Prof. John H. Munro
Department of Economics
University of Toronto

munro5@chass.utoronto.ca
john.munro@utoronto.ca
http://www.economics.utoronto.ca/munro5/

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ECONOMICS 303Y1

The Economic History of Modern Europe to1914

Prof. John Munro

Lecture Topic No. 16:

III. GREAT BRITAIN AS THE UNCHALLENGED INDUSTRIAL POWER, 1815 - 1873

G. The Revolution in Steel Making

F. **The Maturation of the British Industrial Economy**: for independent reading only.

G. The Revolution in Steel Making

1. **The Importance of Steel in Modern Industrialization**: the essential building block of later 19th century industrialization, across the world.

a) **The Definition of Steel**: as a special and indeed optimum form of iron.

i) **Steel is in fact a form of wrought iron, which is the purest form of iron,**

(1) steel is manufactured by adding the proper amount of carbon to already refined wrought iron,

(2) which is then mixed to produce an homogeneous blend, one that we call steel:

(2) the addition of carbon:

- is from 0.5% to 1.5% of the total metal,
- with an average of 1.0%.

ii) **In terms of carbon content, consider the relation of steel to other forms of iron:**

(1) **cast iron:** with 2.5% to 4.0% carbon

(2) **steel:** with 0.5% to 1.5% carbon

(3) **wrought iron:** from 0.5% to 0.1%

iii) **That mixture meant that steel had the best resistance of any metal to pressure and stress:** so that it would:

(1) neither crack nor shatter like cast iron,

(2) nor bend like wrought iron: which was thus also known as malleable iron.

b) **Other Properties of Steel**:

i) **Can be cut to far greater precision with far sharper edge than wrought iron**:

(1) holding the edge and shape far longer,

(2) and with the hardness of cast iron.

ii) **Has far greater strength in proportion to its weight than any other form of iron**:

(1) and thus its great importance for construction, in building large-scale bridges,

(2) and also for railroads, ships, high- powered machinery, etc.

iii) **These properties of steel can be varied both by varying the carbon content and by adding other metals as special alloys**:

(1) **tungsten -** for greater hardness

(2) **manganese -** for greater malleability (flexibility)

(3) **chromium -** for better resistance to rust and weathering: for ‘stainless steel’.

c) **Economic Importance of Steel**: **as the essential building block of industrialization from the 1860s into the 20th century.**

i) **For the so-called 'Second Industrial Revolution':** of the later 19th century, with three main components

(1) **the steam turbine** – invented by the British engineer Charles Parsons (1884)

- already seen with steam shipping (lecture 13: on the transportation revolutions: last term),
- but even more important for the next component, in the mass generation of electricity

(2) **electrical engines and machines**: electrical power

(3) **the internal combustion engine: for automobiles, trucks, airplanes, industrial engines**

ii) **Reasons why steel was so important for this 'Second Industrial Revolution'**:

(1) because of its hardness, strength, and resistance to stress, compared to cast or wrought iron

(2) ability to be cut and fashioned with precision measurements and edges, so vitally necessary for all forms of machinery, especially powered machinery.

iii) **In general steel provided the essential foundation for late 19th and 20th century industrialization**:

(1) in making physically possible far larger scale forms of industry and transportation

- as already seen with the revolution in steam-powered oceanic shipping
- and also with railways, as will be noted later in this lecture

(2) and far larger scale forms of powered machinery:

iv) **The Revolution in Steel Making** (along with the steam-turbine of 1884) constituted Britain's last major technological contribution to 19th-century industrialization.

(1) it marked the culmination of Britain's industrial leadership;

(2) but it also provided the chief mechanism by which Britain's main industrial rivals, Germany and the US, overtook Great Britain in certain key fields of industrial leadership by the late 19th century, though not all.

v) **On this, see especially David Landes,** *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge, 1969; 2nd edn, 2003), pp. 249-69; and pp. 276-93, for the Second Industrial Revolution.

2. <u>Earlier Methods of Steel Making</u>

a) **Steel was of course known from ancient times**:

i) **it was then probably discovered accidentally in the process of making wrought iron:**

(1) by processes that left too much carbon in supposedly purified or refined iron

(2) yet enough carbon, if properly mixed throughout the wrought iron, to produce genuine steel.

ii) **In ancient and medieval times, however, steel was enormously costly to make:**

(1) i.e., because first the artisans had to produce wrought iron in completely pure form, an already expensive task, as seen last term.

(2) and then they had to create the optimum homogeneous blend of wrought iron and carbon,

(3) a task whose high costs I will illustrate in a moment.

iii) **Consequently with its very high costs and price,**

(1) steel was long limited to just luxury or other high-cost uses:

(2) e.g., in making armour, weapons, surgical tools, other fine precision tools, etc.

iv) **Nevertheless, according to Jared Diamond,** in his now famous book *Guns, Germs, and Steel*, western Europe's application of steel, particularly, its military uses, was a significant factor in allowing Europeans to conquer the New World, and then other parts of the world, from the 16th century.[1]

b) **Cementation Process**: **the Traditional Method of Making Shear Steel**:

i) **This was the traditional steel-making method from ancient times up to the Industrial Revolution**: small scale and very costly, as just suggested.

ii) **First, wrought iron itself had to be produced**:

(1) itself an enormously costly process: as just noted

(2) especially before Cort and Onion's Puddling and Rolling Process of the Industrial Revolution, in the 1770s, which we examined closely last term. [See lecture no. 9]

iii) **Blister Steel**:

(1) The wrought iron was then heated in a bath of carbon, using a charcoal furnace, until the iron was almost molten and the carbon was absorbed onto the surface.

(2) It was called 'blister' steel because of the way that the carbon adhered to the surface of the metal.

iv) **The Blister Steel was then forged red hot over a charcoal fire**

(1) and pounded by forge hammers**,** small bits at a time,

(2) in order to distribute the carbon as evenly as possible.

v) **This process was very costly in fuel, labour, and time:** taking up to two or three weeks to produce good quality steel, whose final result was called 'shear steel'.

c) **Huntsman's 'Crucible Process' of 1742**:

i) **Created or invented on the eve of the Industrial Revolution,**

(1) this process dominated steel making for more than a century,

(2) so that no further advances took place during the Industrial Revolution era itself (i.e., leaving or delaying

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[1] Jared M. Diamond, *Guns, Germs, and Steel : The Fates of Human Societies* (New York : W. W. Norton & Company, 1999). A Pulitzer-Prize winning monograph.

the truly major revolution until the 1850s).

ii) **First, 'blister' steel had to be produced by the traditional cementation process**: thus this innovation affected only the later stage of steel making.

iii) **The 'blister steel' was then heated until molten in a charcoal furnace (later: coke-fired)**:

(1) The molten metal was then poured into clay crucibles containing a carbon coating.

(2) The crucibles were then hermetically sealed to isolate the metal.

(3) This was very similar to the 'potting and stamping process' in iron making,

- which the Wood brothers had subsequently devised, in the 1760s,
- perhaps inspired by this crucible process [See lecture topic no. 9].

iv) **The clay crucibles were then heated in a charcoal furnace**: (later also coke-fired furnace)

(1) so that the carbon in both the crucible and the molten blister steel would produce a more homogeneous mixture with the iron.

(2) Any excess carbon and other impurities were then burned off, in this furnace.

v) **The resulting steel was more homogeneous, purer, and harder metal**:

(1) but it was a very small scale process

- with only small ingots used in each crucible
- and thus it still remained very costly.

(2) In the early 19th century, crucible steel cost about £100 a ton,

(3) compared to about £4 - £5 a ton for wrought iron by the Puddling and Rolling Process.

d) **German 'Puddled Steel' from the 1840s**:

i) **With the success of the Puddling and Rolling Process** (as devised by Cort and Onions, in the Industrial Revolution: see first-term lectures)

(1) in producing such cheap iron, and with increasing economic pressures to find cheaper steel,

(2) thus, some engineers considered the possibility of making steel by adapting the Puddling and Rolling process.

ii) **Obvious question**: why not stop this process when the iron still contained about 1% carbon?

(1) Because it was almost impossible to tell with any certainty when this stage had been reached, with just 1% carbon.

(2) The puddled iron -- beginning as pig iron:

- was not molten or at all fluid, but viscous (sticky),
- and thus indeed too sticky to permit the even distribution of the carbon.

(3) Stopping before all the carbon had been oxidized or burnt off meant that some other impurities (such as

silicon) would also remain in the iron.

iii) **The British rejected any consideration of this process;**

(1) but some German iron makers tried making puddled steel in the 1840s:

(2) the result was a very inferior type of steel, much inferior to Crucible Steel,

(3) but also much cheaper: about £22 per ton (after further refining) compared to £100 a ton for Crucible Steel.

3. The First Revolution in Steel-Making: the Bessemer Converter of 1856

a) **The Revolution in Steel-making** had three stages: as did many other processes of radical technological change that we have seen in modern industrialization:

i) **Bessemer Converter:** the first stage: to mass produce cheap but lower grade steel on large scale.

ii) **Siemens-Martin Open Hearth:** on a smaller scale, with better quality controls, to produce much higher grades of steel, necessary for precision machinery parts.

iii) **Gilchrist-Thomas Basic Process:** applicable to both of the above methods, to resolve the problem of phosphorous in many iron-ore deposits, especially in continental Europe.

b) **Henry Bessemer** (1813-1898): who inaugurated the revolution in steel making in 1856. [2]

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[2] From Answers.com: British inventor and engineer (1813–1898): Bessemer was the son of a mechanical engineer who had fled from the French Revolution. After leaving the village school in Charlton, where he was born, he worked as a type-caster, until the family moved to London in 1830. At the age of 17 he set up his own business to produce metal alloys and bronze powder. In 1843 he had an idea that made his fortune. On purchasing some 'gold' paint (made of brass) for his sister he was horrified at its high price. He designed an automatic plant to manufacture the paint and made sufficient money to pursue a career as a professional inventor. During the Crimean War (1853–56) Bessemer invented a new type of gun with a rifled barrel. To manufacture the gun he needed a strong metal that could be run into a mold in a fluid state. At that time cast iron (pig iron) contained carbon and silicon impurities, which made it brittle. Wrought iron, which was relatively pure, was made by a laborious process of refining pig iron. The temperature of the furnace, while sufficient to melt the pig iron, was not sufficient to keep the purer iron molten. The refined metal was extracted in lumps after which it was 'wrought'. Bessemer proposed burning away the impurities by blowing air through the molten metal. The Bessemer converter that he invented is a cylindrical vessel mounted in such a way that it can be tilted to receive a charge of molten metal from the blast furnace. It is then brought upright for the 'blow' to take place. Air is blown in through a series of nozzles at the base and the carbon impurities are oxidized and carried away by the stream of air. Bessemer announced his discovery in 1856. At first his idea was accepted enthusiastically and within weeks he obtained £27,000 in license fees. However, though the process had worked for him, elsewhere it failed dismally because of excess oxygen trapped in the metal, and because of the presence of phosphorus in the ores. (By chance Bessemer's ore had been phosphorus-free.) His invention was dropped and Bessemer found himself the subject of much ridicule and criticism. Bessemer established his own steelworks in Sheffield (1859) using imported phosphorus-free iron ore. Robert Mushet (about 1856) solved the problem of the excess oxygen by the addition of an alloy of iron, manganese, and carbon to the melt. Bessemer's process then worked, provided that non-phosphoric ores were used, but it took

i) **He was a British military engineer:** commissioned to produce a new, powerful artillery shell.

ii) **But so powerfully explosive was his shell:**

(1) that traditional iron artillery would not withstand the stress;

(2) and so, for his invention to be practical, he needed steel artillery -- and thus he had to find some way of mass-producing cheap steel.

(3) Yet another example of how military problems led to positive economic innovations

c) **The Bessemer Converter of 1856**: the first solution

i) **This was a coke-burning furnace with a container into which was placed pig iron**:

(1) The coke-fired furnace, reaching temperatures over 1000^{o} C, heated the pig iron until it became molten (liquid).

(2) and from the bottom of the container, compressors blasted jets of air through the molten pig iron to produce an intense combustion.

(3) With that intense combustion, at very high levels of heat,

- all of the carbon in the pig iron, along with silicon, sulphur, and other impurities (excepting phosphorous) were thus rapidly oxidized, burnt off,
- leaving purified wrought iron
- and, very important, left that wrought iron in purely molten form

(4) **Note,** however, that wood-charcoal

- could also be used in this and other steel-making processes, instead of coke:
- and charcoal was indeed used in steel production in Sweden, Russia (Urals mountains region), and Canada, where wood-charcoal still remained relatively cheap.[3]

ii) **To this still molten and fluid, and fully purified, wrought iron was added the optimum amount of pure carbon**: about 1% -- along with an alloy of manganese and iron called *spiegeleisen* in German;

iii) **and this was thoroughly stirred to produce a perfectly homogeneous mixture,** which was then poured, still molten, by ladles, into moulds, to produce steel ingots.

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much time and determination to convince ironworkers after the initial failure. The invention eventually reduced the price of steel to a fifth of its former cost, made it possible to produce it in large quantities, and made possible its use in a variety of new products. The problem of dealing with the phosphorus impurities was solved in 1878 by Sydney Gilchrist Thomas and Percy Carlyle Gilchrist. Bessemer retired a rich man in 1873.

[3] See for example: Ian Blanchard, 'Russian Railway Construction and the Urals Charcoal Iron and Steel Industry, 1851-1914', *The Economic History Review*, 2nd ser., 53:1 (February 2000), 107-26.

iv) **This process required very large scale production, and meant mass production of steel**: producing three to five tons of steel in 30 minutes.

d) **Cheap, mass-produced steel was the result, at relatively very low cost**: at £7 per ton (with a royalty of £1 a ton for then now Sir Henry Bessemer).

i) **That price of £7 a ton compared very favourably with prices of:**

(1) £22 for inferior puddled steel, and

(2) £100 a ton for crucible steel, and

(3) also favourably, in competing with wrought iron, even with its current price of £4 a ton – favourably when you consider the enormous quality advantages of steel.

ii) **To repeat: with the enormous advantages of steel over wrought iron,** steel was relatively far cheaper than wrought iron or any other form of metals for most industrial purposes.

iii) **So steel quickly came to replace wrought iron for most uses,**

(1) except where softness was desirable or permissible (to warrant use of wrought iron).

(2) Conversely, the hardness and durability of steel was its key advantage: for example, in railways, steel rails lasted 10-15 longer than wrought iron rails.

e) **Disadvantages of the Bessemer Process**:

i) **It did not produce uniformly high quality steel**: because of the very large scale and rapidity of production (3 to 5 tons in 30 minutes), quality controls were very difficult to impossible to achieve.

ii) **Consequently, the Bessemer process came to be reserved for making cheap, bulk steels**:

(1) where cheapness was more important than precision or quality:

(2) especially in construction, bridges, railways, etc.; but not for machinery parts.

iii) **The Bessemer Process could not be used for making steel out of iron ores that contained phosphorous**:

(1) it could not eliminate the phosphorous, which made the steel too brittle.

(2) This was a big problem for continental steel producers, whose iron ores were largely phosphoric.

iv) **Britain, however, was very fortunate in having large deposits of non-phosphoric iron ores**, called haematite (blood-red) ores; and so did not really need to resolve this problem.

4. **The Second Stage of the Steel Revolution**: **Siemens-Martin Open Hearth Process (1861-64)**: the Regenerative Furnace

a) **Siemens and Martin:** the two inventors responsible for this process of making high-quality steels:

i) **the German-born Englishman William Siemens (1823-1883):** brother of the German inventor and industrialist Werner Siemens, who devised the fundamental process, in 1861-62; and

ii) **the French engineer Pierre-Emile Martin (1824-1915):** who perfected the new process in 1864.

b) **The Open-Hearth Process worked as follows**: [4]

i) **the open-hearth itself was a large, long, but shallow brick furnace,** which in fact (despite its name) was completely closed, except for the entrance and exit.

ii) **Technically, it was a regenerative type furnace,** to build up the heat by reflecting it off the brick lining, in fact retaining and re-utilizing the heat from combustion (resembling the reverberatory furnaces examined last term).

iii) **The furnace was heated by a coke fire** (or, again, as above, with wood-charcoal):

(1) and the heat from the combustion processes in steel-making was trapped by the brick lining

(2) in order to increase the trapped heat and to aid in further combustion of the metal.

iv) **This furnace also contained pig iron heated to a molten stage**:

(1) and to the surface of the molten pig iron were applied blasts of burning torch gas and air to achieve combustion and decarburisation .

(2) i.e., to burn out the carbon and other impurities in the pig iron.

v) **This process also used a mixture of pig iron with wrought iron:**

(1) commonly in the form of scrap iron, to ensure the exact proportions of carbon added,

(2) thus providing much closer quality controls.

(3) This was in fact Pierre Martin's chief contribution. [5]

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[4] From Wikipedia: Sir Carl Wilhelm Siemens developed the Siemens regenerative furnace in the 1850s, and claimed in 1857 to be recovering enough heat to save 70-80% of the fuel. This furnace operates at a high temperature by using regenerative preheating of fuel and air for combustion. In regenerative preheating, the exhaust gases from the furnace are pumped into a chamber containing bricks, where heat is transferred from the gases to the bricks. The flow of the furnace is reversed so that fuel and air pass through the chamber and are heated by the bricks. Through this method, an open-hearth furnace can reach temperatures high enough to melt steel, but Siemens did not initially use it for that. The regenerators are the distinctive feature of the furnace and consist of fire-brick flues filled with bricks set on edge and arranged in such a way as to have a great number of small passages between them. The bricks absorb most of the heat from the outgoing waste gases and return it later to the incoming cold gases for combustion.

[5] From Wikipedia: In 1865, Emile Martin and Pierre Martin took out a licence from Siemens and first applied his furnace for making steel. Their process was known as the Siemens-Martin process, and the furnace as an "open-hearth" furnace. The rapid production of large quantities of basic steel, such as that which is used to construct tall buildings, is the most appealing characteristic of the Siemens regenerative furnace. The usual size of furnaces is 50 to 100 tons, but for some special processes they may have a capacity of 250 tons or even 500 tons. The Siemens-Martin process complemented rather than replacing the Bessemer process. It was

c) **Advantages of the Siemens-Martin Open Hearth Process**:

i) **far better quality control producing much higher quality steel**: from the smaller scale, slower process, closer heat regulation, and more exact addition of carbon.

ii) **economies in the use of fuels**:

(1) in re-utilizing heat from the combustion processes: from the brick design of the regenerative furnace.

(2) in using lower grades and thus much cheaper coal.

iii) **economies in the use of iron**:

(1) greater quality controls produced 10% more usable steel per ton of pig iron.

(2) process used recycled scrap iron and scrap steel -- both a raw material saving and an advantage in quality control.

(3) Indeed, this was the first major industrial example of recycling and resource conservation.

d) **Disadvantages of Siemens-Martin**: offsetting factors

i) **much more costly process than the Bessemer converter**: i.e., higher priced steels, because:

(1) production was on a far smaller scale.

(2) production process took far longer:

- 10 to 16 hours to produce a ton of steel,
- compared to just 30 minutes with the Bessemer process.

ii) **But the advantages of quality vs. the disadvantage of higher costs worked out about even**:

(1) Siemens-Martin steel obviously was reserved for those uses requiring higher quality steel,

(2) for which higher prices were justified: especially in machinery parts.

iii) **Siemens-Martin process also could not utilize phosphoric iron ores**: thus necessitating a third stage to the revolution in steel-making.

5. <u>**The Steel Revolution Completed: Gilchrist-Thomas 'Basic Steel': 1878**</u>

a) **Percy Gilchrist and Sydney Gilchrist Thomas:**

i) **Two British (Welsh) chemical engineers,** two cousins, resolved this remaining barrier to steel making:

ii) **by inventing a process for removing phosphorous from iron ores,** to be used in either form of steel making; i.e., Bessemer Converters or Open Hearths.

b) **'Basic Process' was the term applied:**

i) **as opposed to 'Acid Process',** in the alternative types of steel-making just discussed:

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slower and thus easier to control.

ii) **Both the Bessemer converter and the Open Hearth were lined with magnesium limestone or basic limestone,** containing calcium oxide, calcium carbonate, and magnesium carbonate.

iii) **when the pig iron became fully molten,** and decarburisation had commenced,

(1) the phosphorous in the pig iron then combined with the magnesium in the limestone

(2) to produce a slag that was easily skimmed off the surface.

iv) **This phosphoric slag proved to be valuable in itself**: it could be marketed as a very useful chemical fertilizer.

v) **The extra cost of lining the converters or hearths with magnesium limestone was offset by**:

(1) the use of far cheaper phosphoric iron ores;

(2) the extension to the furnace life provided by the lining.

c) **This completed the revolution in steel-making**: permitting both Bessemer Steels and Open Hearth Steels to produce excellent quality steels from phosphoric iron ores:

i) **but this Basic process was far more important for continental steel producers than for the British,** because, as noted earlier, most continental iron ores were phosphoric (except in Spain and Sweden).

ii) **Germany gained the greatest advantage**:

(1) from its victory over France in the Franco-Prussian war (in 1870-71), the newly created German Empire, under the domination of the Kingdom of Prussia, by defeating France

- acquired the provinces of Alsace-Lorraine (a province that had once been German, as part of the old Holy Roman Empire),
- this region contained vast deposits of phosphoric or 'minette' iron ores.

(2) In 1871, however, they were considered to be virtually useless, because they could not be processed;

(3) but after 1878, with the adoption of the Gilchrist-Thomas process, they certainly became enormously valuable, and a very major component of the new German steel industry.

6. <u>The Economic Revolution in Applying Cheap Steel</u>

a) **First: the fall in steel prices, from 1860 to 1900**:

i) **As noted before,** the price of Bessemer steel at the outset was only 7% of the price for good quality Crucible Steel (though initially inferior in quality).

ii) **By 1880,** with the establishment of Basic Steel (Gilchrist-Thomas), the price of steel had fallen by another 50%.

iii) **By 1900,** the cost and price of steel had fallen by 85% (from Bessemer's price in 1856):

(1) with various incremental improvements and increases in scale,

(2) and with vertical integration of pig iron and steel, to produce steel in 'one heat', to be seen when we examine the German steel industry;

(3) and with various other economies on raw materials,

b) **Initial Uses of Steel**: chiefly Bessemer

i) **Railways were the first major consumers of steel**: because, as noted, steel rails lasted 10-15 times longer than wrought iron rails.

ii) **Then came shipbuilding**: both for

(1) the high powered compound steam engines and steam turbines, and

(2) for steel hulls in ships, as noted earlier (transportation revolution).

iii) **Also the military**:

(1) for steel artillery and steel-jacketed shells;

(2) and with the enormous arms build up before World War I, the military became perhaps the major steel consumer.

iv) **Construction**: for steel girders in large buildings, bridges, etc.

c) **Industrial Applications**:

i) **Basic ingredient for the Second Industrial Revolution in mechanical power**:

(1) for steam turbines, electrical engines, internal combustion engines.

(2) Steel was the only metal that could withstand the stress of such high powered machinery,

(3) which, in turn, produced an entirely new set of engineering industries.

(4) Equally important: only steel could be cut or fashioned with the exact precision required for the intricate and often complicated parts used in the machinery of this Second Industrial Revolution.

ii) **Steel** also vitally important elsewhere, in making precision machinery parts and for fine cutting tools (lathes): to withstand wear and stress.

iii) **Internal Combustion**: indeed produced another transportation industry with as big an impact on economic development as railroads and steam shipping:

(1) namely, automobiles, trucks, airplanes, etc.

(2) and these industries were also major consumers of steel, obviously (and plastics, rubber).

d) **Historic Patterns in Bessemer and Open Hearth Processes**:

i) **Initially, of course, the Bessemer process led the way (and not just because it was the first process)**:

(1) it had the advantage of much lower cost, at a time when

(2) the major demand for steel for most developing and industrializing countries was in the form of cheap, bulk steel for construction, railways, ships, etc.

ii) **But by the early 20th century, the Siemens-Martin process was overtaking the Bessemer Converter, first of all in Britain**:

(1) where a more highly industrialized and diversified industrial economy required much higher quality precision steels for tools and machinery.

(2) and where there was an abundance of cheap scrap metals, scrap steels to make the Siemens-Martin process economically more advantageous.

iii) **Germany and the US followed Britain** in the transition from Bessemer to Open Hearth Steels: as we shall see later.

e) **Magnitude of the Steel Revolution can be seen from the statistics on the screen**.

i) **The table shows that while Britain led the way in the initial phase of the steel revolution,** the US had overtaken Britain by the late 1880s, and then so had Germany by the 1890s.

ii) **As for the reasons why Britain lost her supremacy in steel-making (or in certain forms) to Germany:** these shall be discussed in subsequent lectures.

Table 1. **World Steel Production, 1865 - 1910**

in Thousands of Metric Tons (2,204.6 lb.)

Year	Britain	Germany	U. S.	World Total
1865	225	100		
1870	286	169	68	703
1880	1,320	660	1,267	4,273
1890	3,637	2,161	4,346	12,096
1900	5,130	6,645	10,382	28,727
1910	6,374	13,698	26,512	58,656

Table 2. **Decennial Averages of the Output of Pig Iron and Steel in France, Germany, Russia, and the United Kingdom: in millions of metric tons, 1830-9 to 1910-3**

Average of 1880-9 = base 100   1 metric ton = 1000 kg. = 2,204.6 lb.

Decade	France Output	Index	Germany Output	Index	Russia Output	Index	U.K. Output	Index
IRON								
1830-39	0.286	16	0.129	4	0.172	31	0.921	11
1840-49	0.442	25	0.172	5	0.192	35	1.625	20
1850-59	0.731	25	0.334	5	0.243	44	3.150	39
1860-69	1.164	66	0.813	25	0.304	56	4.602	57
1870-79	1.337	75	1.678	52	0.400	73	6.6482	81
1880-89	1.772	100	3.217	100	0.547	100	8.040	100
1890-99	2.192	124	5.155	160	1.539	281	8.090	101
1900-09	3.028	171	9.296	289	2.786	509	9.317	116
1910-13	4.664	263	14.836	461	3.870	707	9.792	122
STEEL								
1870-79	0.260*	52			0.080*	33	0.695	30
1880-89	0.500	100	1.320	100	0.240	100	2.340	100
1890-99	1.015	203	3.985	302	0.930	388	3.760	161
1900-09	2.175	435	9.505	720	2.490	1038	5.565	238
1910-13	4.090	818	16.240	1230	4.200	1750	6.930	296

*1875-9 only.