XII. MANUFACTURING INDUSTRIES: INDUSTRIAL CHANGE IN EARLY-MODERN EUROPE, 1520 – 1750

B. Industrial Change in Tudor-Stuart England: Coal and Coal-Burning industries

revised 5 April 2012

24. **4 April 2012** **Davis**, ch. 12; **Cipolla**, ch. 6, 9 (pp. 227-34), 10 (pp. 259-75); **de Vries**, ch. 3; **Musgrave**ch. 6, 7 **ET 9, 10**	**28**	**MANUFACTURING INDUSTRIES:** **England: Nef's 'Industrial Revolution'**: in Coal-Burning Industries, 1540 - 1640; **Metallurgy (Iron):** Blast Smelters and the Rise of the English Iron Industry, 1540 - 1640; **'The Tyranny of Wood and Water'** and Stagnation in the Iron Industry, 1640 - 1740; **The Origins of the Industrial Revolution in Metallurgy;** British/European industries on the eve of the 'Industrial Revolution' in 1750.

Tudor-Stuart Origins of the modern Industrial Revolution - 1

- 1) **Introduction: John Nef's 'Minor Industrial Revolution in Tudor Stuart England (ca. 1558 -1714)**
- -a) **to evaluate his thesis that a preparatory 'industrial revolution' based on a new coal-burning furnace technology** paved the way for the modern Industrial Revolution
- - b) **modern industrialization was indeed based fundamentally on COAL**
- - c) **Britain's key advantages:** England, Scotland, Wales
- - **a two-century head-start** over the rest of the world in coal-based technologies
- - **abundant supplies of very cheap coal**

Tudor-Stuart Origins of the modern Industrial Revolution - 2

- 2) **Key Components of the modern Industrial Revolution, 1760 – 1820: based on COAL:**
- a) **cotton-textile manufacturing**: with **steam-powered iron-built** machinery & factories
- b) **metallurgy: iron manufacturing:**
- -**using coal throughout** to overcome the 'tyranny of wood & water', in both smelting & refining
- c) **steam-power: coal fired steam engines**
- - **steam engines** (made of iron) to drive new machinery in both textiles and metallurgy
- - that itself required a revolution in iron-making

Tudor-Stuart Origins of the modern Industrial Revolution - 3

- 3) **Coal: its importance for industrialization: in the modern mineral-based industrial economy**
- a) **coal: the essential mineral ingredient for the Industrial Revolution era**
- i) **as the prime industrial fuel** – in place of wood and peat
- ii) **coal fuel purified as coke**: to produce iron [next lecture]
- iii) **fuel to provide steam-power** (boil water):

Tudor-Stuart Origins of the modern Industrial Revolution - 4

- 3) **Coal: its importance for industrialization:**
- b) **coal: in 19th-century British and European Industrialization: a map of its coal fields**
- i) **for the 19th-century transportation revolutions:**
- (1) **railroads:** from the 1820s
- (2) **steam shipping**: especially with the steam turbine
- ii) **For the revolution in steel-making**: Bessemer Converter, 1856 (using coke, as purified coal)
- ii) **For the new electrical industries**: **coal-fired** steam turbines to power generators
- iii) **For the new chemicals industries:** aniline dyestuffs and other **coal-tar** based chemicals – in the thousands

Tudor-Stuart Origins of the modern Industrial Revolution - 4

- 4) **The Organic Economy of Pre-Industrial Europe: based on:**
- a) **wood:**
- - **for fuel**
- - **for tools and construction**
- - **for shipbuilding**
- b) **water power**: water-mills
- c) **wind:** for
- - **windmills** (as a supplement to water mills): very minor role
- - **powering** sailing ships
- d) **animals:** for power and transport: major role
- i) **oxen and horses** above all
- ii) **donkeys and mules**

The Nef Thesis: adoption of coal as the prime industrial fuel - 1

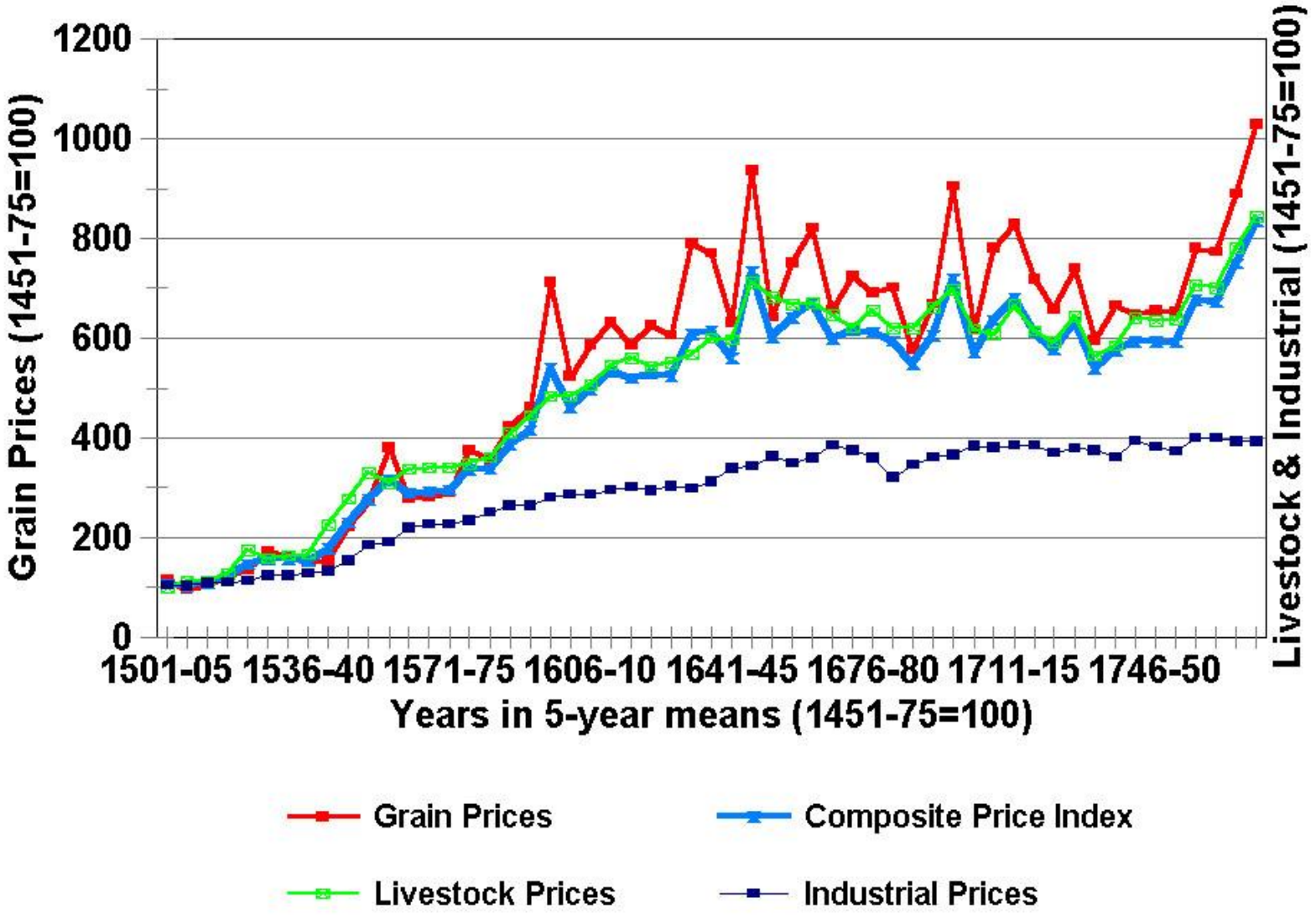
- 1) **Basic question: did Tudor-Stuart England experience a 'fuel crisis'** that led to the shift from an organic (wood) to a mineral (coal) based economy
- 2) **The Nef Thesis: Chicago historian John Nef: in the 1930s**
- -a) **argued that true foundations of modern industrialization took place in the 16th and 17th centuries-** rather than in the 18th century
- - **a 'fuel crisis' led to such a shift from wood to coal** – with a new coal-burning technology

The Nef Thesis: adoption of coal as the prime industrial fuel - 2

- b) **Beginnings of modern industrial capitalism: as response to a fuel crisis**
- - **with large-scale, capital intensive coal-burning industries**: which meant a shift from artisan to capitalist modes of production
- - **culmination**: 1710: Abraham Darby's coke-smelting (in place of wood charcoal): but no Industrial Revolution yet
- c) **Tawney's Century, 1540 – 1640: Importance of the contemporary Price Revolution:**
- i) **Hamilton**: **Profit-Inflation thesis**: origins of modern industrial capitalism (seen earlier: Price Revolution topic)
- ii) **Nef**: **opposed Hamilton's thesis** with his alternative 'fuel crisis' thesis

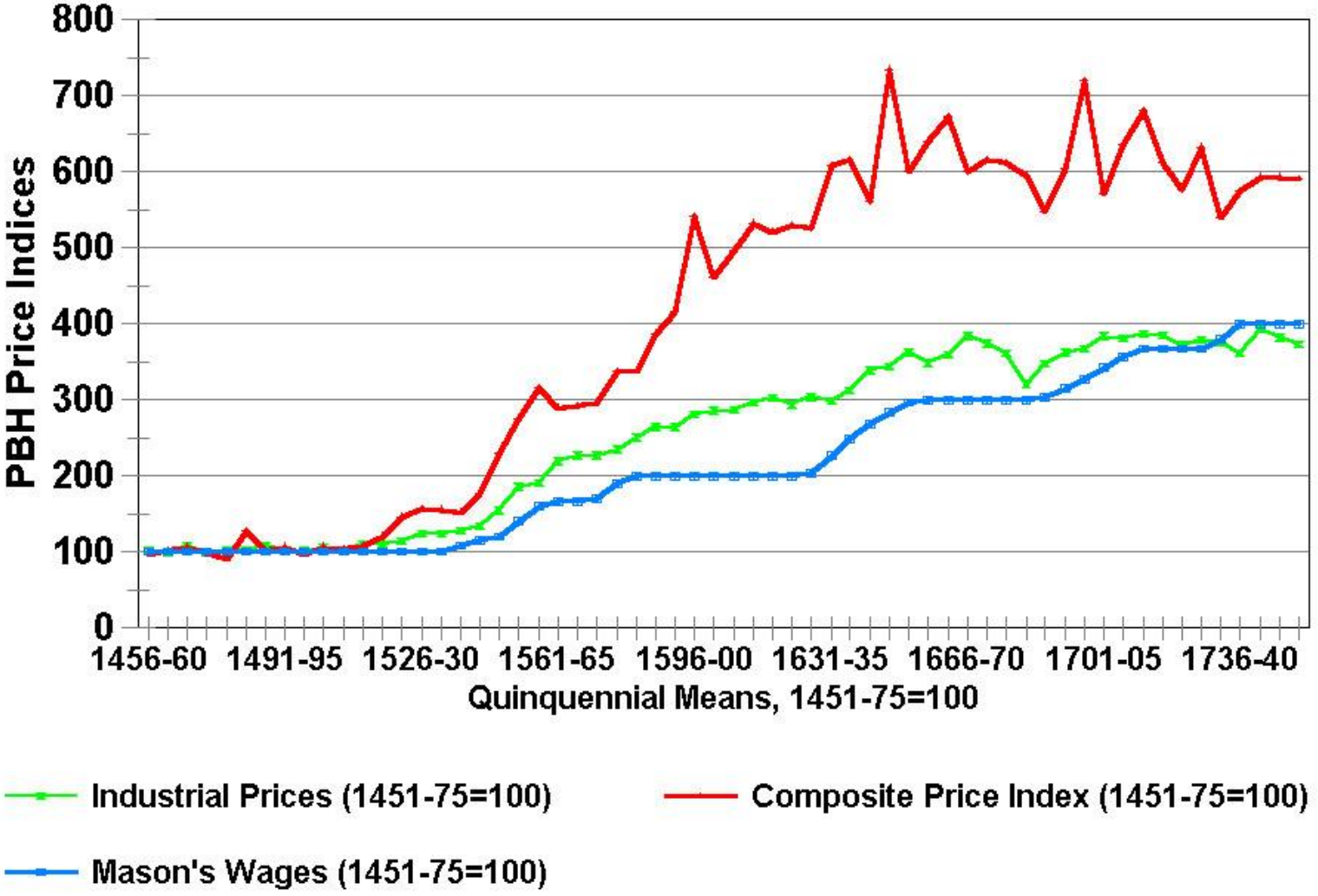
English Prices 1501-1770 (1451-75=100)

Grain, Livestock, Industrial Prices



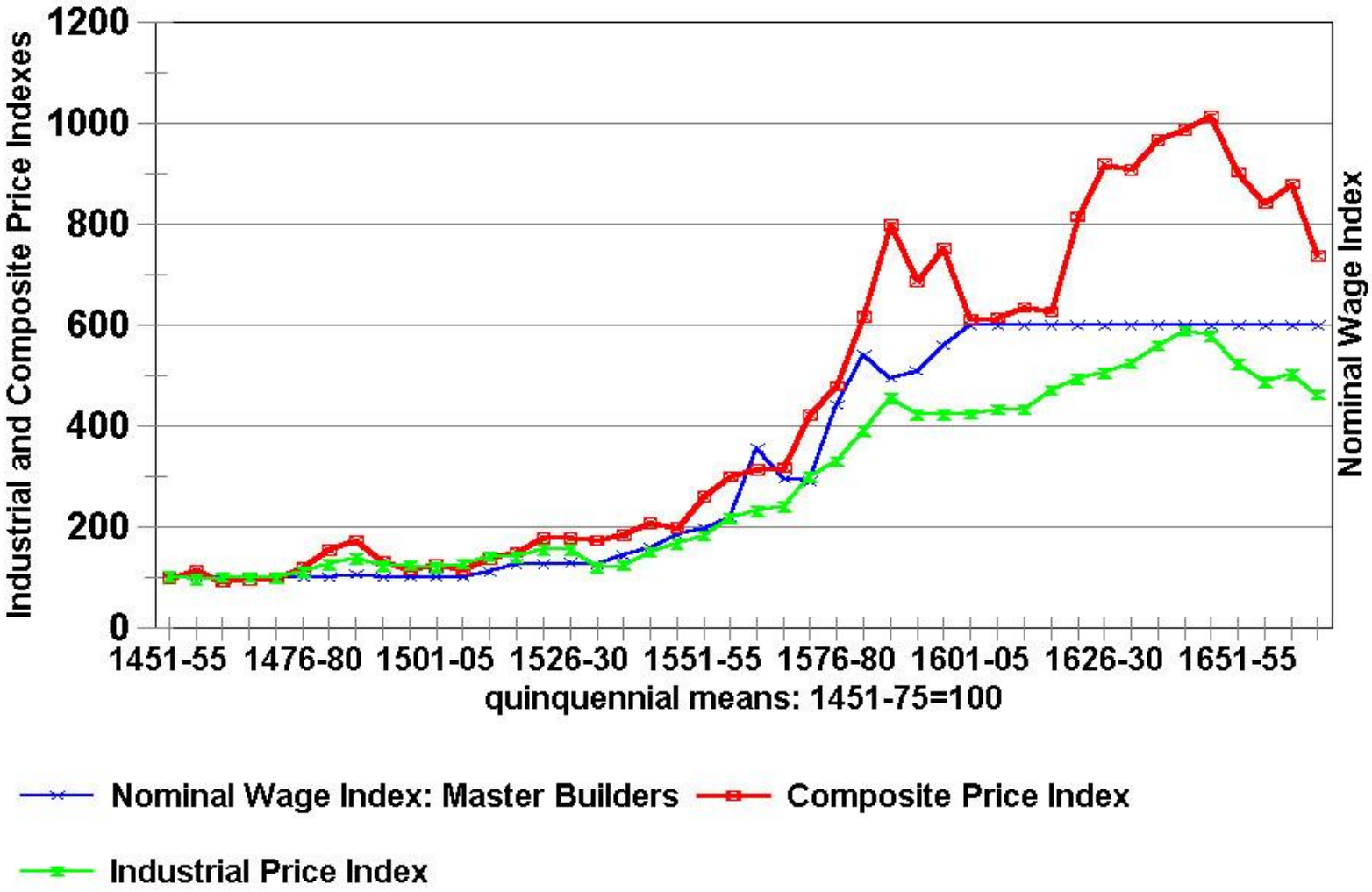
Money Wages and Industrial Prices

England, 1451 - 1750



Brabant Price & Wage Indexes 1451-1670

Industrial Prices, CPI, Nominal Wages



The Nef Thesis: adoption of coal as the prime industrial fuel - 3

- 3) **Problems with the Nef thesis:**
- a) **encountered furious attacks from the 1930s**: based on both concepts and evidence (to be examined in this lecture)
- b) **Nef had indeed overstated his case:**
- - i) **no signs of any industrial revolution** in Tudor-Stuart England
- - ii) **the one major change: rise of the New Draperies**,
- - but with **no** significant changes in industrial technology or industrial scale
- - iii) **New coal-burning industries**: had no major impact on England's manufacturing industries before 18th century

The Nef Thesis: adoption of coal as the prime industrial fuel - 4

- 3) **Problems with the Nef thesis:**
- c) **no major shift from agriculture to industry in Tudor-Stuart England**, as in the true Industrial Revolution era (1760 – 1820)
- d) **The Fuel or Energy Crisis**: took place not in 1540-1640, but **after** the 1640s
- e) **Nef still had one major point of great importance: that the foundations of modern industrialization lie in England with the shift from an organic (wood) to mineral (coal) based economy** [Wrigley]

The Nef Thesis: adoption of coal as the prime industrial fuel - 5

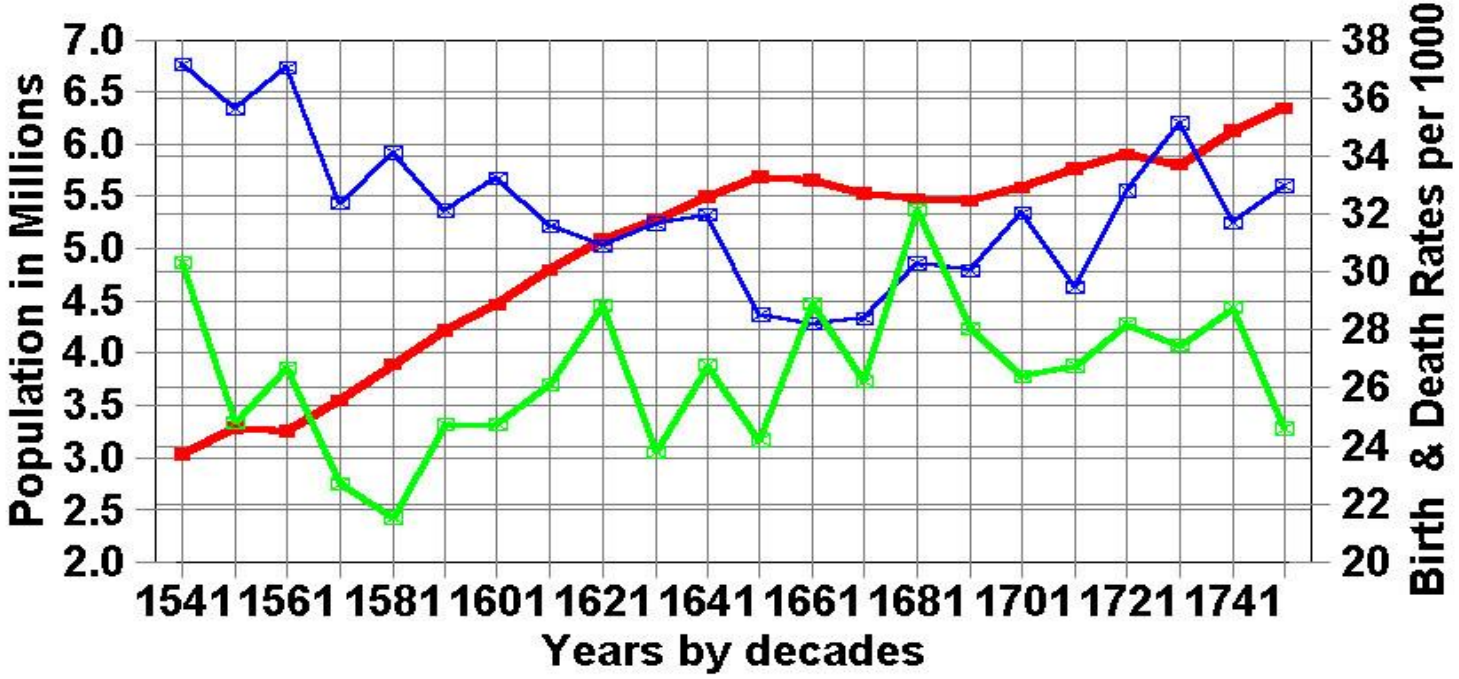
- 4) **The Economics of the Fuel (Energy) Crisis:**
- a) **Nef thesis**: a steep rise in the cost of both wood and wood-charcoal fuels from the 1540s ➔ creating a fuel or energy crisis
- b) **Why was England the first to respond to the 'fuel crisis'?**
- - i) **wood-fuel crisis far more severe** than in most other countries:
- - (1) **problems from rapid population growth, urbanization, economic development, and shipbuilding** ➔ extensive deforestation
- - (2) **major costs lay in labour and transportation**, as timber supplies became more & more distant from urban markets
- - (3) **Charcoal especially a problem**: 'friable nature' ➔ cannot be readily transported ➔ thus produced from timber at the industrial work site.

The Nef Thesis: adoption of coal as the prime industrial fuel - 6

- b) **Why was England the first to respond to the 'fuel crisis'?**
- -ii) **coal: a readily available alternative fuel** then found in abundance only in England – not in continental northern Europe until the 19th century
- - **compare**: Netherlands, France, Germany, Italy, Spain
- - **Belgium:** only other country with accessible coal ➔ 2nd to industrialize

POPULATION: ENGLAND & WALES 1541-1741

in millions, by decades



The Nef Thesis: adoption of coal as the prime industrial fuel - 6

- 4) **The Economics of the Fuel (Energy) Crisis:**
- c) **The importance of London**: its growth from ca. 50,000 in 1500 to ca. 350,000 by 1650s (and to 550,000 by 1750)
- - accommodating that growth with wood-fuels would have been impossible ➔ Δ dependence on sea-borne coals from Newcastle ➔ promoted growth of coal-mining industries ➔ larger-scale mechanized coal mining (using German technology)
- d) **evidence from the tables and graphs:**
- **while wood and charcoal prices rising faster than coal prices from 1570s,** wood-based fuel prices did not consistently rise above the price-level (CPI) until the 1640s: era of the English Civil War

Population of London (estimates)

Year	Population Estimate
1500	50,000
1600	200,000
1650	350,000
1750	550,000
1801 (census)	1,088,000
1851 (census)	2,491,000

Price-Relatives of Charcoal, Timber, Industrial Products, Grains, and the Phelps-Brown & Hopkins 'Basket of Consumables,' in Decennial Averages, 1530-9 to 1640-9

Mean value of 1530-9 = base 100

Decade	Charcoal (Cambridge)	Timber (National)	Industrial Products (Average)	Grains (Wheat, Rye, Oats, Barley)	Basket of Consumables Index
1530-9	100	100	100	100	100
1540-9	122	115	115	116	124
1550-9	203	174	169	216	186
1560-9	217	178	198	196	180
1570-9	230	206	203	230	203
1580-9	270	247	209	282	230
1590-9	287	289	216	366	305
1600-9	320	335	233	348	306
1610-9	359	397	249	407	341
1620-9	345	450	240	399	333
1630-9	378	475	255	491	397
1640-9	535	524	278	488	398

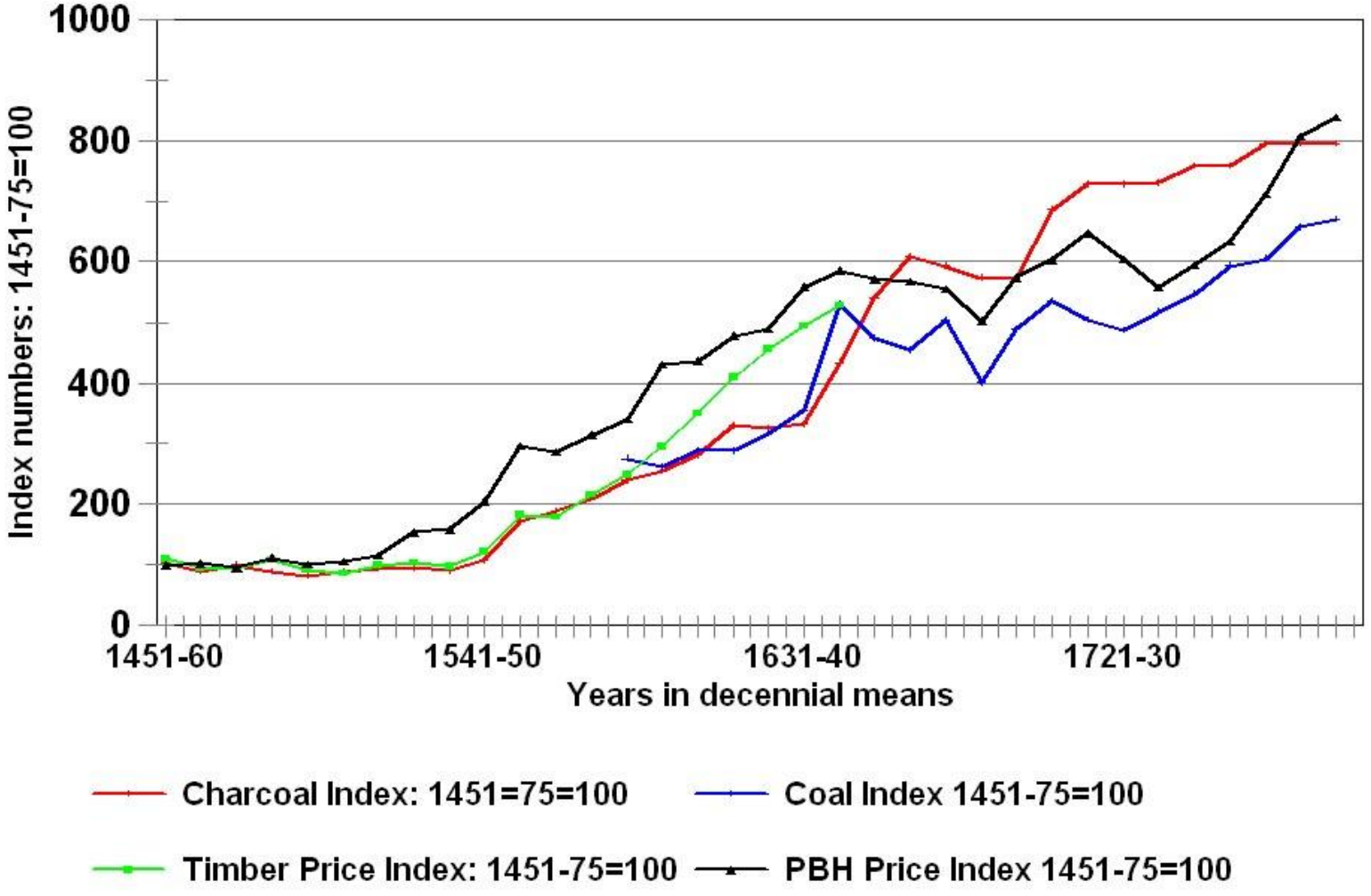
Prices and Price-Relatives of Wood-Charcoal and Coal at Cambridge, and the Phelps-Brown & Hopkins 'Basket of Consumables' Price Index, 1580-9 to 1690-9

Index Base: Average of 1580-9 = 100

Decade	Charcoal: Shillings per Load	Index	Coal: Shillings per Chaldron of 36 bushels	Index	Basket of Consumables Price Index
1580-9	19.52	100.0	13.22	100.0	100.0
1590-9	20.79	106.5	13.41	101.4	132.2
1600-9	23.18	118.8	15.19	114.9	133.0
1610-9	25.96	133.0	13.88	105.0	148.0
1620-9	24.97	127.9	15.82	119.7	144.5
1630-9	27.38	140.3	16.78	126.9	172.5
1640-9	38.70	198.3	23.71	179.3	172.9
1650-9	38.40	196.7	20.76	157.0	178.2
1660-9	38.64	198.0	19.65	148.6	181.1
1670-9	43.50	222.8	21.48	162.5	172.2
1680-9	n.a.	--	19.28	145.8	161.6
1690-9	n.a.	--	24.07	182.1	181.2

English Wood, Charcoal, Coal Prices

1451-60 to 1781-90



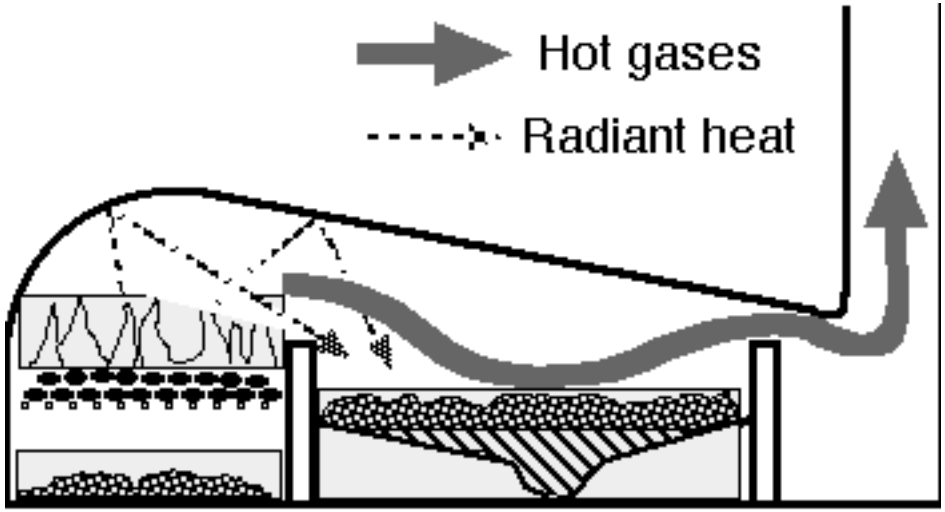
The Nef Thesis: adoption of coal as the prime industrial fuel - 5

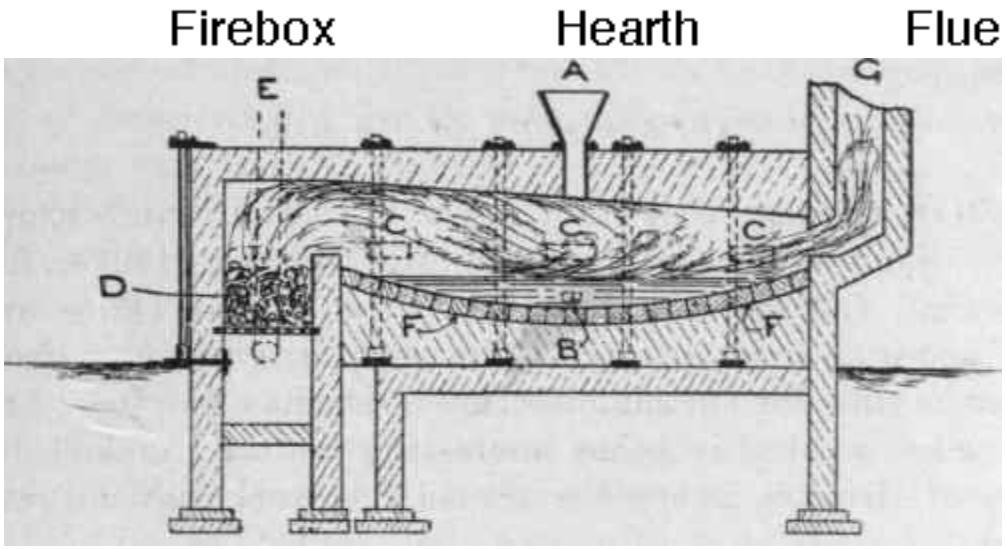
- 5) **Solutions to the Energy Crises?**
- a) **move industrial production to forest sites**:
- - **iron manufacturing did do so**
- - **but not practical for urban based industries:** requiring urban commercial + financial facilities + skilled urban labour + other urban (especially port) facilities
- b) **find an alternative fuel**: **beginning with coal**

The Nef Thesis: adoption of coal as the prime industrial fuel - 6

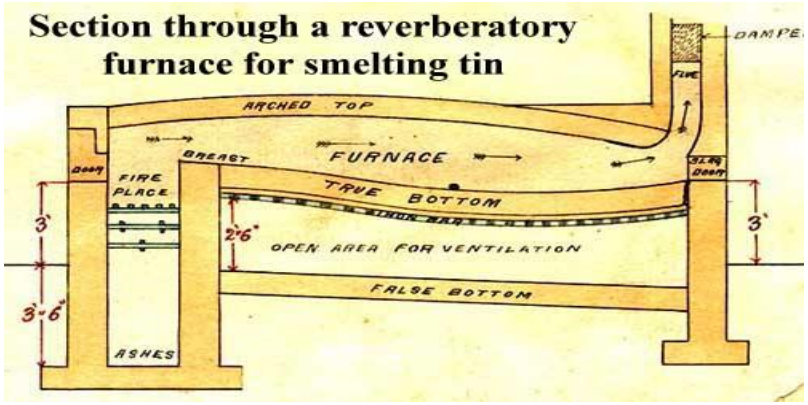
- 6) **Technological Innovations in Coal-Burning Industries**:
- a) **Problems in switching to coal:**
- - **coal is a very dirty fuel** ➔ contaminates product manufactured
- b) **the reverberatory furnace: the first solution: from the 1540s (Italy)**
- - **large-scale brick kiln furnace** transmitting reflected heat from furnace roof by convection
- - **isolates coal fuel and noxious fumes** and gases from the product
- - **requires costly hydraulic machinery** to fan the burning coals

The Reverberatory Furnaces (A)





Reverberatory Furnaces (B)



Skiennor / RBT furnace at Endurance technologies Chekan, India

The Nef Thesis: adoption of coal as the prime industrial fuel - 7

- 7) **Economic Importance of New Furnace Technologies:**
- a) **very large scale, capital intensive production**: vastly larger furnaces with hydraulic machinery (to increase furnace air-flow)
- → required far larger production runs → larger volumes of sales to cover fixed capital costs
- b) **Economies of large-scale** → increasing returns with much lower average + marginal costs → lower commodity prices

The Nef Thesis: adoption of coal as the prime industrial fuel - 8

- c) **summary of cost-reducing factors:**
- i) **increasing returns to scale**
- ii) **centralization: savings on transport + transaction costs**
- iii) **relatively cheaper coal fuels**
- d) **example of the glass industry** (one of the first: ca. 1610)
- - amalgamated all steps of production in one factory-furnace unit, replacing many small, scattered charcoal-burning furnaces

Glass-making Furnace: ca. 1610

The Nef Thesis: adoption of coal as the prime industrial fuel - 9

- 8) **The New Coal-Burning Industries:**
- a) **initial applications of coal-furnaces:**
- i) **metallurgy:**
- - **calcining metal ores** (burn out impurities)
- - **metal-making:** silver-lead separation, brass and bronze manufactures (from copper)
- - **metal finishing**: drawing wire; nails, etc.
- - BUT NOT used in iron-manufacturing

The Nef Thesis: adoption of coal as the prime industrial fuel - 10

- a) **initial applications of coal-furnaces:**
- ii) **'New Industries': previously unimportant**
- - **beer-brewing** with hops (as an urban industry)
- - **brick-making and glass-making**
- - **soap and paper manufacturing**
- - **gunpowder; alum and dyestuffs**

The Nef Thesis: adoption of coal as the prime industrial fuel - 11

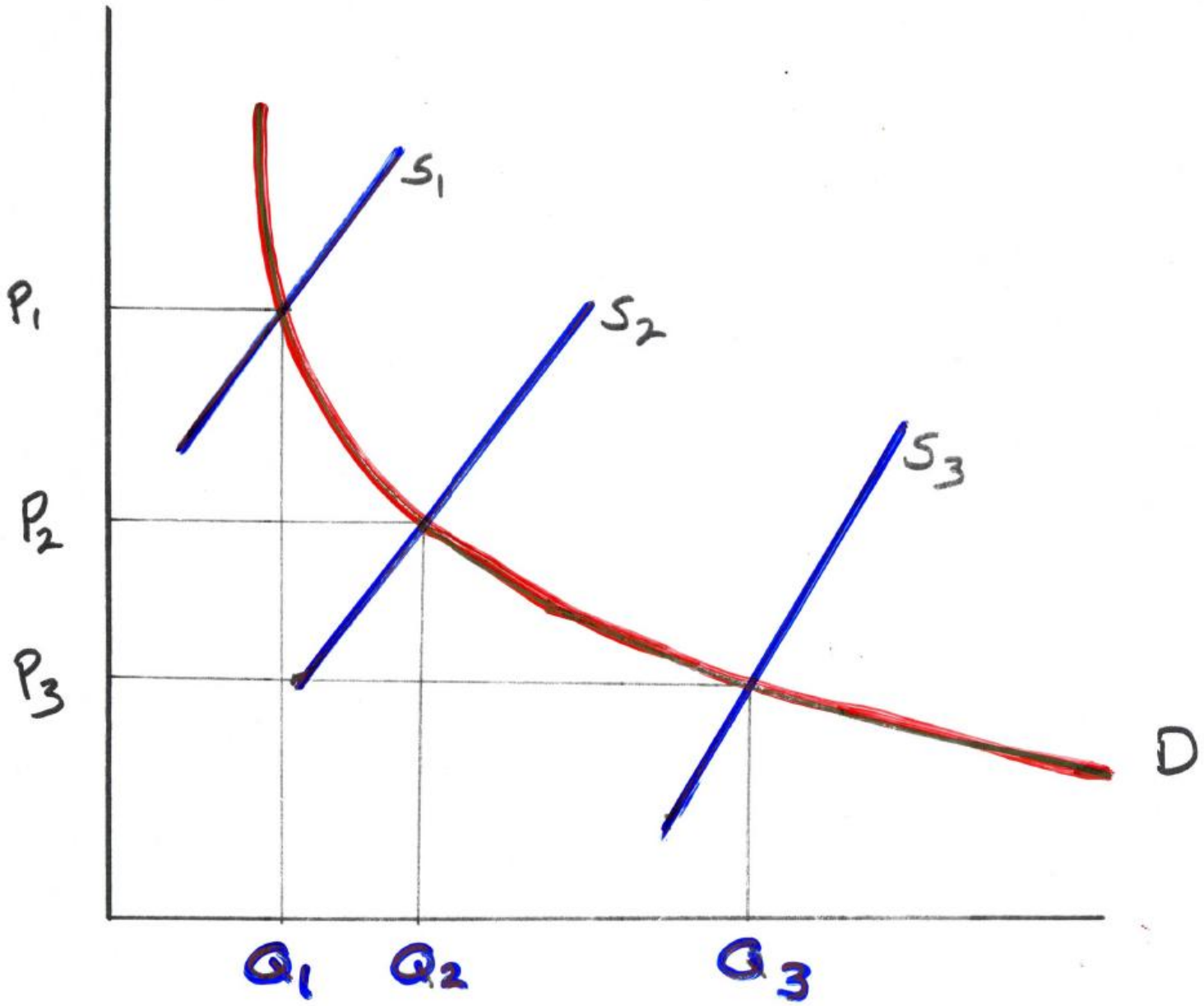
- a) **initial applications of coal-furnaces:**
- ii) **'New Industries': previously unimportant**
- - **beer-brewing** with hops (as an urban industry)
- - **brick-making and glass-making**
- - **soap and paper manufacturing**
- - **gunpowder; alum and dyestuffs**

The Nef Thesis: adoption of coal as the prime industrial fuel - 12

- 8) **The New Coal-Burning Industries:**
- b) **Coal and Industrial Capitalism:**
- i) **putting-out system** (as seen in textiles) could hardly function with this type of production
- ii) **centralized large-scale, capital intensive production** based on single coal-burning furnace ➔ **shift from artisan to capitalist mode of production,** in which:
- - **industrial capitalist owns the means of production**: furnace, tools, raw materials
- - **industrial artisans**: sell only their labour power, for wages (Marxist)

The Nef Thesis: adoption of coal as the prime industrial fuel - 13

- 8) **The New Coal-Burning Industries:**
- c) **market essential for this capitalist mode of production** to be effective & profitable: i.e., to generate a large enough volume of sales to cover the fixed capital costs, and with lower prices
- i) **function of population growth + disproportionate urbanization**: especially the growth of the **London market**, as noted.
- ii) **price elasticity of demand** for industrial products, with falling prices


S_1
S_2
S_3
P_1
P_2
P_3
D
Q_1
Q_2
Q_3

English Coal Production in tonnes

Year	Output in metric tonnes
1560	227,000
1700	2,640,000
1800	15,000,000
In 1800, British coal production was FIVE (5) times that of the rest of Europe combined (Wrigley and Hatcher)- Belgium was 2nd in levels of coal output	

XII. MANUFACTURING INDUSTRIES: INDUSTRIAL CHANGE IN EARLY-MODERN EUROPE, 1520 – 1750

C. The Birth of the Modern English Iron Industry: Industrial Capitalism, Growth, and Stagnation

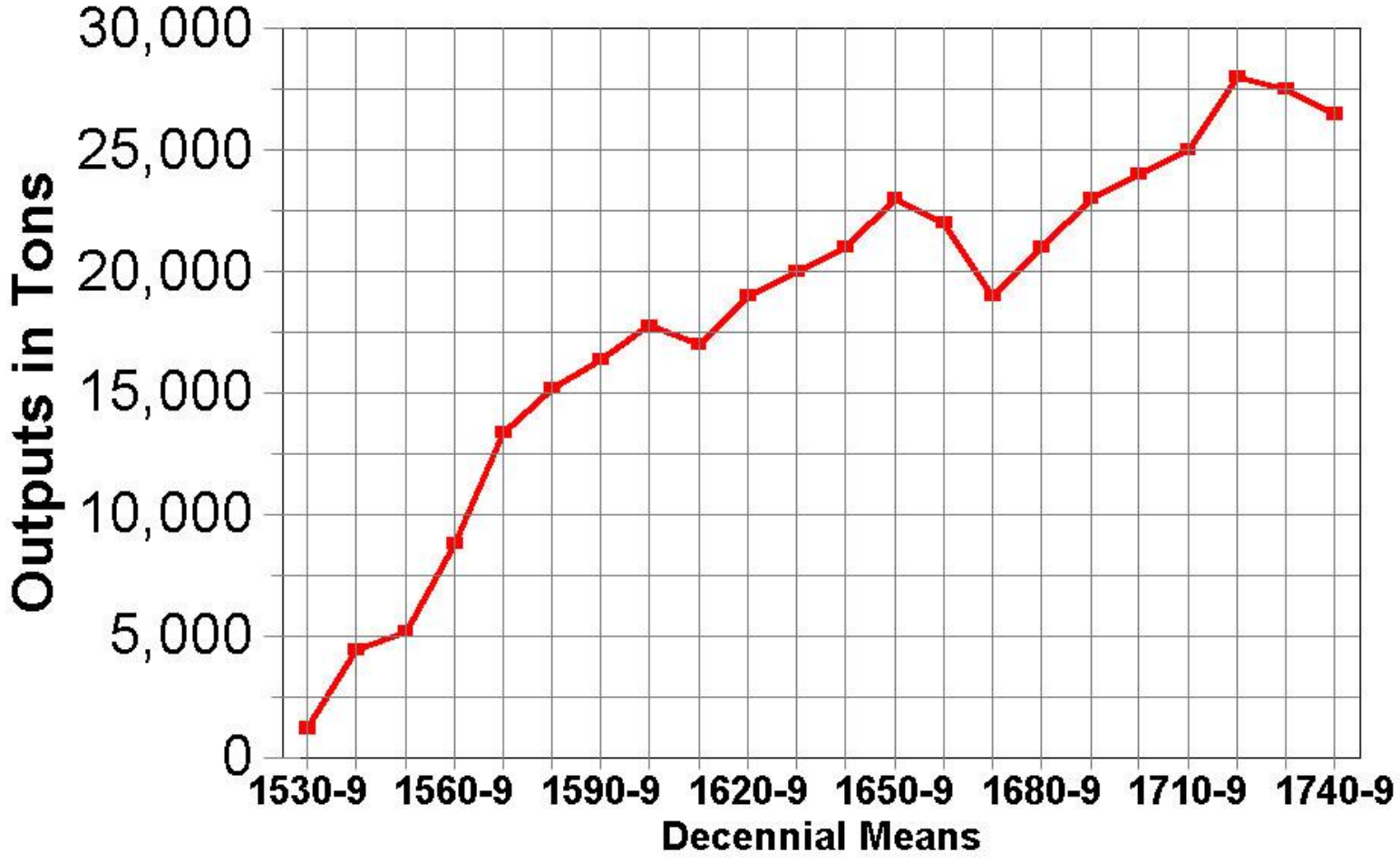
revised 4 April 2012

Growth of the English Iron Industry, 1500 to 1640

- 1) **Iron (& Steel) Manufacturing: Capital Goods industry** → **'building blocks'** of modern industrialization, everywhere in the world from 1760s
- a) **technological innovations** → **birth of a genuinely capitalist iron industry** first took place in eastern Low Countries & Germany, in later 14th century
- b) **England: rapid growth** from 1520s to 1640s
- c) **Nef and Ashton: 'tyranny of wood and water' - from 1640s: relative stagnation** of the iron industry
- - though some recovery from 1680s to 1720s
- c) **essential problems solved only with the modern Industrial Revolution:** from the 1760s (ECO 303Y)

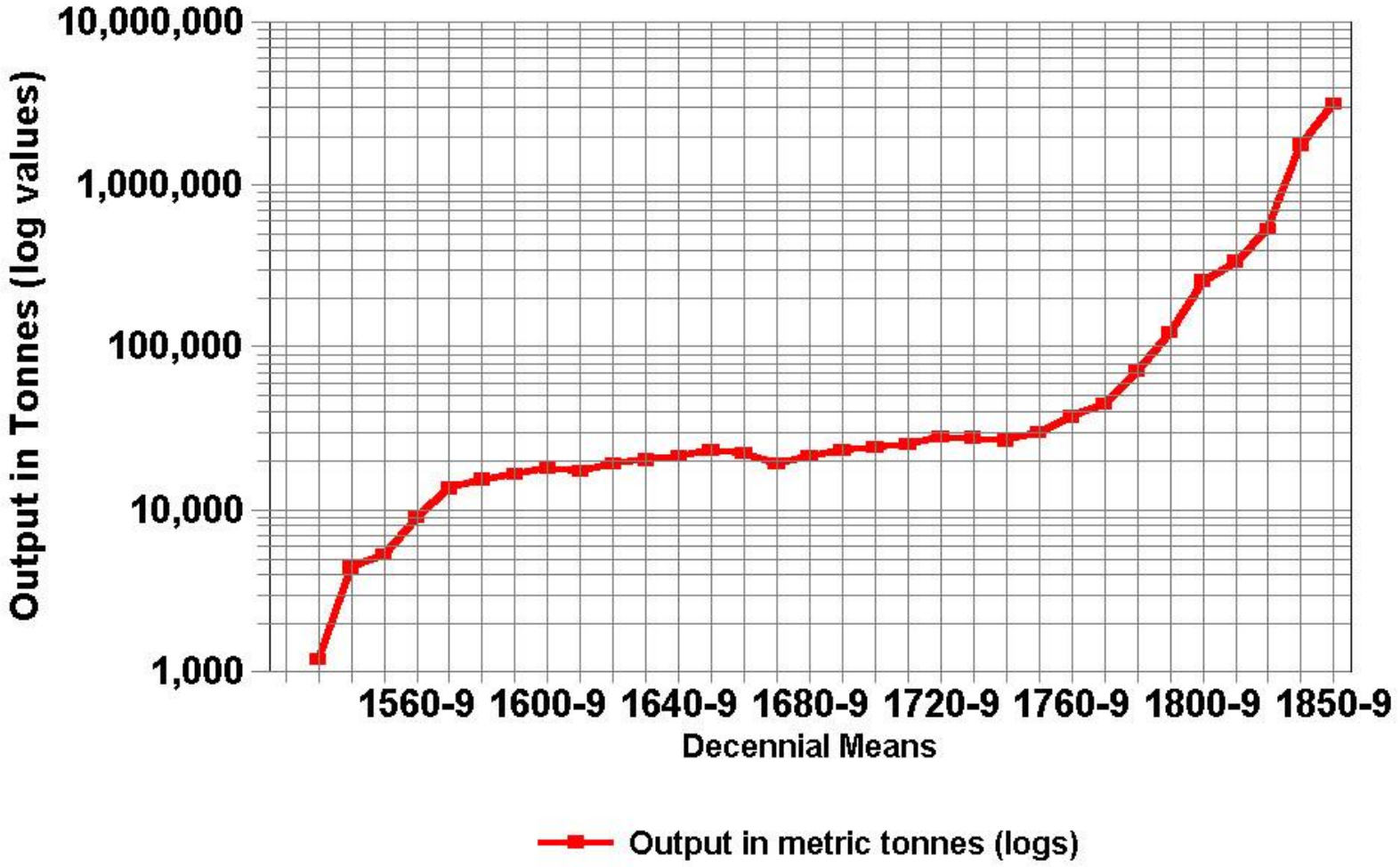
OUTPUT OF ENGLISH/BRITISH PIG IRON

Mean Output in Tons, 1530-9 to 1740-9



Outputs of English/British Pig Iron

Mean Outputs: Tonnes, 1530-9 to 1850-9



Growth of the English Iron Industry, 1500 to 1640 - 2

- 2) **Traditional Modes of Iron Making: 'Direct Process'**
- **with Bloomery Forges (Catalan Heaths)**
- a) **chemistry of iron extraction ('iron-winning')**:
- **to use a charcoal fire to combine that fuel's carbon with oxygen in iron oxide** → to liberate the iron from iron ore (Fe_2O_3) and produce residual carbon dioxide (CO_2)
- - formula: **$3C + 2\ Fe_2O_3 \rightarrow 4Fe + 3CO_2$**

Growth of the English Iron Industry, 1500 to 1640 - 3

- 2) **Traditional Modes of Iron Making**
- b) **iron purification by forging: to produce wrought iron**:
- **carbon adhering to the iron**: had to be oxidized, burned off by repeated heating & pounding, with a charcoal fire + water-powered forge tilt-hammers + water-powered forge bellows
- - **end result: virtually pure iron with about 0.1% carbon**
- c) **Economics of Bloomery Forges:**
- - **very small scale and inefficient** in fuel + labour
- - **extracted only 1/3rd of potential iron** from the ore
- - **produced about 20 – 30 tonnes** of wrought iron per year

Forge Bellows Operated by an Overshot Water-Wheel

(with camshaft) from Taccola, c.1449

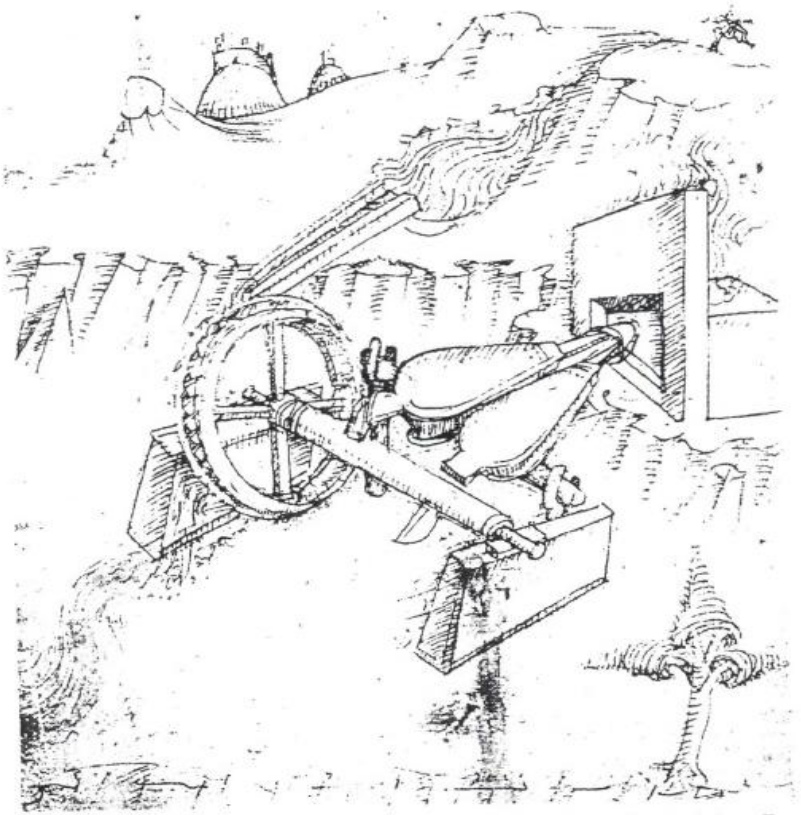


FIGURE 2–25. Forge bellows activated by overshot water wheel and camshaft from Taccola, c1449.

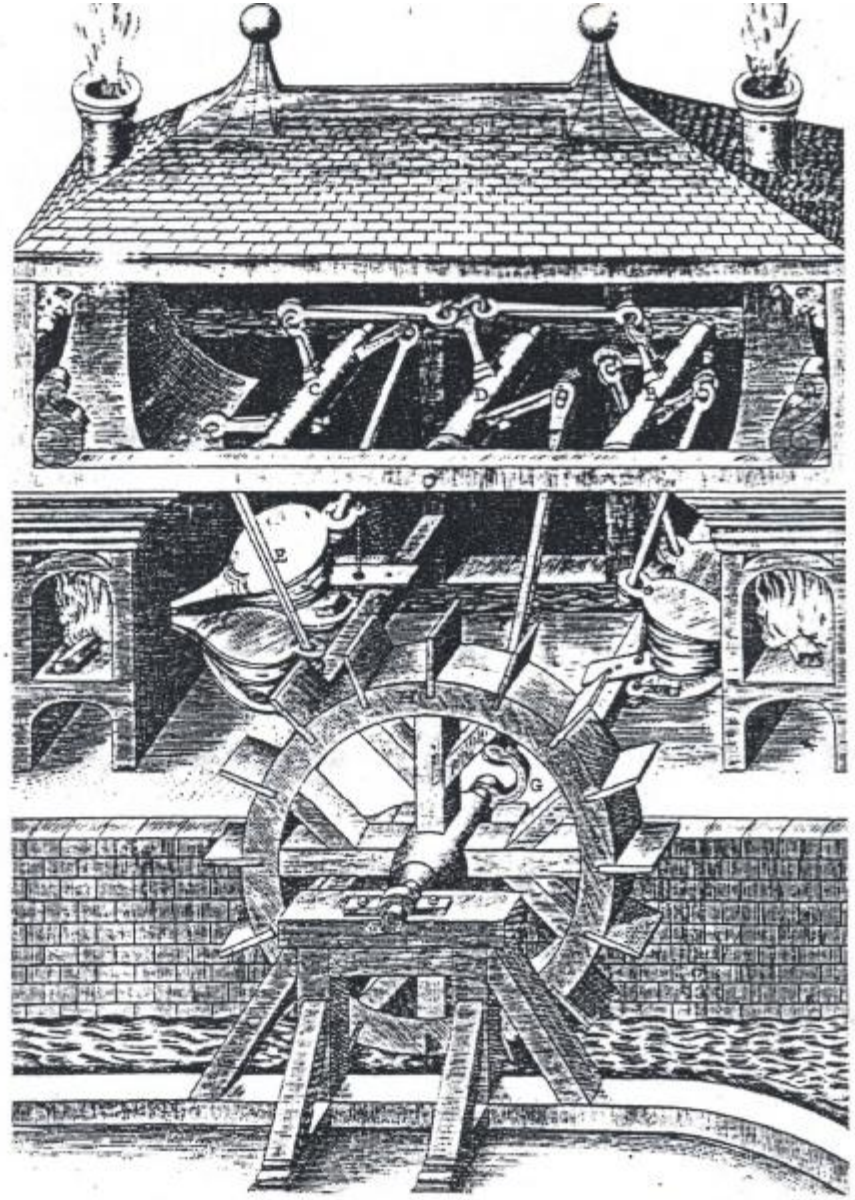
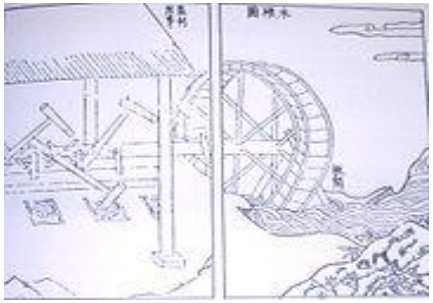


FIGURE 2–30. Water-activated bellows in a forge hearth from Ramelli, 1588. Note the use of a crank in this system as opposed to the cams used in the Taccola drawing of Fig. 2–25. Vertical rods from the rocking arms (*B*, *C*, *D*) raised the upper leaf of the bellows, which was lowered by the rope connected to the upper leaf and to the weighted, hinged flap beneath the lower leaf.

Water-Powered Tilt Hammers in Forges



Growth of the English Iron Industry, 1500 to 1640 - 4

- 3) **Introduction of the Blast Furnace: Indirect Process**
- a) **two-stage process: smelting & then refining**
- (1) **Smelting Iron Ore with the blast furnace** ➔ to produce basic iron, with high carbon content, poured molten into pre-cast or pre-shaped moulds
- - **cast iron, with 3% - 5% carbon**: if used as **consumer product**: in iron pans, pots, pipes, tool parts, and especially artillery (cannons)
- - **pig iron:** if used as an **input to be refined**, in the second stage
- (2) **Refining Iron Ore: to decarburize the iron in water-powered forges:** to produce purified wrought iron

Growth of the English Iron Industry, 1500 to 1640 - 5

- b) **origins obscure:** possibly near **Liège** (eastern Low Countries) or Rhineland: in 1380s; but introduced in England only in the 1490s
- c) **Metal casting: had begun with bronze (copper + tin)** to produce **church bells** → and then **artillery**, in 14th century (in place of forged iron cannons, with iron bars strapped together: could not handle powerful explosives
- d) **Superiority of cast bronze cannon over cast iron cannon**: already noted: bronze less likely to shatter, into shards, as cast iron cannon did.

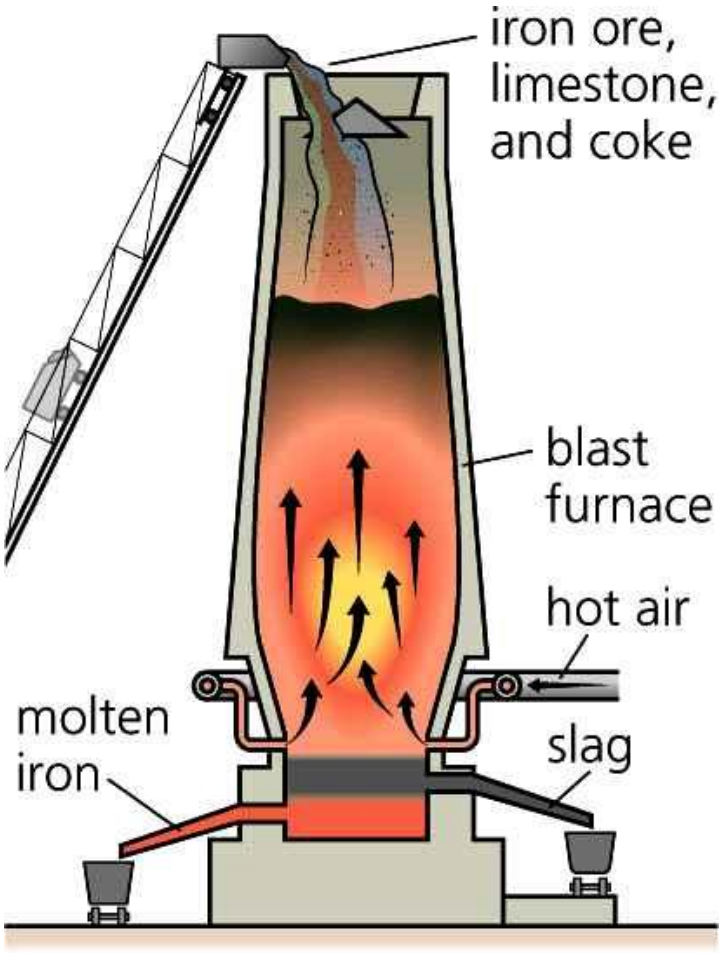
Growth of the English Iron Industry, 1500 to 1640 - 6

- 4) **Technology of the new Blast Furnace: For Smelting Iron Ore**
- a) **large brick-kiln furnace** – about 8 metres tall
- b) **necessarily used wood-charcoal as a fuel**: **since carbon (pure in charcoal) had to combine with the iron oxide, as noted to free the iron**
- c) **required hydraulic machinery**: to operate leather bellows (as in forge) to fan heat of charcoal fires
- d) **process: with bellows, charcoal-fire built up to about 1000^{o} C.**, to cause the charcoal to combine with the oxygen in Fe_2O_3 to liberate the iron and produce carbon dioxide (CO_2)

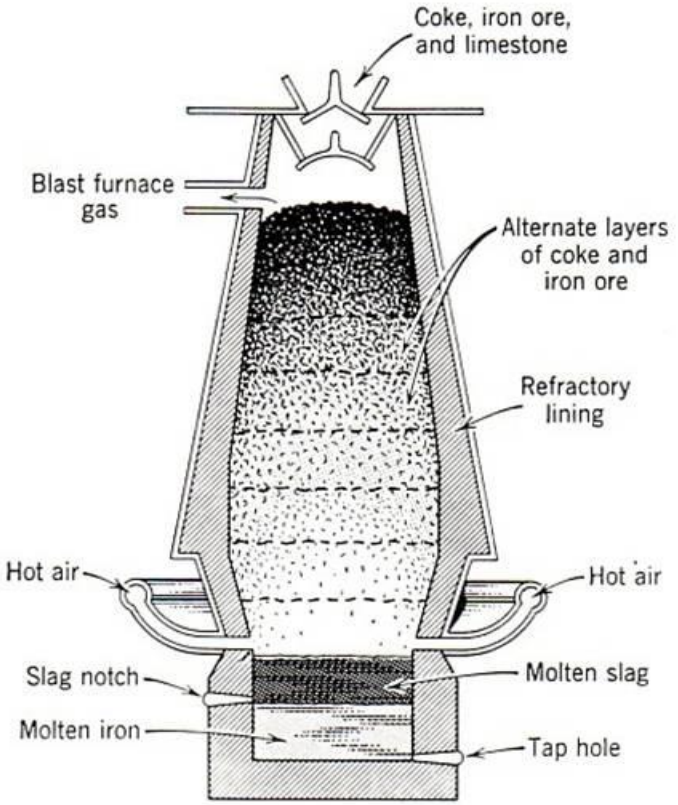
Growth of the English Iron Industry, 1500 to 1640 - 7

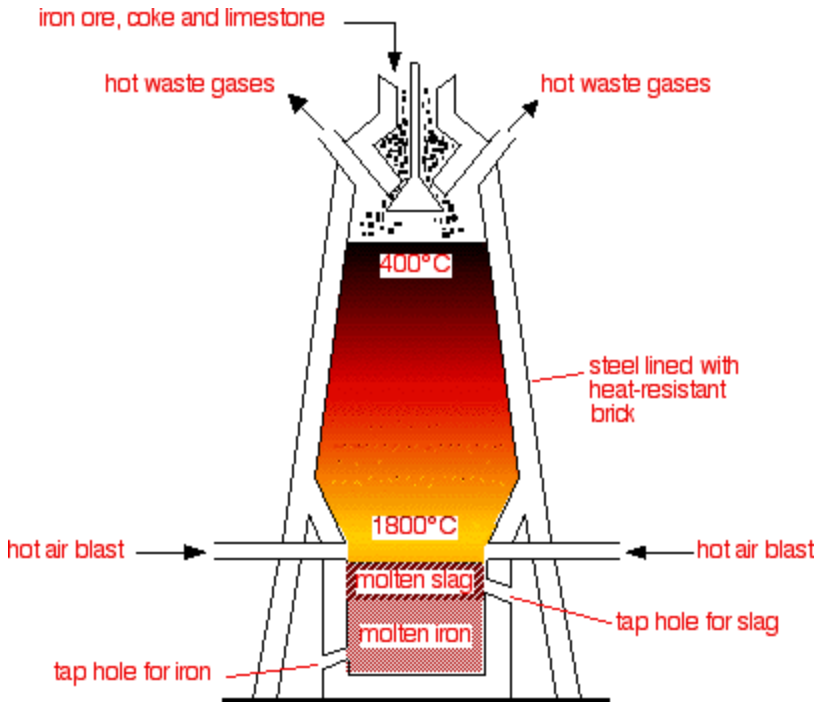
- 4) **Technology of the new Blast Furnace**
- e) **high carbon content (2.5% - 5%) made the iron alloy very hard and very brittle:** so that it could be worked only by being poured molten in pre-shaped casts, or moulds, as already indicated
- f) **vastly more efficient than Bloomery Forges**: in reducing large quantities of iron ore into either cast or pig iron
- g) **but required large quantities of both wood for charcoal and water power:**
- ➔ **thus the 'tyranny of wood and water'**

The Blast Furnace: A



The Blast Furnace: B





Growth of the English Iron Industry, 1500 to 1640 - 8

- 5) **Economics of the Indirect Process**
- a) **second stage of refining required:**
- i) **to produce purified wrought iron**: for 90-95% of iron manufactured in early-modern Europe.
- ii) **refinery forges or fineries, chaferies**: basically as seen in the Direct Process: with hydraulic machinery for both tilt-hammers and forges bellows (fan the heat)
- iii) **more efficient:** produce 0.75 tonne of wrought iron from 1.0 T pig iron
- iv) **smaller scale than Blast Furnaces**: but increased in scale to produce 120 – 200 tons by 1700

Growth of the English Iron Industry, 1500 to 1640 - 9

- 5) **Economics of the Indirect Process**
- b) **Output of Blast Furnaces**: rose from 200 T in 1530s to 300 T by the 1680s (some up to 800 T by the 1740s)
- c) **Industrial Capitalism (again)**: **born in this Tudor-Stuart era**, with no fundamental changes subsequently during the Industrial Revolution (post 1760)
- i) **vast increase in scale with more costly hydraulic machinery** ➔ large capital investments that only industrial or mercantile capitalists could supply, enabling them to own plant, machinery, raw materials
- ii) **iron workers**: supplying only their labour, worked for wages

‘Tyranny of Wood & Water’: Relative Stagnation from the 1640s? - 1

- 1) **The Nef – Ashton Thesis: thesis of inevitable industrial decline**
- a) **the tyranny of wood: that both blast furnaces (smelting) and finery forges (refining) required vast quantities of timber to produce charcoal**, and at the forest site (because charcoal is ‘friable’)
- i) **charcoal prices rising much faster than other prices** – from the 1640s: see my graph
- ii) **charcoal accounted for about 70% of smelting costs**: thus single most important production cost factor
- iii) **industrial migration from Weald sites to new sites:** in search of new sources of unused timber

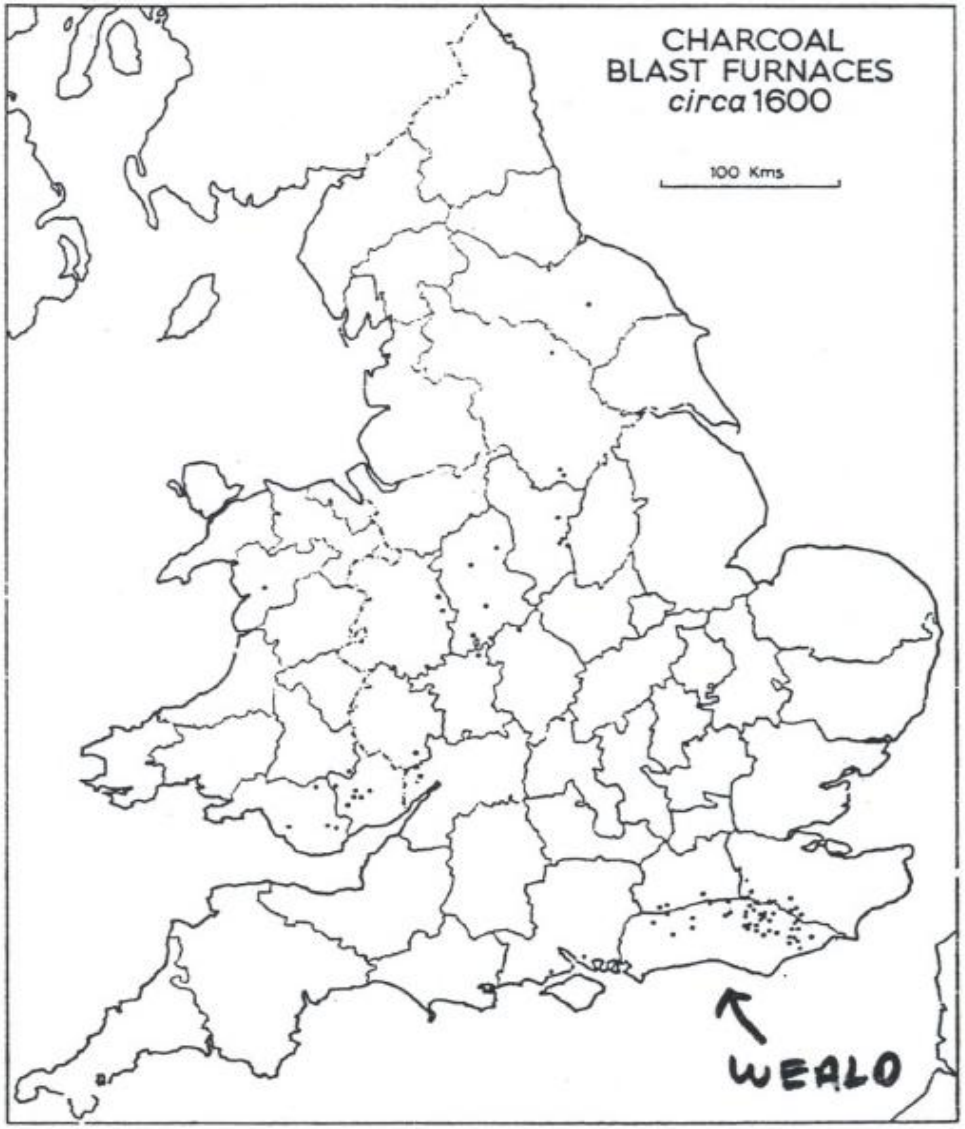


Fig. 61 Charcoal blast furnaces *circa* 1600
Based on H. R. Schubert, *History of the British iron and steel industry from c. 450 B.C. to A.D. 1775* (London, 1957), 354–92.

‘Tyranny of Wood & Water’: from the 1640s? - 2

- b) **tyranny of water: as much tied to water as to wood**
- i) **need for free water sites** (low opportunity costs) for both smelting and refining
- ii) **rarely were there enough free water sites + abundant wood fuel sites** to permit side by side location of blast furnaces (smelters) & forges ➔ meant scattering of small scale units in rural areas ➔ high internal transportation and transaction costs
- iii) **seasonal water shortages**: winter freezes & summer droughts

‘Tyranny of Wood & Water’: from the 1640s? - 3

- 2) **Major Opponents of the Nef-Ashton Thesis:**
- a) **Michael Flinn, George Hammersley, Donald Coleman, Charles Hyde, Joel Mokyr,** etc.
- b) **chief counter-arguments (see lecture notes)**
- - i) **That the industry staged a recovery from 1680s** (but ignore post-1720s stagnation)
- - ii) **that the iron industry grew and replaced its wood fuels quickly** – from young ‘coppice woods’ rather than from aged timbers: that the fuel source was ‘inexhaustible’ - but many coppice woods took 20 years to grow back

‘Tyranny of Wood & Water’: from the 1640s? - 4

- b) **chief counter-arguments cont’d (see lecture notes)**
- iii) **that ‘industrial migration’ instead reflected English economic development:** the need for iron production to service newer markets
- iv) **decline in number of blast furnaces offset by an increase in their output scales:** but they assume that all furnaces were in operation, year around, and that their scale outputs are correctly calculated
- c) **neglected to consider the ‘tyranny of water’ arguments**
- d) **diseconomies of rural scattering of industrial sites**

The Costs of Smelting Pig Iron with Wood-Charcoal

Production Costs in 1720-21 to Produce 360 tons of Pig Iron (per year)

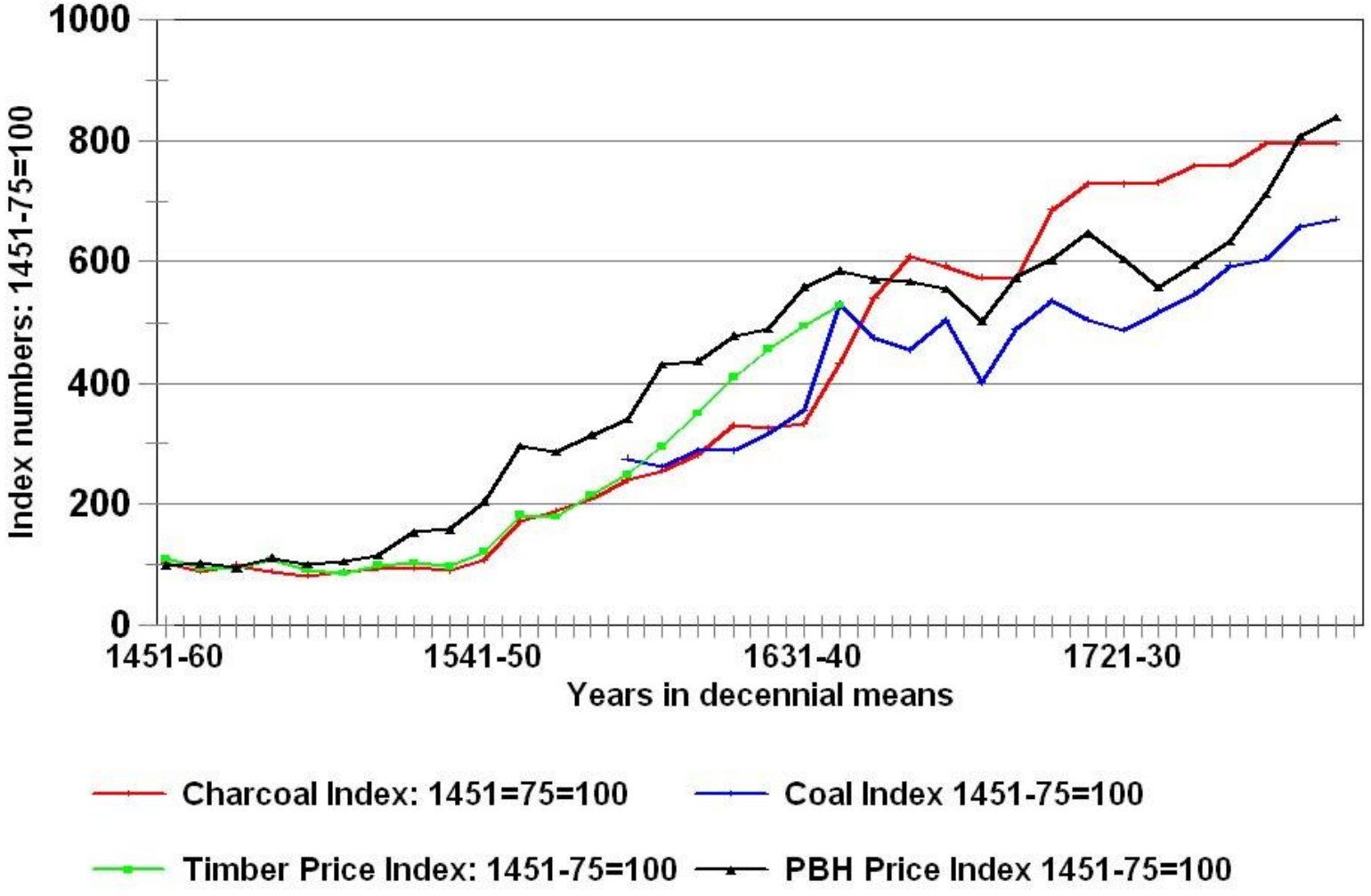
FACTOR INPUT	TOTAL COSTS PER YEAR in Pounds Sterling	PERCENTAGE OF TOTAL COSTS
Charcoal	1,459	71.0%
Iron Ore	313	15.2%
Furnace Labour	61	3.0%
Clerical Salaries	40	1.9%
Rent	40	1.9%
Repairs and Maintenance	63	3.1%
Other Miscellaneous Costs	78	3.8%
TOTAL COSTS	2,054	100.0%

Costs per ton of pig iron: £2,054/360 tons = £5.706 per ton.

A ton of refined bar iron [wrought iron] cost almost three times as much: £15.200 per ton.

English Wood, Charcoal, Coal Prices

1451-60 to 1781-90



The English Iron Industry, 1580 - 1740

Charcoal Prices, Pig Iron Outputs, and Bar Iron Imports

in selected decades

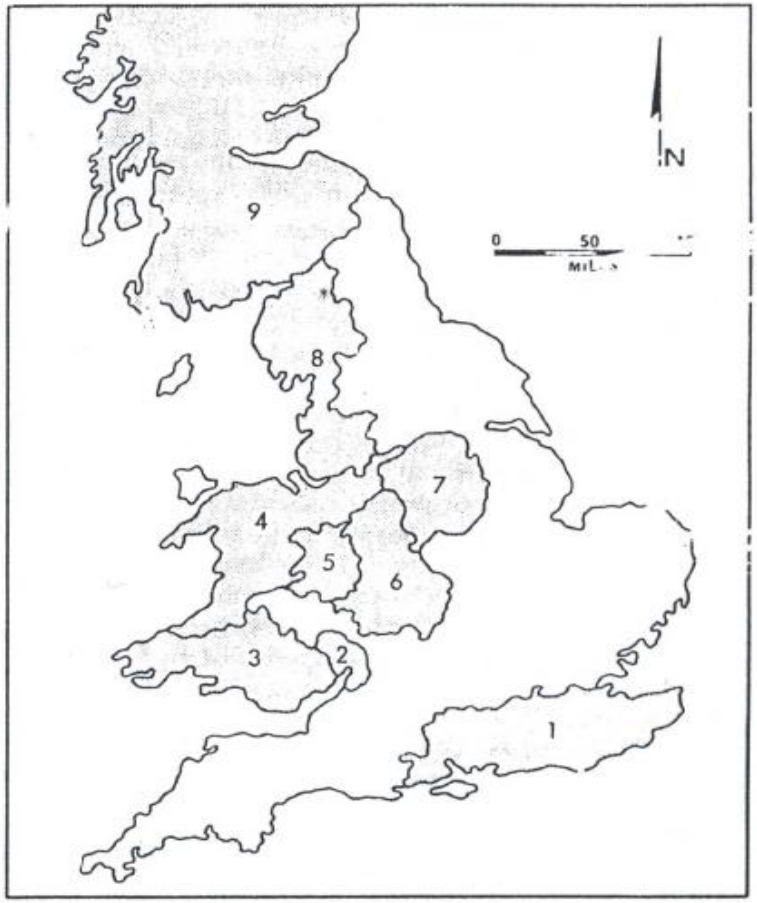
PERIOD	CHAR-COAL PRICES £ sterling per load	PIG IRON OUTPUT in thousands of tons	BAR IRON IMPORTS in thousands of tons	PRICE INDEX 1451-75 = 100
1580-89	1.0	15.2	1.7	357
1630-39	1.4	20.0	3.7	616
1680-89	2.6	21.0	23.0	577
1730-39	3.0	27.5	34.6	553

Charcoal Prices in Iron-Manufacturing in England, 1539 - 1771

Year	Place	shillings per load	Base = 1539	PBH Index	Base = 1539	Ratio of Charcoal to PBH Index
1539	Newbridge	3.00	100.00	147.00	100.00	100.00
1546	Panningridge	2.83	94.44	248.00	168.71	55.98
1577	Middleton	3.42	113.89	363.00	246.94	46.12
1585	Cannock	9.50	316.67	338.00	229.93	137.72
1595	Middleton	10.00	333.33	515.00	350.34	95.15
1595	Oakamoor	12.00	400.00	515.00	350.34	114.17
1607	Lismore	4.17	138.89	449.00	305.44	45.47
1608	Lismore	7.17	238.89	507.00	344.90	69.26
1616	Lismore	10.00	333.33	562.00	382.31	87.19
1628	Pontrillas	14.25	475.00	466.00	317.01	149.84
1629	Waldron	25.00	833.33	510.00	346.94	240.20
1630	Cary	15.67	522.22	595.00	404.76	129.02
1632	Cary	22.08	736.11	580.00	394.56	186.57
1632	Goodrich	17.17	572.22	580.00	394.56	145.03
1658	Dean	18.08	602.78	646.00	439.46	137.16
1662	Dean	14.00	466.67	769.00	523.13	89.21
1691	Dean	29.00	966.67	493.00	335.37	288.24
1691	Dean	33.33	1111.11	493.00	335.37	331.30
1692	Bishopswood	32.08	1069.44	542.00	368.71	290.05
1700	Bishopswood	34.58	1152.78	671.00	456.46	252.55
1700	Elmbridge	33.33	1111.11	671.00	456.46	243.42
1699	Lydney	29.67	988.89	773.00	525.85	188.06
1700	Lydney	37.17	1238.89	671.00	456.46	271.41
1701	Bishopswood	30.38	1012.50	586.00	398.64	253.99
1703	Bishopswood	34.63	1154.17	551.00	374.83	307.92
1703	Heathfield	25.08	836.11	551.00	374.83	223.06
1705	Pontypool	29.00	966.67	548.00	372.79	259.31
1748	Pennybridge	34.00	1133.33	599.00	407.48	278.13
1748	Cunsey	30.00	1000.00	599.00	407.48	245.41
1757	Ashburnham	37.75	1258.33	733.00	498.64	252.35
1763	Pennybridge	38.25	1275.00	655.00	445.58	286.15
1771	Pennybridge	41.17	1372.22	775.00	527.21	260.28


FURNACES AND FORGES, 1717
Furnaces (Pig iron capacity)
Forges (Bar iron capacity)
Tons
100
300
700
100 Kms

MAP 1: IRONMAKING DISTRICTS OF GREAT BRITAIN



KEY

1: The Weald (Sussex, Kent, Surrey, and Hampshire)
2: Forest of Dean
3: South Wales and Monmouthshire
4: North Wales and Cheshire
5: Shropshire
6: Staffordshire, Worcestershire, and Warwickshire
7: South Yorkshire, Derbyshire, and Nottinghamshire
8: Lancashire, Cumberland, and Westmoreland
9: Scotland

Geographical Distribution of Early Eighteenth-Century Ironworks

Region	Number	Tons of Output	Share of National Output (%)	Tons Output Per Furnace
A. Furnaces (1720)				
1. The Weald	15	2,000	11.5	133
2. Forest of Dean	9	4,250	24.4	472
3. South Wales	6	1,500	8.6	250
4. N. Wales-Cheshire	5	2,250	12.9	450
5. Shropshire	7	2,550	14.6	364
6. Staff.-Worcester.	6	2,400	13.8	400
7. S. Yorkshire-Derby	11	2,400	13.8	218
8. Lancashire-Cumberland	-	-	-	-
9. Scotland	-	-	-	-
Total/Average	**59**	**17,350**		**297**
B. Forges (1717)				
1. The Weald	15	920	6.9	61
2. Forest of Dean	20	1,840	13.8	92
3. South Wales	13	1,750	13.1	134
4. N. Wales-Cheshire	8	880	6.6	110
5. Shropshire	14	2,010	15.0	143
6. Staff.-Worcester.	28	3,920	29.4	140
7. S. Yorkshire-Derby.	16	1,690	12.6	105
8. Lancashire-Cumberland	2	320	2.4	160
9. Scotland	-	-	-	-
Total/Average	**116**	**13,330**		**115**

Occupied Blast Furnace Sites, by Decades

Decade	Total Furnace Sites	Index 1600-09 = 100	Weald Furnace Sites	Index 1600/9 = 100
1530-9	6	6.7	6	11.5
1540-9	22	24.7	22	42.3
1550-9	26	29.2	26	50.0
1560-9	44	49.4	36	69.2
1570-9	67	75.3	52	**100.0**
1580-9	76	85.4	54	103.8
1590-9	82	92.0	50	96.2
1600-9	89	**100.0**	52	100.0
1610-9	79	88.8	47	90.4
1620-9	82	92.1	46	88.5
1630-9	79	88.8	41	78.8
1640-9	82	92.1	43	82.7
1650-9	86	96.6	42	80.8
1660-9	81	91.0	37	71.2
1670-9	71	79.8	24	46.2
1680-9	68	76.4	22	42.3
1690-9	78	87.6	23	44.2
1700-9	76	85.4	23	44.2
1710-9	82	92.1	21	40.4
1720-9	60	67.4	13	25.0
1730-9	55	61.8	12	23.1
1740-9	49	55.1	12	23.1

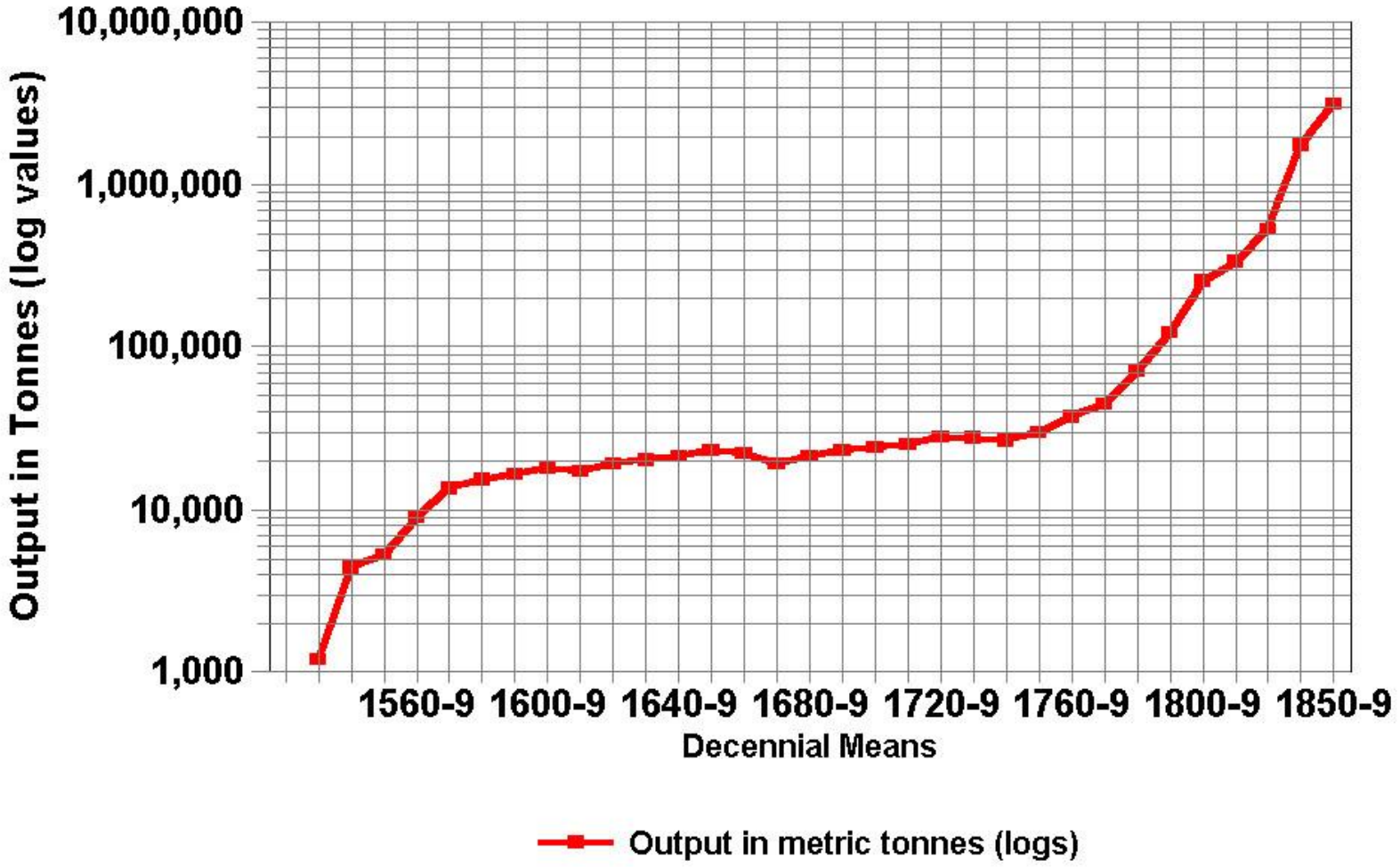
English Pig Iron Production, 1530-1750

Occupied Blast Furnaces, Average Output per Furnace, and Estimated Annual Average Output in Tons, per Decade, 1530-9 to 1740-9

Decade	No. of Blast Furnaces Occupied	Average Output per Furnace in tons	Average Annual Iron output in tons
1530-9	6	200	1,200
1540-9	22	200	4,400
1550-9	26	200	5,200
1560-9	44	200	8,800
1570-9	67	200	13,400
1580-9	76	200	15,200
1590-9	82	200	16,400
1600-9	89	200	17,800
1610-9	79	215	17,000
1620-9	82	230	19,000
1630-9	79	250	20,000
1640-9	82	260	21,000
1650-9	86	270	23,000
1660-9	81	270	22,000
1670-9	71	270	19,000
1680-9	68	300	21,000
1690-9	78	300	23,000
1700-9	76	315	24,000
1710-9	74	340	25,000
1720-9	80	350	28,000

Outputs of English/British Pig Iron

Mean Outputs: Tonnes, 1530-9 to 1850-9



‘Tyranny of Wood & Water’: from the 1640s? - 5

- 3) **Growing English dependence on imported iron: from Sweden and Russia**
- a) **Imports of Swedish bar iron rose from 1200 tonnes** in 1580s to about 18,000 tonnes in 1690s to over 25,000 tonnes by the 1730s ➔ to account for over half of English consumption
- b) **Swedish imports all the more remarkable:**
- i) **burdened with Swedish export duties of £3.45 per ton and English import duties of £2.05 per ton,** for total duties of £5.50 per tonne of bar iron
- ii) **those duties = 36% of English price** of £15.20 per tonne of bar iron in the 1750s

‘Tyranny of Wood & Water’: from the 1640s? - 6

- 3) **Growing English dependence on imported iron:**
- c) **Swedish & Russian advantages:**
- i) **super abundance of both forest (wood) and water**
- ii) **far cheaper labour**
- iii) **richer iron ores** → producing higher quality bar iron

English Iron Production and Imports: Average Annual Estimates per Decade of Imports and Production of Bar Iron, 1720-9 to 1740-9

Decade	Bar Iron Imports in tons	Bar Iron Domestic Production in tons	Imports as Percentage of Total Consumption
1720-9	19,650	19,700	50%
1730-9	25,650	19,350	57%
1740-9	22,500	18,650	55%

Note: 1 ton of bar (wrought) iron requires about 1.35 tons of pig iron; and about 5% of pig iron production was reserved for castings. Therefore bar production in England has been estimated as: 0.95/1.35 = 0.7037 tons of pig iron per ton of bar iron.

The English Iron Industry, 1580 - 1740

Charcoal Prices, Pig Iron Outputs, and Bar Iron Imports

in selected decades

PERIOD	CHAR-COAL PRICES £ sterling per load	PIG IRON OUTPUT in thousands of tons	BAR IRON IMPORTS in thousands of tons	PRICE INDEX 1451-75 = 100
1580-89	1.0	15.2	1.7	357
1630-39	1.4	20.0	3.7	616
1680-89	2.6	21.0	23.0	577
1730-39	3.0	27.5	34.6	553

Beginnings of the Industrial Revolution in Iron Making - 1

- 1) **Coke Smelting: Abraham Darby**
- a) **coke as the solution**:
- - **purify coal by burning out all impurities** in a sealed airless furnace – almost same process as making charcoal from wood!
- b) **Abraham Darby: ca. 1710** - he succeeded where many others before him (e.g., Dud Dudley) had failed: in distilling coal into almost pure carbon as ‘coke’

Beginnings of the Industrial Revolution in Iron Making - 2

- c) **Why Darby's coke-smelters did not produce an industrial revolution:**
- i) **Blast furnaces with coke fuels: produced pig/cast iron with a high silicon content** → meant much higher refining costs (when most demand was for wrought or bar iron)
- ii) **Nobody followed Darby in building coke smelters** (blast furnaces) because of high costs: → continued decline of the iron industry, until the 1750s:
- d) **One major advantage of the Darby process**: **the silicon in coke smelting produced far higher quality cast iron** → increased demand for **cast iron as a consumer** + military product (breakthrough for cast iron cannons)

Beginnings of the Industrial Revolution in Iron Making - 2

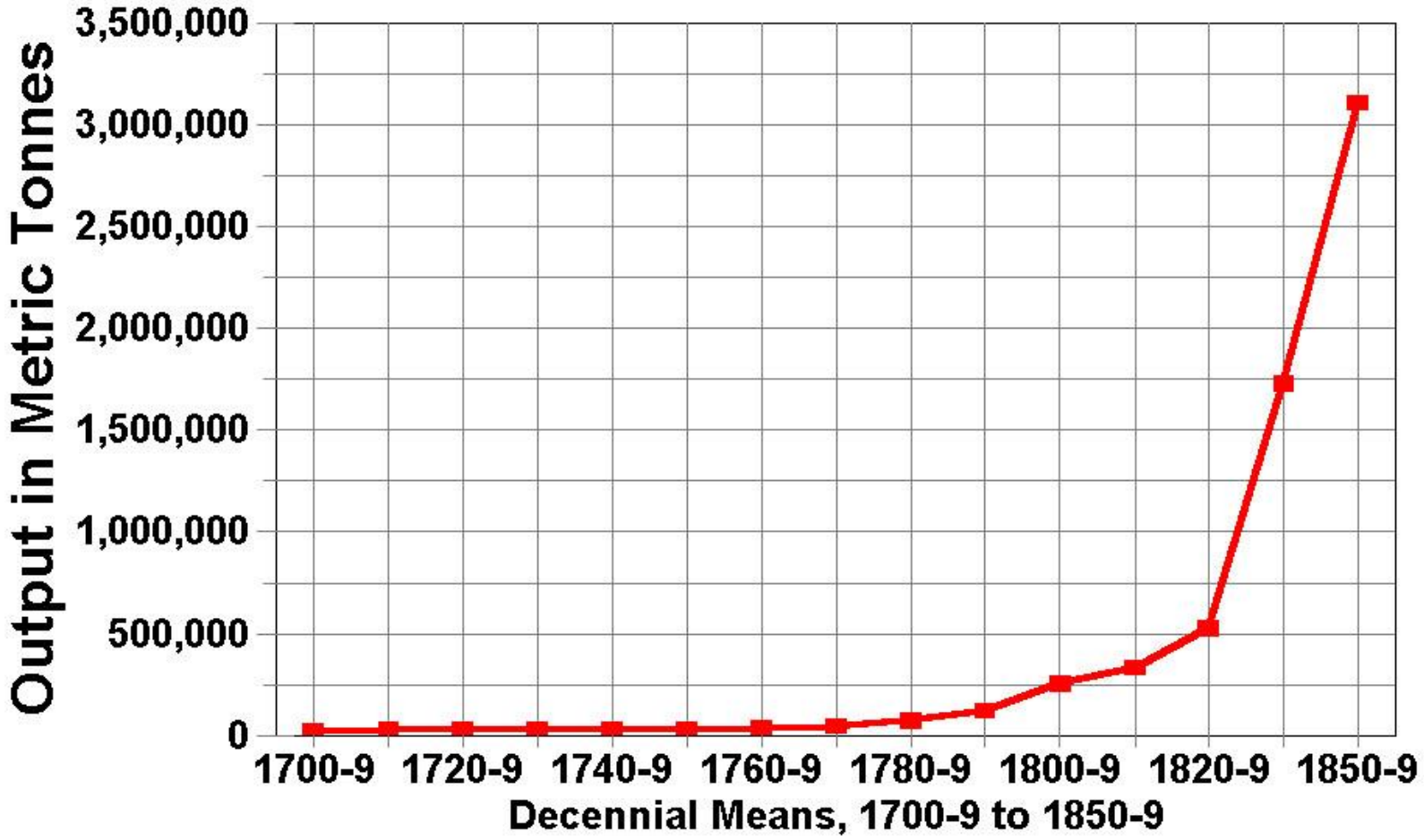
- 2) **The required economic + technological changes for an Industrial Revolution:**
- a) **continued rise of wood charcoal prices while coal and coke prices fell**: intersection of price changes took place in 1750s [with advances in coal-mining]
- b) **Cost-reducing improvements in Coke Fired Blast Furnaces:**
- i) **John Smeaton: 1760: water-powered piston air pumps** (to replace leather bellows)
- ii) **James Watt: 1776: steam engine, for steam-powered piston air-pumps** → cut fuel costs by over one half → the crucial innovation for iron revolution

Beginnings of the Industrial Revolution in Iron Making- 3

- c) **Industrial Revolution in Refining: 1783**
- **- Cort and Onions 'Puddling and Rolling' Process: with coke-fired steam powered refineries**: but that story belongs to ECO 303Y)
- d) **An Industrial Revolution: based on coal throughout:**
- - **coal distilled into coke for smelting & refining**
- - **coal-fired steam engines in both coal mining and iron (and later steel) manufacturing**

OUTPUT OF BRITISH PIG IRON

Mean Output: Tonnes, 1700-9 to 1850-9



Industrial Revolution: Steel - 1

- 1) **Steel is the optimum form of iron,** with a carbon content half-way between cast and wrought iron:
- a) **cast iron**: 2.5% - 5.0%
- b) **steel:** about 1.0% carbon
- c) **wrought iron**: under: about 0.1% carbon
- 2) **Steel has the greatest resistance to stress:**
- a) **will not bend like wrought iron**,
- b) **nor shatter like cast iron**
- c) **steel has the hardness of cast iron**

Industrial Revolution: Steel - 2

- 3) **Steel was an extremely costly metal before the Industrial Revolution**
- - **in essence: purified wrought iron has to be produced first,** and then the requisite amount of carbon is then added, in a homogenous mixture (with many problems, a few solved in the 18th century)
- 4) **Revolution in Steel Making**
- **began in 1856 with the Bessemer Converter,**
- which reduced the iron ore to molten decarburized iron (purified), to which was added the 1% carbon in a homogenous mixture

The Curse of Coal?? - 1

- 1) **The modern, coal-based Industrial Revolution transformed the entire world, for both good and ill**: but more good, than ill
- 2) **The Curse of Coal: pollution and Global Warming**
- a) **not the same: global warming** from carbon dioxide and methane emissions
- b) **note from following graph**, the steady rise in global temperatures from the onset of modern industrialization in the mid-18 the century

The Curse of Coal?? - 2

- 3) **Counter Considerations about coal and global warming:**
- a) **note that the rise in global temperatures commenced at the end of the Little Ice Age** (later 17th, early 18th century)
- b) by this graph, current global temperatures are no higher than in the early 14th century
- c) and much lower than the peak of the Medieval Warming era, in Carolingian times

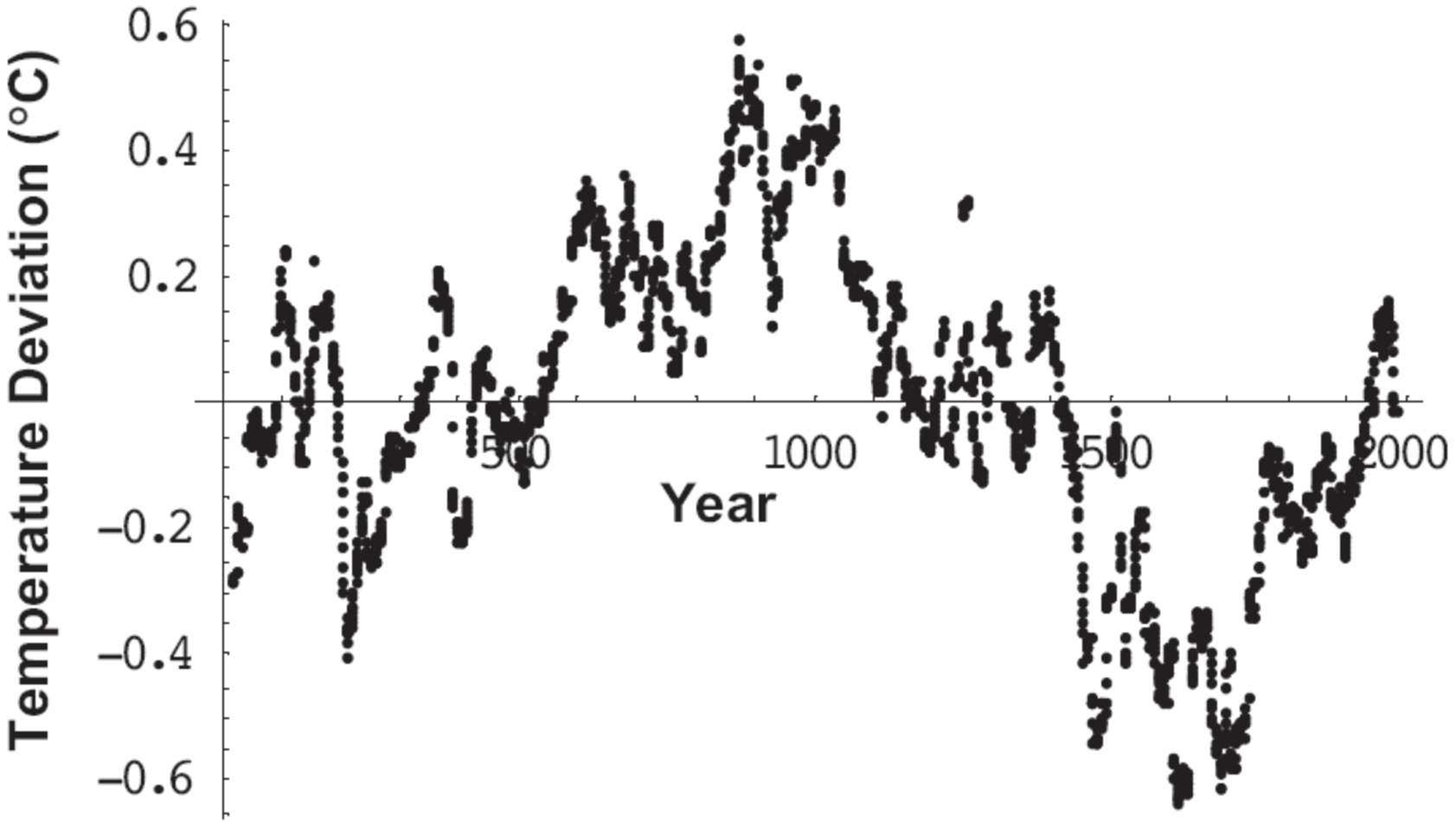


Figure 1. Mean of temperature data for 18 series.
Data archived at http://www.ncasi.org/programs/areas/climate/LoehleE&E2007.csv

TIPS ON PREPARING FOR THE FINAL EXAMINATION IN ECO 301Y

Updated: Tuesday, 3 April 2012

The educational purpose of this final examination is not to terrorize, punish, or fail you, but rather to let you synthesise and integrate a large body of material that you have studied over the course of a year -- of facts, concepts, models, theories, hypotheses, and even unanswered questions -- so that you may gain an even better understanding of the nature and processes of (European) economic development, of growth and decline, of modern urban industrialization, and modern urban societies.

1. **READ OVER THE DETAILED COURSE OUTLINE** and then read over the schedule of lecture topics for the year. **Get the key topics and their order clearly focused in your mind.**

2. **READ OVER THE LIST OF REVIEW QUESTIONS**, following the instructions to ignore those questions, or parts of questions, not covered this year. Try to pick out those questions that you think most likely to appear on the final examination. See the following website.

3. **REVIEW THE PREVIOUS YEARS' FINAL EXAMINATIONS**, at this website: http://www.economics.utoronto.ca/munro5/301Oldexams.htm

4. **READ OVER THE TEN 'A' LIST TOPICS**: all of which will be on the final exam in some form (even if two may be combined). Read the introductory analyses of each of these topics in the **Master List of Topics for Essays and General Readings** [see course materials on my website]

5. **READ OVER YOUR TERM ESSAYS,** and any notes that you made for those essays

6. **READ OVER THE POWER POINT LECTURE SUMMARIES, ONLINE:** also in PDF. ECO 301Y, at this URL: http://www.economics.utoronto.ca/munro5/301LectSummaries.htm

7. **SKIM READ THE ONLINE LECTURE NOTES FROM THE BEGINNING TO THE END**, in one or two sittings, if possible. **Focus on the passages that are in bold font.** Try to see relationships between economic sectors, between regions and countries, and relationships evolving over time. Focus on cause and effects; focus on economic and historical analyses, not on dry facts. Try to concentrate your energies on those topics that seem most likely to appear on the final examination. **MARK THOSE PASSAGES (in the margins) THAT REPRESENT CONCLUSIONS OR SUMMARIES especially for topics that you selected,** from the list of Review Questions, as those most likely to appear on the exam. If you lack sufficient time to do this, then concentrate on skim-reading the Power Point slides, online (do not print them out). If you are reading these notes for the first time – **if you are not re-reading them** – you are wasting your time.

8. **Read the following web document: 'An Explanation of Why Some Students do Poorly on the Final Examination': at** http://www.economics.utoronto.ca/munro5/ExamFailure.pdf
The chief reason why some students do poorly is their failure to answer the ENTIRE question, as the question is posed.

9. **READ these other following web documents on my Home Page:**

- Master List of Topics for Essays and General Readings (for each course).
- Grades on the Mid-Year Tests and Term Essays: How to Get An "A"
- Instructions on Writing Term Essays

10. **Do not forget to bring the Time-Chart (for ECO 301Y) with you to the final examination.** This is the ONLY aid that you are permitted to have and use at the final examination

ECO 301Y1 Y
The Economic History of Later Medieval and Early Modern Europe, 1250 - 1750

Aids Allowed: Time-Chart of European Economic History **Duration - 3 Hours**

Answer any **THREE** of the following **twelve (12)** questions, provided that they are **different** questions, spending no more than one hour on each. All questions are of equal value. You may answer questions related to your term essays. **Do not, however, give similar answers to the questions selected; and thus do not select questions with similar themes, since many of the questions have overlapping topics.**

Answer every question selected IN FULL, and answer all the questions as posed. Please number your questions properly; write legibly, on one side of the page only; and double-space your answers.

1. The Malthusian Problem in European Economic History: Positive and Prudential Checks. Discuss the role of famines and diseases, and any relevant socio-economic institutions, in determining or influencing cycles of demographic growth and decline in the western European economy, from the early 14th to the mid-18th centuries. In your answer, consider these issues:
   a) were population growth and decline thus due more to endogenous or exogenous factors?
   b) was population growth the cause or consequence of economic growth? Or both?
   c) up until the modern Industrial Revolution era, did population growth inevitably meant a decline in real incomes, and thus an increase in malnutrition, disease, and mortality (and declining fertility): i.e., a 'Malthusian trap'?
   d) If so, did the emergence of the European Marriage Pattern offset the 'Malthusian trap?

2. Analyse the role of serfdom in European economic development from the 13th to 17th centuries, in terms of the following major issues:
   a) Why was serfdom almost always found in feudal manorial agriculture (on feudal manors)?
   b) Was serfdom invariably a barrier to agricultural efficiency and economic growth?
   c) Why did serfdom decline in late-medieval western Europe and then, subsequently, spread into eastern Europe, culminating in the 17th century 'General Crisis' era?
   d) Discuss the relevant roles of demographic, commercial, and institutional factors.

3. Compare and contrast the role of monetary factors and monetary forces in affecting the course of European economic development during the two following 'B-Phase' periods:
   (a) the late-medieval 'Great Depression' (c. 1320 - 1520);
   c) the 'Seventeenth-century General Crisis' (1640 - 1740).

4. Examine the economic and social consequences of feudal warfare and warfare-related public borrowing and taxation, in terms of the following issues:
   a) the impact of such warfare on European trade and finance, in particular in changing the patterns of international trade routes.
   b) the impact (actual or theoretically potential impacts) on both production and consumption – and thus on living standards.
   c) the role that such warfare and taxation played (if any) in the so-called late-medieval 'Great Depression', or in periodic late-medieval recessions.

5. Analyse the role of usury and of other Church doctrines in the evolution of the western European economy, and especially its role in the formation of its banking & financial institutions and credit

instruments, for both private mercantile finance and public finance, from the 13th to 18th centuries.

6. Compare the role of demographic and monetary factors in explaining both the **causes** of inflation of the Price Revolution era (ca. 1520 - ca. 1650) and its **consequences**: in terms of the impact of changes in both relative and absolute prices (i.e., particular commodity prices and the price level) in the agricultural, industrial, and commercial sectors (long distance trade). In particular, analyse the changes in the key factor costs of production, and their consequences, as for example, in Hamilton's thesis of 'Profit Inflation'.

7. Discuss the causes and consequences of enclosures in Tudor-Stuart and early-modern England, in terms of the following issues:
   a) How did enclosures take place: how and why did enclosures come to displace communal forms of farming: i.e., the common or open field systems, especially in the Midlands?
   b) How did the decline of serfdom in late-medieval and early-modern England facilitate the spread of the Tudor Stuart enclosures?
   c) What roles did the following play as causes of enclosures: social (Rise of the Gentry), commercial, demographic, monetary (Price Revolution), and institutional factors.
   d) Why did England experience more enclosures than anywhere else, before the French Revolution?
   e) Were enclosures necessary for advances in agricultural productivity and economic growth?
   f) Who gained and who lost from the Tudor-Stuart Enclosures?

8. In the context of the ongoing 'proto-industrialization' debate, discuss the role of rural industries, especially textiles, in the development of the European but especially the English economy during the late-medieval and early-modern eras. Answer the following questions:
   (a) what were the changing relationships between agriculture and rural industries in early-modern Europe: especially in north-western Europe?
   (b) why did so many textile industries that had been predominantly urban in the later medieval era become largely (if not entirely) rural during the early-modern era? Thus, compare the economics of industrial locations in both periods.
   (c) was Franklin Mendels justified in asserting that that the 'rapid growth of traditionally organized but market-oriented, principally rural industry ... induced the passage to modern industry' and 'paved the way for factory industrialization'?

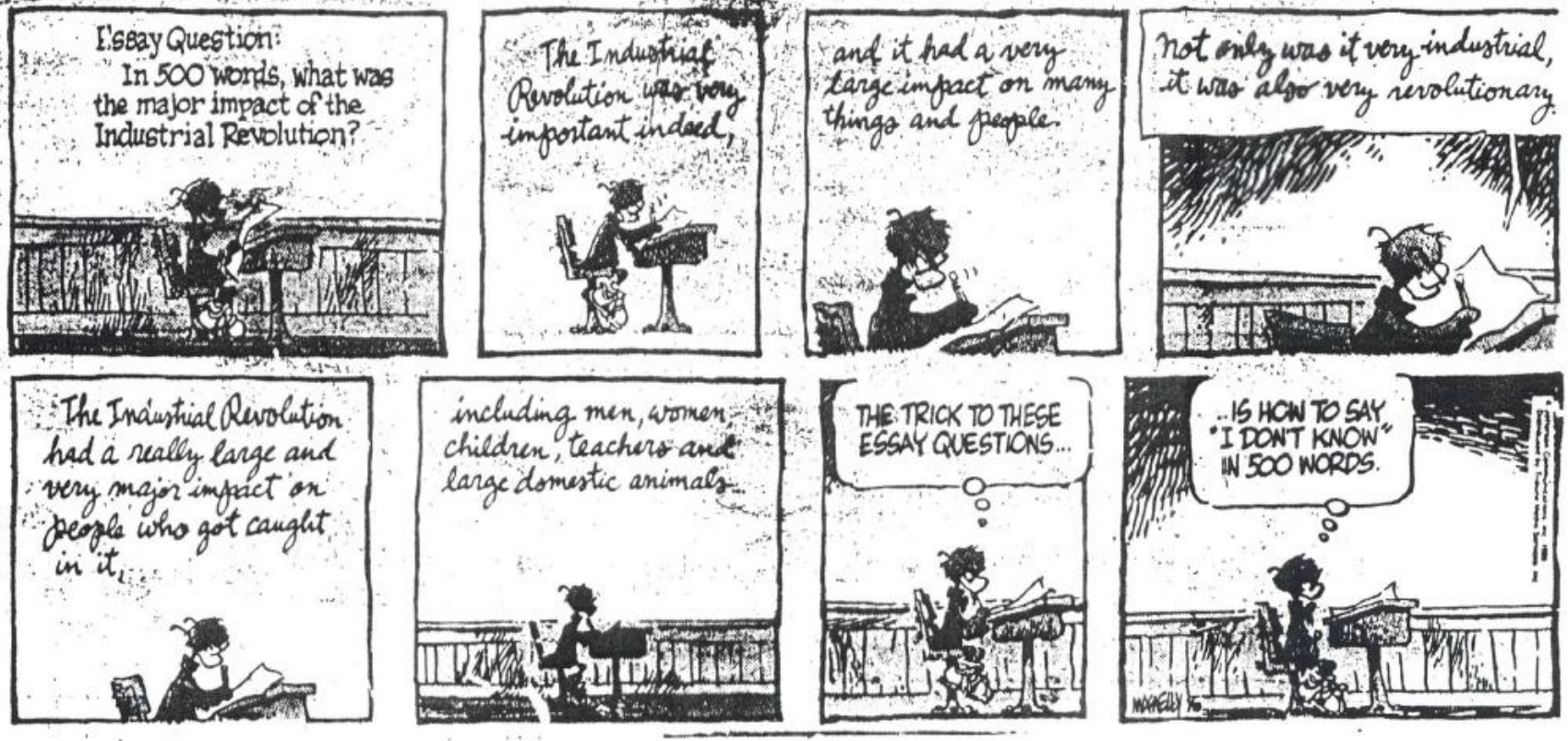
9. Were the 'economic declines' of Spain, Portugal, and Italy aspects of the more 'General Crisis' of the 17th century – or independent phenomena? In your answer, explain briefly the debate about the 17th century 'General Crisis', and then compare and contrast the changing economic fortunes of Iberia and Italy with those of England and the Dutch Republic, during from the later 16th to early 18th centuries.

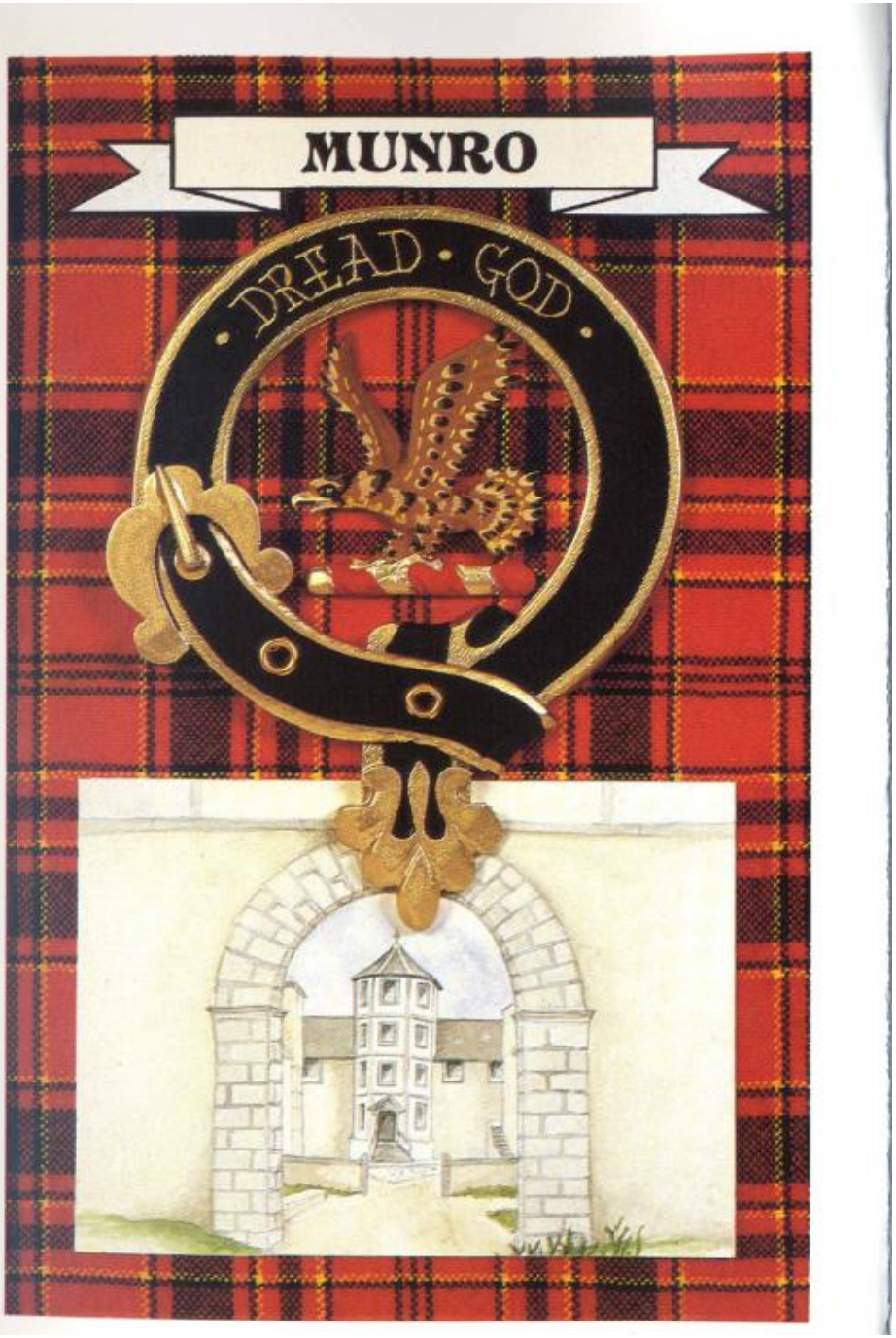
10. Compare and contrast the role of maritime trade, shipbuilding, and sea-power in the economic development of later-medieval and early modern Europe, in the following three regions: the Mediterranean, the Baltic, and the Atlantic. Why and how did the third region provide the origins of European overseas colonialism (imperialism)?

11. Did England experience a 'minor industrial revolution' during the 16th and 17th centuries? Evaluate the strengths and weaknesses of the Nef thesis, and the extent to which England did experience the formation and development of genuine industrial capitalism in this period – in which industries?

12. Explain why, in late-medieval and early-modern Europe, international supremacy in international banking and finance shifted from: Italy (Florence and Venice) to South Germany and then to Antwerp, then to Amsterdam, and finally to London? In your answer, explain the relationships between international trade and international banking.

SHOE **by Jeff MacNelly**




MUNRO
DREAD · GOD