux statistiques de l'administration des mines en... (1837-1846), Paris, 1838-1847; ministère de l'Agriculture, du Commerce et des Travaux publics, direction des Mines, Résumé des travaux statistiques de l'administration des mines en .... (1847-1872), Paris 1854-1877. On the foreign trade figures see Administration des Douanes, Tableau général du commerce de la France avec ses colonies et les puissances étrangères, pendant l'année..., Paris, years 1825-1870.

Table 4

On the production figures see Marchand, Hans, Säkularstatistik der deutschen Eisenindustrie, Essen 1939, pp. 88, 115, 129. On the foreign trade figures see Ferber, C.W., Beiträge zur Kenntniß des gewerblichen und commerciellen Zustandes der preußischen Monarchie, Berlin 1829, pp. 29 ff.; Ferber, C.W., Neue Beiträge..., 1832, p. 23; Dieterici, C.F.W., Statistische Übersicht der wichtigsten Gegenstände des Verkehrs und Verbrauchs im preußischen Staate und im deutschen Zollverbande, in dem Zeitraume von 1831 bis 1836, Berlin 1848, p. 95; Sering, Max., Geschichte der preussisch-deutschen Eisenzölle von 1818 bis zur Gegenwart, Leipzig 1882, pp. 290 f.

Table 5

Le Ministre de l'intérieur, Statistique générale de la Belgique, Exposé de la situation du Royaume, période décennale de 1841-1850, 1851-1860, Brussels 1852, 1865;
Commission central de statistique, Exposé de la situation du Royaume de 1861 à 1875, Brussels 1885;
Ministère de l'intérieur et des affaires étrangères, Tableau général du commerce de la Belgique avec les pays étrangers, pendant l'année.... 1835-1870, Brussels 1837-1871.

Table 6

1811, 1828: Calculated from detailed reports, see Pluymers (1992), Pluymers (1993), Gales/Fremdling (1994) and Fremdling/Gales (1994).
1822/1825: Informed guesses, see Gales/Fremdling (1994, p. 310).
1830-1844: until 1842 estimated by Pluymers (1992/93), for 1843/44 he uses figures from the official statistics, but they deviate from Fremdling (1986, p. 78).
1845-1870: Compiled by Fremdling (1986) based on official sources, see quotations for Table 5.

Table 7

See quotations for Table 5.

Table 8

See Table 3.

Table 9

See Table 3.

Table 10

See Table 3. For other years no data are reported.

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