SUMMARIES OF LECTURES in ECO 303Y1:

the Economic History of Modern Europe, to 1914

for the Academic Year: 2012 - 2013

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Updated: Thursday, 8 November 2012

IXa: Week no. 9: Lecture no. 8: 7 November 2012

Coal and Steam Power in the Industrial Revolution:

1. **Vital Importance of Coal for Modern Industrialization: its essential ingredient**:

a) **"An Industrial map of Europe in the 19th century was essentially a map of its coal-fields":** i.e., urban industrialization was almost everywhere concentrated around coal fields

b) **Anthony Wrigley:** importance of this historic shift from an organic to a mineral based-economy: from an economy based on wood, water, and wind to one based on coal and iron

i) **England's shift from an industrial economy based on wood and water to one based on coal:** was the first stage of modern industrialization:

ii) **beginning in the 16th century:** thus giving England a two-century head-start over the rest of the world

iii) **importance of coal in 18th-19th century industrialization:**
(1) coal to produce steam power
(2) coal purified into coke: to permit the revolution in iron-making and later steel-making
(3) coal and steam for the 19th century transportation revolution: in iron built steam powered railways and steam shipping (iron, then steel ships)
(4) coal-fired steam turbines: for both shipping and generation of electrical power
(5) the chemicals revolution: thousands of new chemicals extracted from coal-tars

2. **The Development of Steam Power in the 18th century:**

a) **what steam power replaced (ultimately):** animal power (horses and oxen); water-power; wind-power (in both wind-mills, and for sails on sailing ships).

b) **key motivations to develop steam powered engines:**

i) **16th-17th centur fuel crisis:** high prices for wood led to increased demand for coal

ii) **problem:** increased coal mining meant deeper mine shafts ==> encountering flooding

iii) **solution:** more efficient pumps to pump water out of mine shafts (see lecture notes)

c) **key innovations in steam power:** in England (based on continental experiments)

i) **Thomas Savery:** 1698: steam-powered pump: did not work, but important for next innovation

ii) **Thomas Newcomen:** 1697-1712: steam-powered atmospheric engine:
(1) proved highly practical for coal-mines, to operate water-pumps: using cheap pit-head coal
(2) but too costly and inefficient to be used elsewhere): involved alternate heating and cooling of the piston cylinder (to produce the vacuum)

iii) **James Watt:** inventor of the successful steam engine
(1) 1763: working for Dr. Black at University of Glasgow: given a Newcomen engine to repair
(2) 1776: perfected an efficient practical steam engine (using a separate condenser to create the vacuum, while the piston cylinder kept permanently hot)
(3) In partnership with Matthew Boulton and Wilkinson: first used in their coal mines in Staffordshire and his Blast Furnace (iron smelter) in Shropshire
(4) 1781-82: double acting steam engine: using both steam power and atmospheric pressure (against vacuum)
(5) 1782: rotary steam engine, using flywheel and crank
(6) 1795: Soho Foundry (with Boulton), in Birmingham, to produce commercial steam engines

d) **economic importance:**

i) **economized on all three physical factors of production:** labour, land, and capital (see notes)

ii) **essential for urban industrialization:** in providing a far more mobile and elastic source of mechanical power that was not tied to water (river) or other sites

iii) **not the founder of the factory system, because original cotton mills were based on water-mills:** but did become, from 1820s, essential source of efficient power in urban factories

iv) **applications:** to be seen in next lectures on metallurgy (iron), textiles (cotton), railroads and steam shipping

IXb. Week no. 9: Lecture Topic no. 9: on 7 November 2012

The Industrial Revolution in Iron Manufacturing (to 1830): a Revolution in a Capital Goods Industry

1. **Introduction**

a) **The twin spearheads of modern industrialization, everywhere in the world:** (beginning with the British Industrial Revolution:
1. (1) Metallurgy — iron, and then steel;
2. (2) Textiles: chiefly cottons, then woollens and linens

b) **Importance of iron for modern industrialization:**
(1) as the chief building blocks of modern industrialization – for machinery, plants, buildings, bridges, railways, steam-ships, etc:
(2) and thus as a capital-goods manufacturing industry — in contrast to cottons, as a consumer-goods industry
(3) difference reflected in export statistics: iron exports were minimal before the Railway Age of the 1820s (and after), while cotton became Great Britain's overwhelmingly dominant export

c) **the chief forms of iron:** as indicated by carbon contents
(1) wrought iron: with about 0.1% carbon (almost pure): as the oldest and most widely used form of iron
(2) cast iron: with a high carbon content – 3% - 5%: product of the late-medieval introduction of the blast furnace (see below)
(3) steel: purified iron with 1% carbon added: the ideal form of iron, but extremely costly before the mid 19^{th} century – and thus a luxury metal (reserved for miliary and medical needs).

d) **the importance of both coal and steam power for both the metallurgical and textile industries:**

i) **purified coal in the form of coke:** as the essential fuel to produce iron (and then steel)
ii) coal-fired steam engines: to power the machinery in both industrial revolution
iii) thus continuing the Wrigley theme: of the shift from an organic (wood) to a mineral (coal) economy.

2. **Iron manufacturing before the Industrial Revolution:**

a) **the ancient 'direct' process of iron-making:** iron-winning:

i) **the essential process involved the use of a carbon fuel:**
(1) to effect a chemical reaction to liberate iron from its natural form of iron oxide (Fe_2O_3): using wood charcoal as the purest form of carbon fuels
(2) the carbon combined with the oxygen to produce carbon dioxide (CO_2) to liberate the iron (Fe) from the Ferric Oxide compound (iron ore): $3C + 2Fe_20_3 \Rightarrow 4Fe + 3CO_2$

ii) **iron forges (Bloomery forges, Catalan hearths, etc.):** using wood-charcoal and water power
(1) The iron ore was heated in charcoal furnace or heath to welding heat
(2) water-powered tilt-hammers, from the 13^{th} century (displacing human labour), pounded the near molten metal to bring the carbon (from the fuel) and other impurities to the surface, to be burned off
(3) final product, very costly, was purified wrought iron (see above)
(4) very small scale production: no more than 20 tons a year

b) **The Late-medieval 'indirect process': a preliminary industrial revolution with the Blast Furnace**

i) **Blast furnace - for smelting iron ores:** probably a German innovation, first found in eastern Low Countries in 1380s; but not introduced into England until the 1390s

ii) **An immense, 30-ft high, brick-kiln furnace:** using wood-charcoal fuels and water-powered bellows to create the blast of air, to achieve a high level of combustion ==> producing molten iron

iii) **smelting:** term given for the process of reducing iron-ore to its first usable stage, known as:
(1) pig iron – if the iron was to be further refined, into wrought iron
(2) cast iron - if used directly as a consumer product, by being poured molten into pre-shaped casts: for pipes, cannon barrels, pans, rods, etc.

iv) **military demands:** first major use, for producing cannons (but inferior to, but less costly than, bronze cannons)

v) **refining - the second stage:** in finery forges:
(1) using wood-charcoal fuel and water-powered bellows and tilt hammers (as in the 'direct process',

described above).
(2) to decarburize the iron (carbon from smelting) and purify it into wrought iron
(3) much smaller scale than blast furnaces, though became larger than the earlier iron forges

vi) **economic significance of the blast furnace:**
(1) vastly reduced cost of smelting iron ore into basic iron, with large scale production
(2) created a truly capitalist iron industry: in which a capitalist had the resources to invest in or create a blast furnace (with hydraulic machinery), to acquire the raw materials (iron, charcoal), hire the labour, and market the finished products
(3) the earlier direct process using small forges were non-capitalist artisan industries in which the skilled craftsmen owned the blast-furnace, the tools, and raw materials but also performed essential labour.

c) **The Tyranny of Wood and Power**: limitations to growth and incentives for innovation

i) **the initially impressive expansion of the English iron industry:** from the 1490s, could not be sustained after the later 16th century, when industrial growth rates slowed down, and industry reached a plateau, by the Civil War era of the 1640s

ii) **Dual problems of the tyranny of wood and water:** both Ashton and Nef (read lecture notes)
(1) dependence on ever costly wood-charcoal fuels for both smelting and refining,
(2) dependence on water power for powering the bellows in both the blast furnace and the forge, and the tilt-hammers in the refining forges.

iii) **The wood-charcoal problem:**
(1) evidence shown in graphs and tables (lecture notes) for soaring wood and charcoal prices
(2) but Nef and Ashton wrong in contending that it occurred in the century 1540-1640: instead new evidence shows that a fuel crisis emerged only after the 1640s, and then became truly severe, with a widening gap between wood-charcoal and coal fuels,
(3) Statistics of smelting costs: that over 70% of the costs were in the wood-charcoal fuels
(4) 'friable' nature of charcoal: that charcoal cannot be transported, because it will crumble into useless dust if agitated or shaken during transport ==> so that the charcoal had to be created at the forest site
(5) that meant that the iron industry had to be small scale, dispersed and scattered through the countryside where woodlands were more readily accessible
(6) The coal-fired reverberatory furnace, invented (Italy) c. 1540, could not be used with coal fuels,

3. the coal problem: a very dirty fuel, with many contaminants that would corrupt and degrade any products being manufactured from it (i.e., from its combustion gasses)
4. solution: the reverberatory furnace, which isolated combustion gases, while reflecting the heat on to the product being manufactured, as used in many other 16th- and 17th-century industries: brewing, soap-making, dye-making, brick and paper making, gunpowder, brass and metal finishing, etc.
5. reason: because the carbon in the fuel had to be in direct contact with the iron ore in order to liberate the iron from the oxygen in the Ferric oxide compound

iv) **the water-power problem:**
(1) water-power sites also had to be scattered and rural where opportunity costs of locating water-mills were lower (far lower than in urban areas)
(2) water-power discontinuous: with winter freezing and summer droughts, often available only for 35 weeks a year

v) **dual tyranny dictating rural dispersion and small scale units:**
(1) rarely were there to be found industrial sites (close to iron deposits) that had sufficient supplies of both wood-charcoal and water power to justify side-by-side location of both furnaces and forges
(2) therefore another reason why the 17th century industry was scattered with small scale units in the countryside

vi) **Increasing dependence on imported Swedish and Russian iron:**
(1) by early 18th century, these imports accounted for over half of domestic English consumption
(2) Swedish and Russian advantages: no tyranny of wood and water: ample supplies of both in sparsely populated iron-making regions of both countries (with higher grade ores)
(3) English problem: danger that these foreign supplies, coming via the Baltic, could be cut off in times of war.

3. **The Industrial Revolution in Iron Manufacture: the use of coal throughout**

a) **The revolution in smelting:** coke-fired blast furnaces: Abraham Darby (1709)

i) **the ultimate answer to the fuel problem was to use coal in its purified form:** known as coke (coal that is burned to a carbon residue in an airless furnace)

ii) **Abraham Darby succeeded where many had failed, in previous decades, around 1709:** a coke-fired smelter to produce pig or cast iron

iii) **problems: why no revolution followed: why no one else built coke-smelters before the 1760s**
(1) because initially still higher cost than wood-charcoal blast furnaces
(2) because the process did not remove the silicon from the iron, thus adding an extra refining costs

iv) **the subsequent victory of coke-fired blast furnaces (smelters):**
(1) continued fall in coal prices (thanks to Newcomen's steam-powered drainage pumps), while wood charcoal prices continued to soar
(2) technological innovations in producing the blast: vastly cutting fuel costs (all by Scottish inventors)

v) **John Smeaton:** 1760: developed water-powered piston air pumps to replace bellows

vi) **James Watt:** 1776: application of his steam engine to John Wilkinson's blast-furnace with piston air pumps: the decisive breakthrough producing the real revolution in producing pig iron

vii) **James Nielsen:** the hot blast, in pre-heating the air before entering the blast furnace.

viii) **the victory of cast iron:** Darby's process, while not revolutionizing iron production, did produce far superior forms of cast iron because of the silicon residues, which acted as sealants to prevent fissures.

b) **the revolution in iron refining**

i) **victory of coke-fired blast furnaces (smelters) created a severe imbalance:** too much pig iron to be refined by current small-scale refineries (finery forges): hence one incentive for innovation

ii) **military incentive:** offered by the British navy: sponsored a competition, with large prize, to those who could produce good quality, low-cost bar iron, to remove England's dependency on imported iron'

iii) **Wood Brothers:** the 'Potting and Stamping' process invented in the 1760s (read the lecture notes): did reduce refining costs, but enough to produce a revolution

iv) **Henry Cort and Peter Onions:** in 1783, independently produced a viable solution in response to the British Navy's competition: known as the Puddling and Rolling Process
(1) Puddling: pig iron was heated in coke-fired reverberatory furnace (no direct contact with carbon need – the reverse was true: the elimination of carbon), provide reflected heat to burn out the carbon (decarburize) and other impurities, leaving a semi-liquid or jelly-like form of iron in puddles at the bottom of the furnace
(2) Rolling: the semi-liquid iron was forced through water-powered rollers to squeeze out all remaining impurities

iv) **James Watt's rotary steam engine:** in 1788, was applied to Wilkinson's rolling mills

v) **Richard Crawshay:**
(1)1790s, introduced many improvement in Puddling & Rolling process in the Cyfarthfa iron-works in South Wales:
(2) increasing the scale of output to 13,000 tons a year (mean statistics).

c) **Economic Consequences of the Industrial Revolution in Iron Making with coal throughout**:

i) **in general:** enormous increase in industrial scale, industrial concentration, and geographic concentration around Britain's major coal fields (ratio of 10 tons coal to 1 ton of iron)

ii) **Vertical Integration:**
(1) capital: as wealthy capitalists acquired coal mines, iron mines, blast furnaces (smelters), refineries, slitting mills (for finished iron)
(2) physical integration: of smelting and refining together, so that smelted pig iron be delivered directly to the refineries without having to expend extra fuel in reheating the iron

iii) **horizontal integration:** from amalgamation of iron firms into a few giant firms (15 firms controlled majority of iron production by 1815)

iv) **geographic concentration:** around major coal fields of South Wales, West Midlands (Shropshire, Staffordshire), Lancashire, Northumberland, and then (from 1830s), also Scotland

v) **industrial organization consequence: oligopolistic competition**:
(1) with a few large producers, enjoying high barriers to entry (and thus competition) producing a homogenous product (i.e., bar iron same by all producers)
(2) highly unstable, cut-throat competition ==> leads to cartel organization

vi) **enormous increase in output (as measured in tons of pig iron):** from 37,000 tons in 1760s to 3,106,000 in the 1850s

vii) **But iron was only a very small, marginal export until the coming of the railways in the 1830s:** with exports of railway iron**:** see the tables in the published online lecture