Lecture 6B
The Industrial Revolution

Macroeconomics (Quantitative)

Econ 101B

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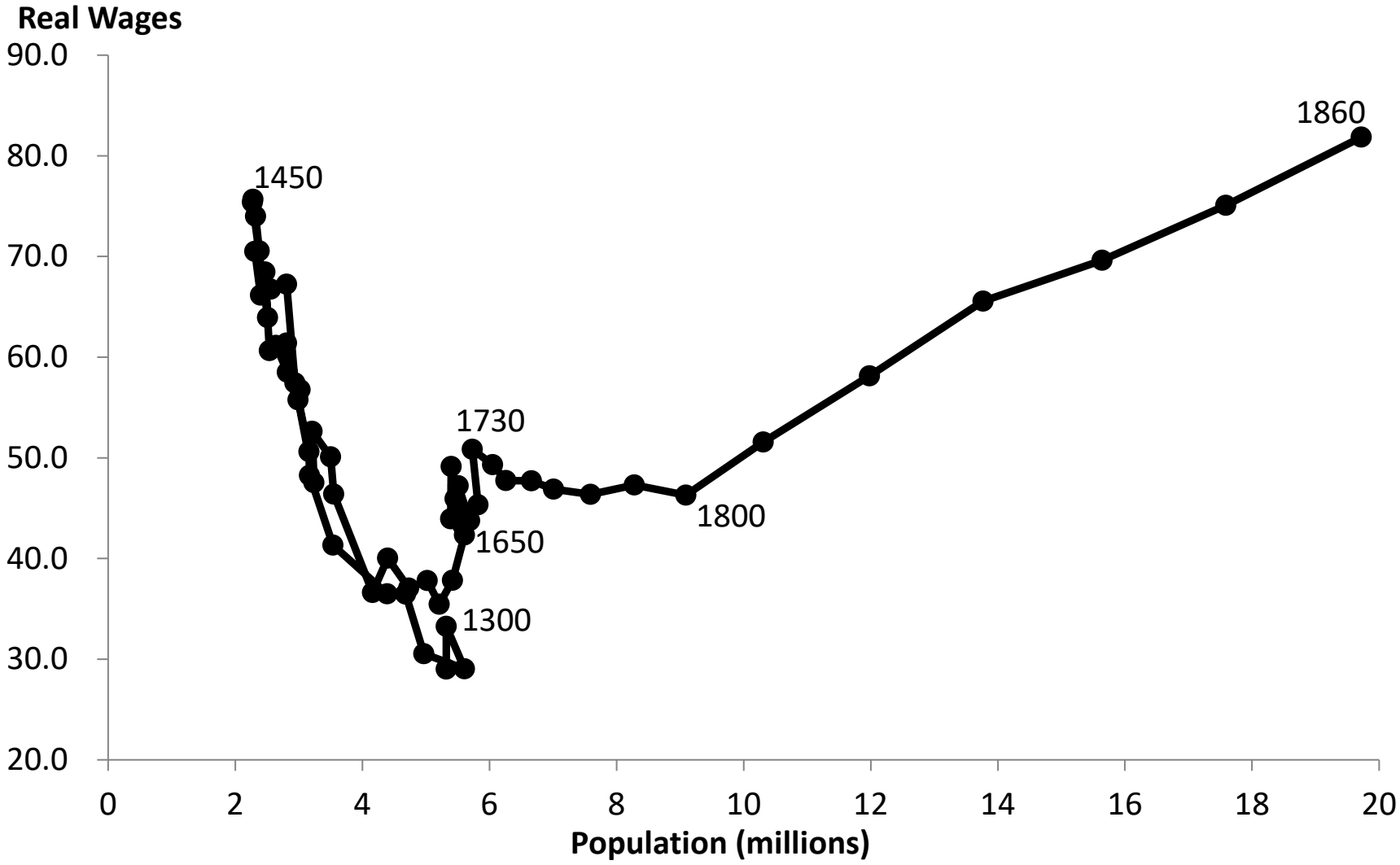
Why Did Industrial Revolution Happen?

- Not a settled issue! (Very contentious, actually)
- We discuss four strands of thought:
  1. Changes to Institutions
  2. The Enlightenment
  3. The Agricultural Revolution
  4. The role of high wages and cheap coal

INSTITUTIONS

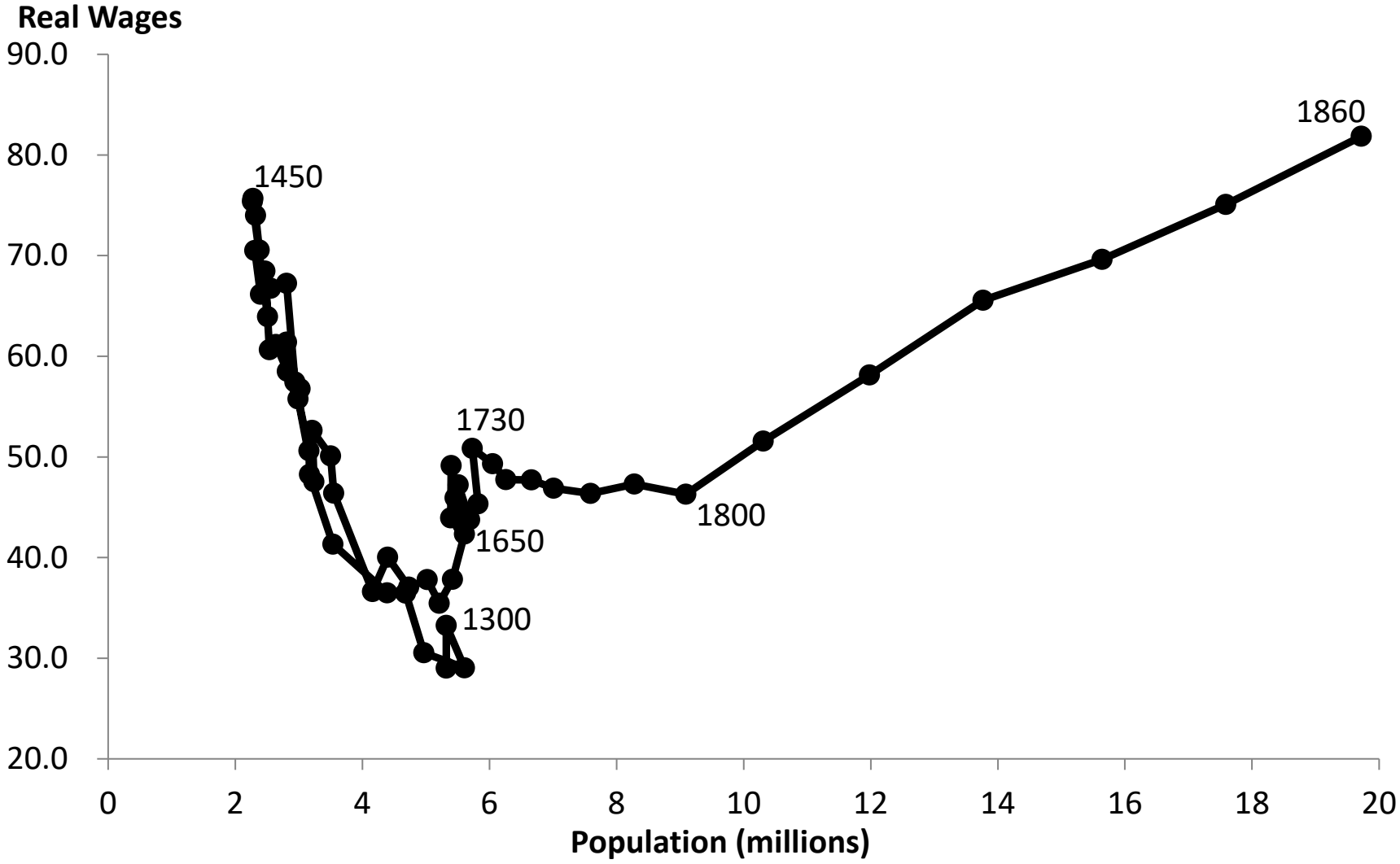
What Happened in the 1640s?



England in the 17th Century

- Two revolutions: 1640s and 1688
- Civil War in 1640's:
  - Parliamentarians overthrow Charles I and set up Commonwealth
  - Great deal of institutional change
- Growth despite much turmoil!!
- "Glorious" Revolution of 1688:
  - Formalization of constitutional monarchy in England
- Marxist historians stress revolution of 1640s, while Whig history stresses Glorious Revolution of 1688

Growth Began at a Time of Institutional Change



North and Weingast (1989)

- The fundamental barrier to growth before Glorious Revolution was despotism of sovereign
- The sovereign faced a commitment problem
  - Would like to promise to respect property rights of citizens. Why?
    - Because this provides citizens with good incentives to invest and produce more (yielding higher taxes)
  - Why is it hard to make such a promise credible?
    - Once citizens have amassed wealth, sovereign has irresistible temptation to renege and confiscate wealth (especially in time of war)

Commitment Problem

- Ex-ante: Sovereign wants to promise to respect property rights
- Ex-post: Sovereign wants to renege and expropriate
- Subjects understand this. Don't believe initial promise
  - Promise is not credible
- Sovereign has a commitment problem

- Parent says to child: "If you don't eat your vegetables, you won't get ice cream."
  - Child may understand that this is not a credible threat
- Government says to banks: "If you get into trouble, we will not bail you out."
  - Banks may understand that this is not a credible threat

Commitment Problem

- How can we solve commitment problems?
  - Reputation (when play is repeated)
    - Weight current profit against future loss
    - Need long horizon
  - Commitment devices:
    - Odysseus tied himself to the mast
    - Cortez burned the boats he arrived on in Mexico
    - Enforceable contracts
    - Constitutions
  - Balance of power
- The Civil War and Glorious Revolution resulted in dramatic institutional change
  - Power of the Crown reduced
  - Power of Parliament enhanced
- Stable power-sharing arrangement between Crown, Parliament, Courts.
- Improved incentives of citizens to innovate and invest

The Financial Revolution

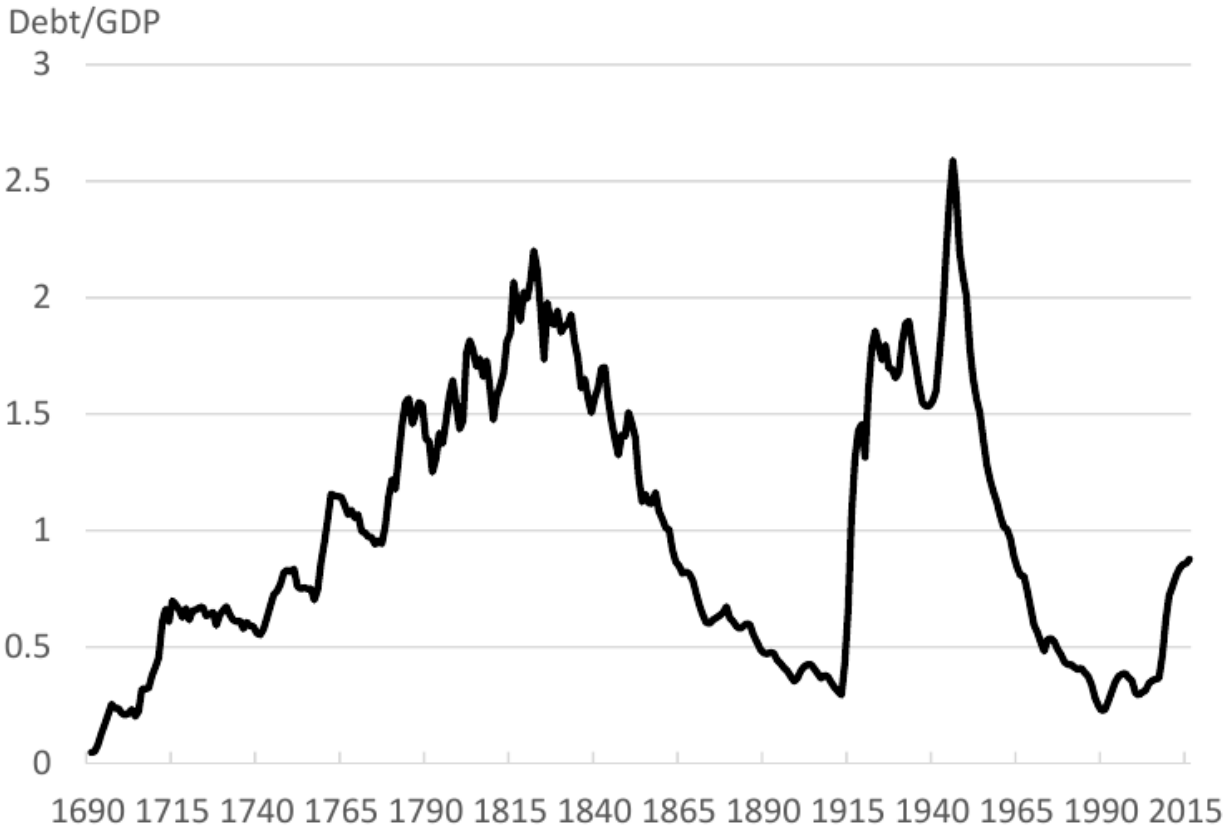


Figure 2: Government Debt to GDP for Britain from 1691 to 2015

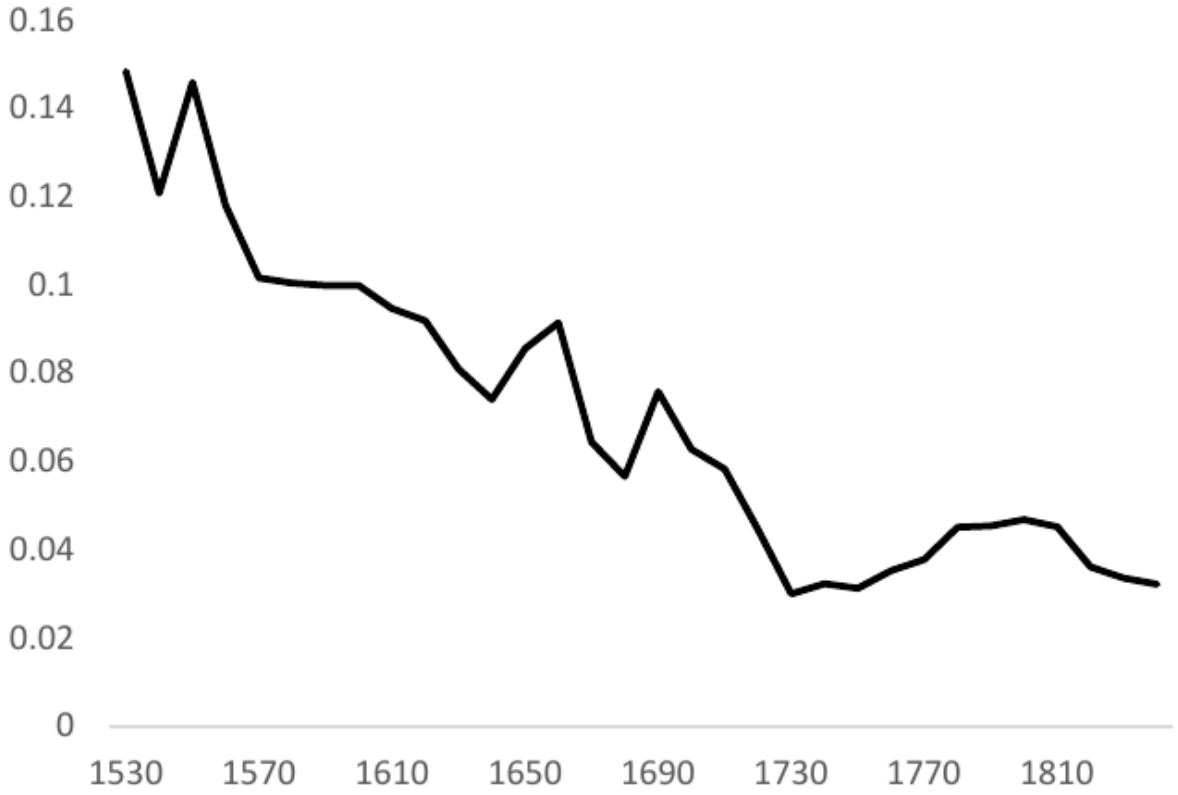
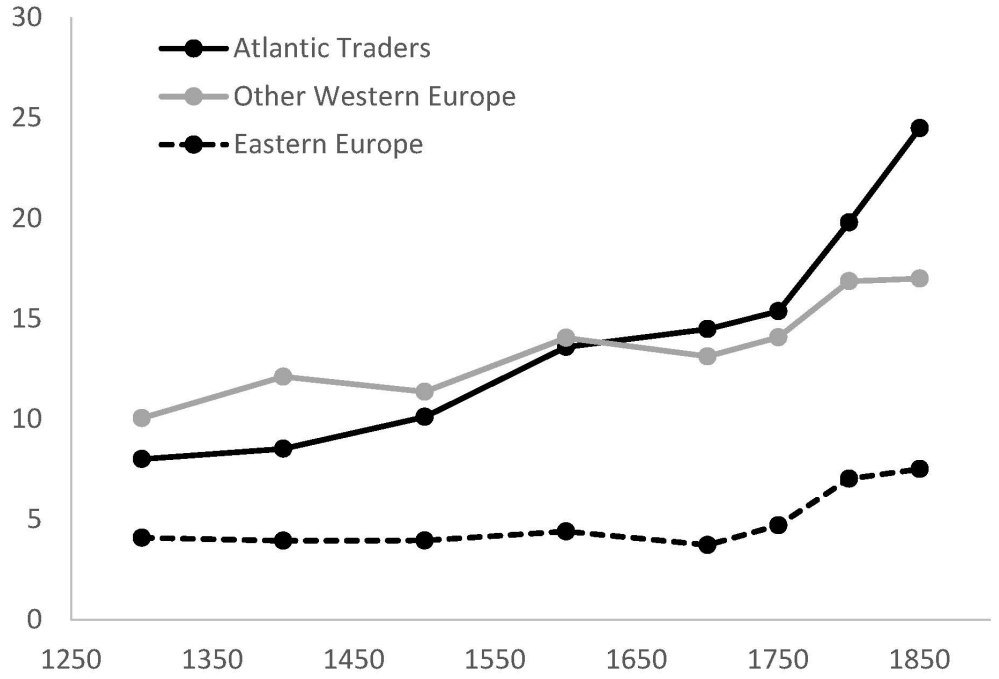
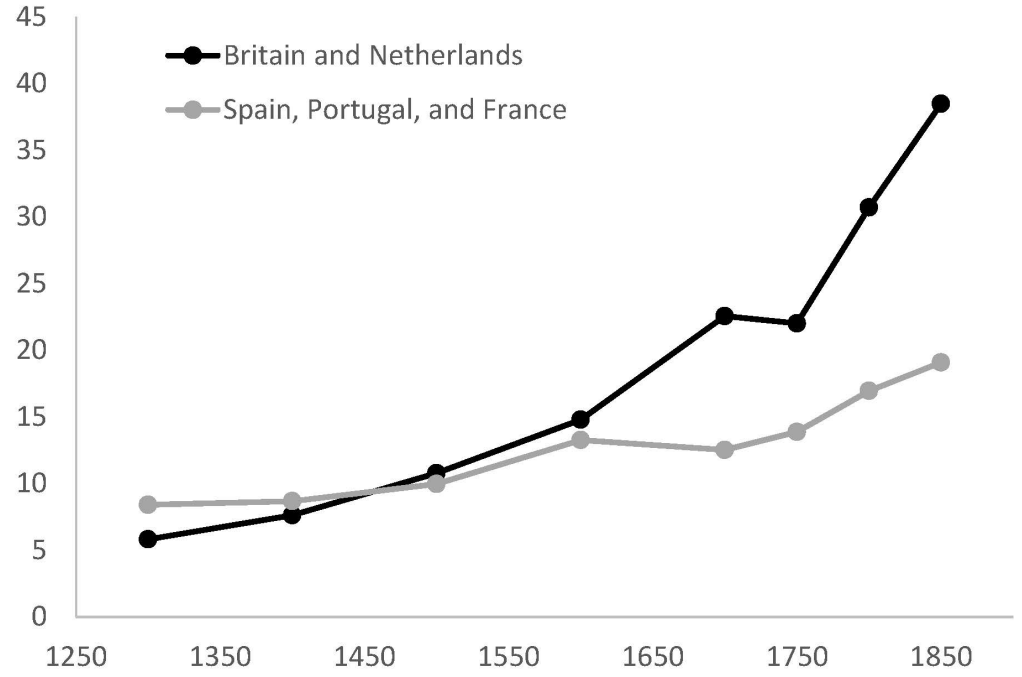


Figure 3: Interest Rates on Government Debt in England

The Role of Atlantic Trade

- Atlantic trade highly profitable after Great Discoveries
- In Britain/Netherlands, created merchant class that demanded better institutions
- In Spain/Portugal(/France) dominated by Crown
- Mediterranean countries (Venice/Baltics) didn't have access





THE ENLIGHTENMENT

Technological Innovation

- Huge increase in speed of technical innovation
  - Textiles: Spinning jenny, water frame, mule, etc.
  - Steam: Newcomen engine, separate condenser, rotary engine, high pressure engine, etc.
  - Coke smelting, railroads, etc.
- “A wave of gadgets swept over England” (Ashton, 1948)
- Why did technological innovation take off?

A Theory of the Enlightenment

- Perhaps there was an unusual clustering of talented and freethinking individuals in Northwestern Europe in the 17th and 18th centuries
- Seems unlikely!
- Plenty of smart and freethinking individuals have likely lived in all places at all times

- So, why have so few ideas survived from other times and places?
- Perhaps because they were suppressed/lost
- Freethinkers are often a threat to the ruling elite

A Theory of the Enlightenment

- Whether the ideas survive depends on the relative strength of:
  - Forces/technologies seeking to suppress new ideas
  - Forces/technologies seeking to spread new ideas
- At most times/places, the forces/technologies seeking to suppress new ideas had upper hand → stagnation

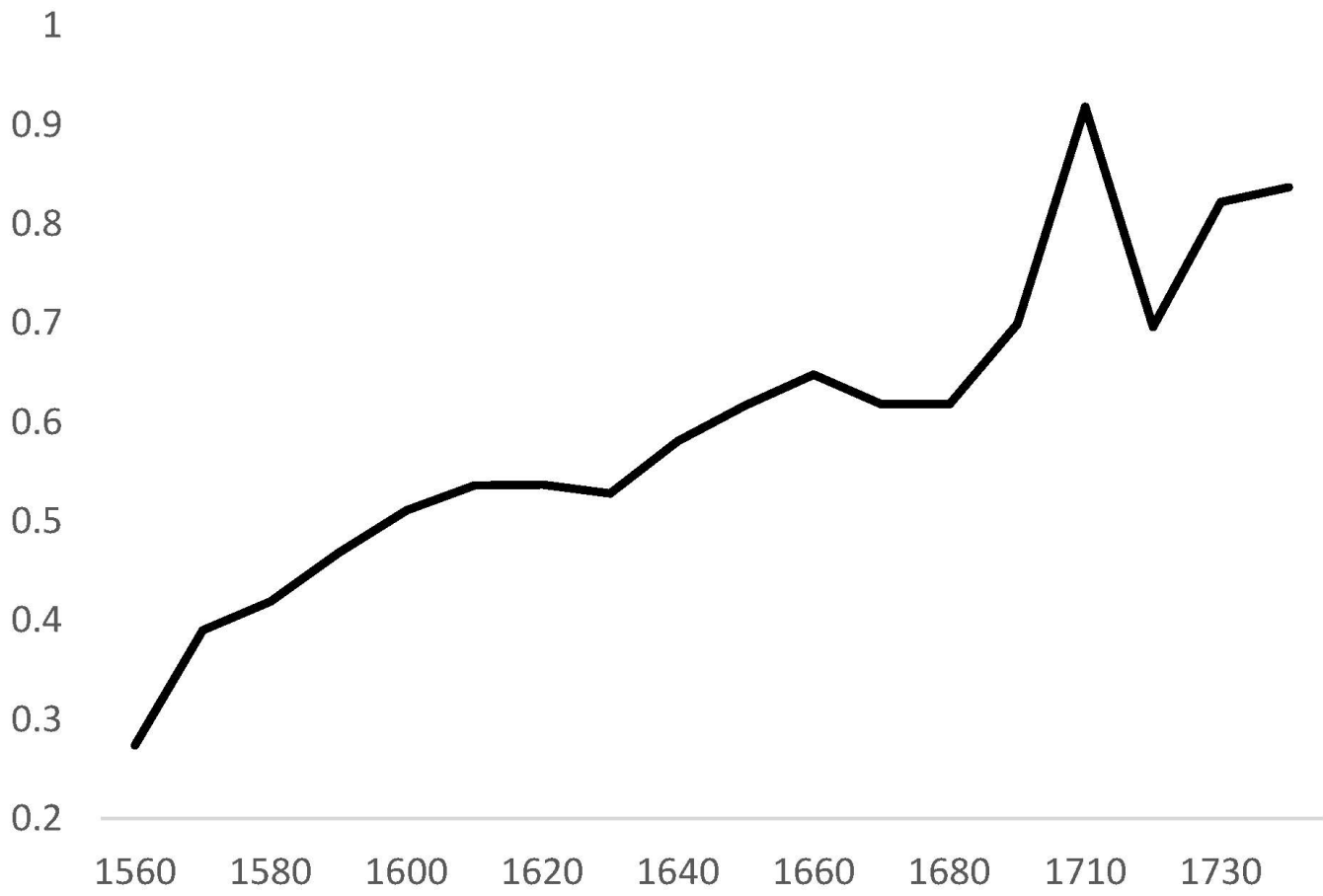
- But then something changed!

A Theory of the Enlightenment

- Watershed moment: invention of the movable-type printing press by Johannes Gutenberg around 1450
- Massively altered the balance of power between those seeking to suppress knowledge and those seeking to spread it
- Led to Reformation → Enlightenment → Industrial Revolution
  - Martin Luther master pamphleteer (ideas spread too fast to suppress)
  - Earlier reformers didn't have this technology to spread their ideas
  - Reformation emphasized literacy
  - Protestant areas relaxed censorship. Crucial for Enlightenment.

Rise in Literacy

- Literacy rates seem to have been extremely low throughout most of history
- Rose rapidly in England over 250 years before Industrial Revolution
- Protestant churches encouraged literacy
- Price of books fell by more than a factor of 20



Source: Estimate of literacy rate of husbandmen in London and Middlesex

Evidence on Role of Enlightenment/Reformation?

- Speculative theory
- Can we provide any “hard evidence” for it?
- Quite difficult
- Becker and Woessmann (2009) provide interesting attempt
  - Did Protestantism cause growth in 19th century Prussia?
  - Max Weber: Protestant Ethic
  - But perhaps literacy is key channel

Protestant Prosperity

- Protestantism correlated with prosperity around 1900
- But a correlation doesn't prove causation!
- Perhaps Protestant areas differed in other way and this explains their prosperity
- How can we test whether Protestantism **caused** prosperity?
- We need "exogenous variation" in Protestantism
- Becker-Woessmann propose "distance to Wittenberg"

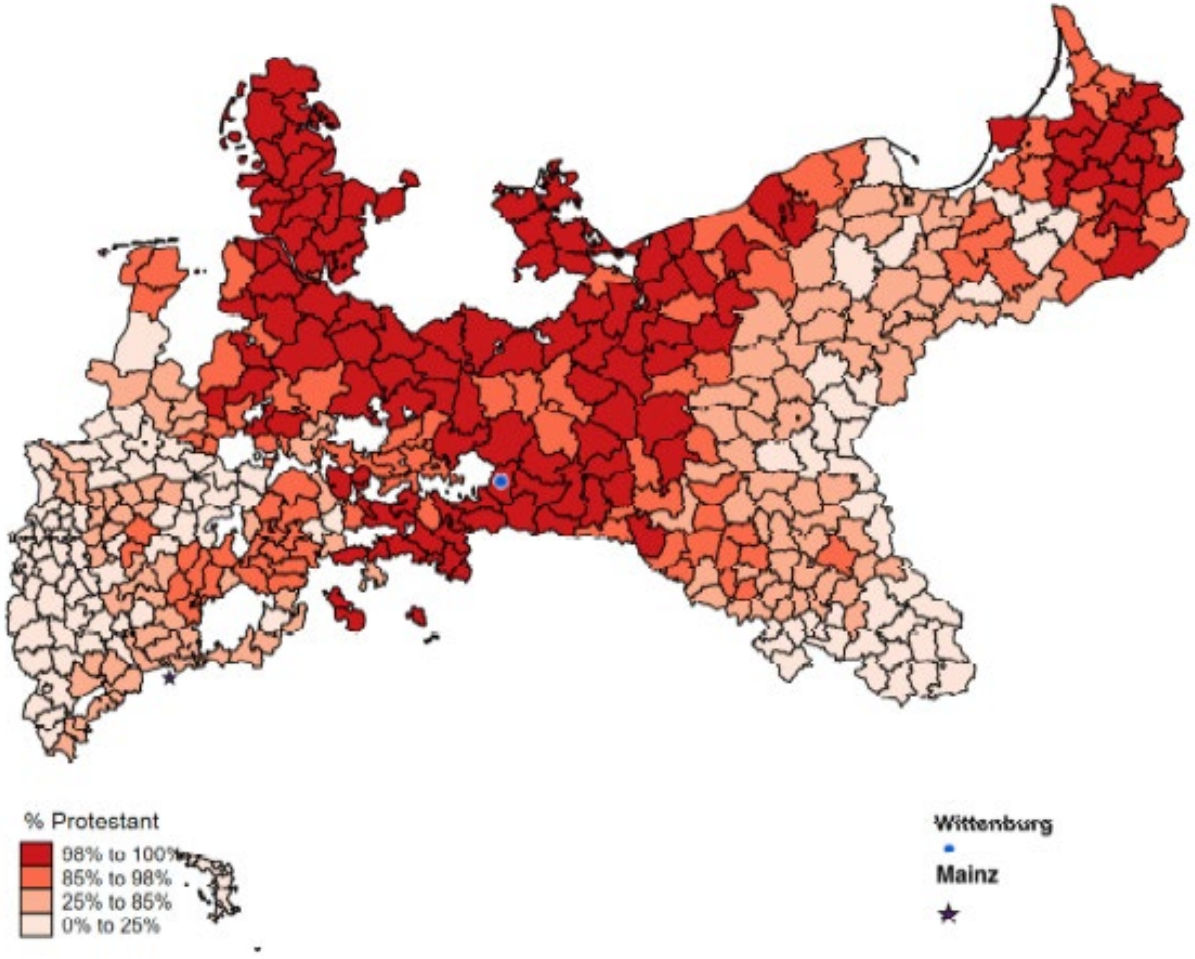


Figure 8: Protestant Population Share in Prussia in 1871

Structure of the Argument

1. First Stage: Is distance to Wittenberg correlated with Protestantism?
2. Balance Tests: Were areas close to Wittenberg different in other ways?
3. Reduced Form: Is distance to Wittenberg correlated with prosperity?

- Becker and Woessmann use data on Prussian counties in late 19th century

Is Distance to Wittenberg Different in Other Ways?

- Becker and Woessmann assume: Nothing special about Wittenberg when it comes to prosperity other than it being center of Protestant revolution
- Can they corroborate this assumption?
- Distance to Wittenberg is not correlated with proxies for economic and educational development prior to Reformation

Table 3: Was Wittenberg a Random Place?

Dependent Variable:	Imperial City in 1517	Urbanization in 1500	University in 1517	School in 1517
Distance to Wittenberg (in 100 km)	0.0034	0.00006	-0.0019	-0.0073
	(0.0071)	(0.00013)	(0.0047)	(0.0099)
Number of Observations	452	452	452	333
R^2	0.0005	0.0004	0.0004	0.002

Notes: These estimates are taken from Table IV in Becker and Woessmann (2009). Standard errors are in parentheses. The dependent variables are: an indicator for whether a county was a free imperial city, urban population per km^2, indicator for whether county had a university, and indicator for whether the county had a school.

$$Y_i = \alpha + \beta \mathrm{DIST}_i + \boldsymbol{X}_i'\gamma + \epsilon_i$$

Distance to Wittenberg and Prosperity

- Final step: Show that distance to Wittenberg is correlated with prosperity
- If DIST is uncorrelated with all determinants of PROSP other than PROT, then any correlation between DIST and PROSP must be due to PROT.

Table 4: Does Distance to Wittenberg Predict Prosperity

Dependent Variable:	Income Tax per capita	Log Teacher Income	Share Manuf. and Services
Distance to Wittenberg	-6.0	-1.00	-0.78
(in 100 km)	(2.3)	(0.48)	(0.36)
Number of Observations	426	452	452

Notes: These estimates are produced using replication code and data provided by Ludger Woessmann. They are the reduced form estimates that correspond to the instrumental variables (IV) estimates presented in Table V of Becker and Woessmann (2009) except that I have included "% missing eduction info" as an additional control for consistency with the first stage reported in Table 2. Income tax per capita is measured in pfennig. Standard errors are in parentheses. The control variables included in the regression are: % age below 10, % Jews, % females, % born in municipality, % of Prussian origin, average household size, ln(population size), population growth from 1867-1871 in %, % missing eduction info, % blind, % deaf-mute, % insane.

$$\mathrm{PROSP}_i = \alpha + \beta \mathrm{DIST}_i + \boldsymbol{X}_i'\gamma + \epsilon_i$$

THE AGRICULTURAL REVOLUTION

Agricultural Revolution

- Population of England tripled from 1700 to 1850
- Very little imports of food
- Share of population working in agriculture fell
- Massive increase in agricultural productivity

- Did Agricultural Revolution cause Industrial Revolution?
- Or did Industrial Revolution cause Agricultural Revolution?

Agricultural Revolution

- Proximate causes:
  - 1) Improvements in land, 2) Intensive crop rotations, 3) breeding of higher yield animals and crops
- Crop rotations:
  - Traditional rotation: 1) Wheat or rye, 2) Barley or oats, 3) fallow
  - New rotation: 1) Wheat, 2) Turnips, 3) Barley, 4) Clover
  - Clover a legume (nitrogen fixing)
  - Turnips/Clover used as feed for animals
  - Much larger animal herds yielded lots of natural fertilizer
- Why did this not happen much earlier?

The Enclosure Movement

- Before 1500:
  - Villages with three open fields + commons
  - Each farmer owned several strips + rights to use commons
- After 1850:
  - Ancient system swept away by thousands of “enclosure” acts and agreements
  - Replaced by modern system of private property rights

- Very controversial!
- One view:
  - Rationalization of property right
  - Crucial for innovation / Ag. Revolution
- Another view:
  - Massive act of expropriation by large landowners of complex system of antient peasant rights
- Enclosed farms were more efficient, but open farms also increased yields substantially

Rural Growth and Urban Growth: Did One Cause the Other?

- Industrial Revolution could not happen without Agricultural Revolution: Food surplus needed to support urban growth
- But not obvious which way causation goes
- AR → IR: Ag Prod. Increases → Pushes people out of Ag → People move to city and pursue trade/industry/innovation
- IR → AR: Returns to trade/industry rise → Pulls people into cities → Higher ag prices spur innovation in Ag
- How can we tell these stories apart?

AR → IR or IR → AR

- How can we tell these two stories apart?
- Allen (2009): Different implications about urban wages
  - AR → IR: People pushed out of country-side → low urban wages
  - IR → AR: People pulled into cities → high urban wages

AR → IR or IR → AR

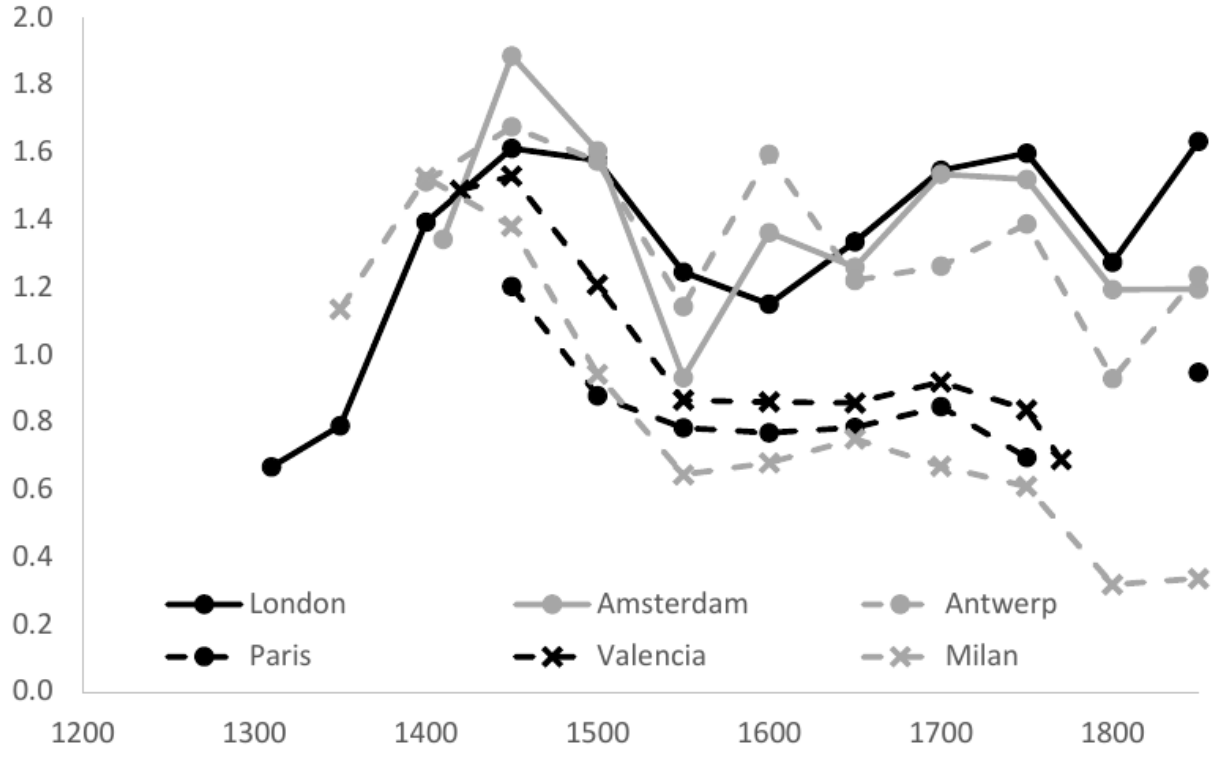


Figure 10: Real Wages in European Cities

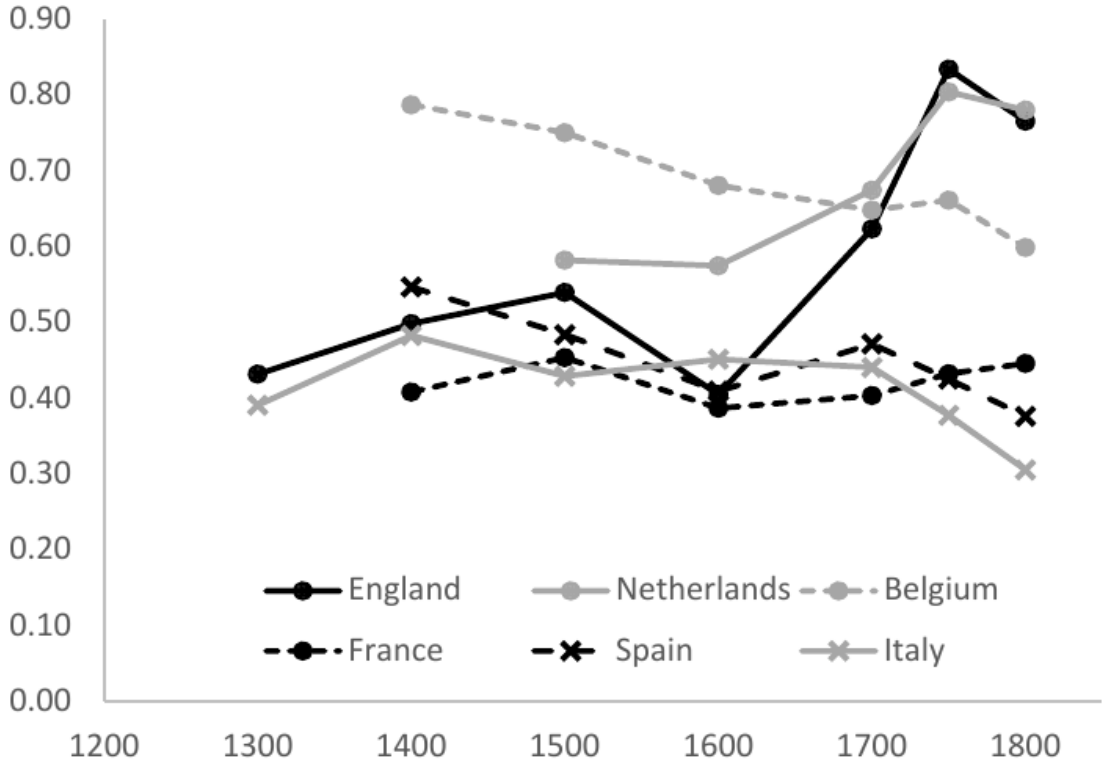


Figure 11: Labor Productivity in Agriculture in Europe Regions

Agricultural Revolution happens in places with high urban wages

Decline of Feudalism and Rise of Capitalism

- Medieval England was a feudal society
  - Crown, lords, freehold farmers, serfs
- Gradual increase in freedom/property rights/rule of law
  - Royal courts gradually protected freeholds from lords (Common Law)
  - Black Death led to collapse of serfdom and early enclosures
  - Crown reacted to expropriation by gradual protection of tenant farmers
- By 17th century: Rise of yeoman farmers with substantial proprietary interest in the soil (and thus incentive to innovate)
- Contrast: More intense serfdom in E. Europe after Black Death

HIGH WAGES AND CHEAP COAL

Why Britain?

- Industrial Revolution very concentrated in Britain
  - Newcomen steam engine, separate condenser, high pressure steam engine, flying shuttle, spinning jenny, water frame, mule, coke smelting furnace, etc.
- In 1500: Britain relatively unimportant island off of NW Europe
- By 1800: Industrial powerhouse / global empire

- What was so special about Britain?

Allen (2009): High Wages and Cheap Coal

- High wages and cheap coal gave British strong incentive to produce labor-saving innovations

- “The Industrial Revolution, in short, was invented in Britain in the eighteenth century because it paid to invent it there, while it would not have been profitable to invent in other times and places.”

Directed Technical Change

- High wages? How can that be an advantage? Shouldn't that make British industry less competitive?
- But it spurs labor-saving innovation
- Industrial Revolution was about the invention of machines
- Needed high wages to make it profitable to invent machines
- Machines use a lot of energy.
- Need cheap energy to invent machines

Ecological Bottleneck

- Pre-industrial economy was very land intensive
- Food land intensive
- Energy land intensive
  - Feed for animals / Firewood
- Energy necessary for growth
- Land intensity of energy was a severe bottleneck
- Steam Engine + fossil fuels cleared this bottleneck

Table 8: Energy Consumption in England and Wales

	1560s	1700s	1750s	1800s	1850s
Farm Animals	21.1	32.8	33.6	34.3	50.1
Population	14.9	27.3	29.7	41.8	67.8
Firewood	21.5	22.5	22.6	18.5	2.2
Wind	0.2	1.4	2.8	12.7	24.4
Water	0.6	1.0	1.3	1.1	1.7
Coal	6.9	84.0	140.8	408.7	1,689.1
Total	65.1	168.9	230.9	517.1	1,835.3
Total less coal	58.2	84.9	90.1	108.4	146.2

Notes: Energy is measured in petajoules. The source of these estimates is Table 2.1 of Wrigley (2010). The numbers for farm animals and the population are estimates of calories consumed. Wind energy includes sail ships. The firewood number for 1850s is actually for the 1840s.

Why Was Steam Engine Invented in England?

- Explosive growth of London led to “timber crisis”
- Led to huge growth in coal industry to heat London houses
- Large demand to drain coal mines
- Strong incentive to invent engine that could help drain coal mines
- First steam engine very inefficient. But coal was free at coal fields

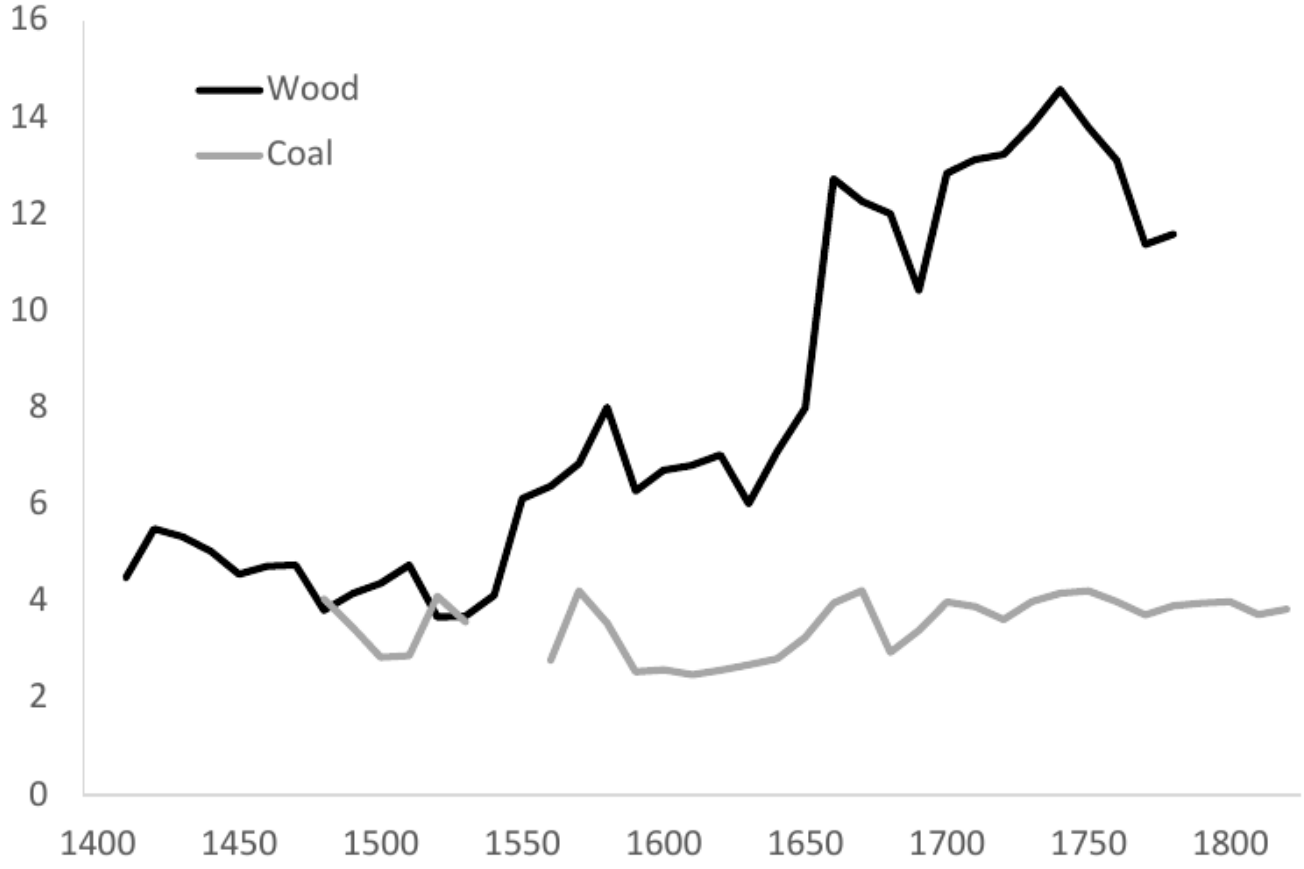


Figure 12: Real Prices of Wood and Coal in London

Gradual Improvement/Expansion of Steam Power

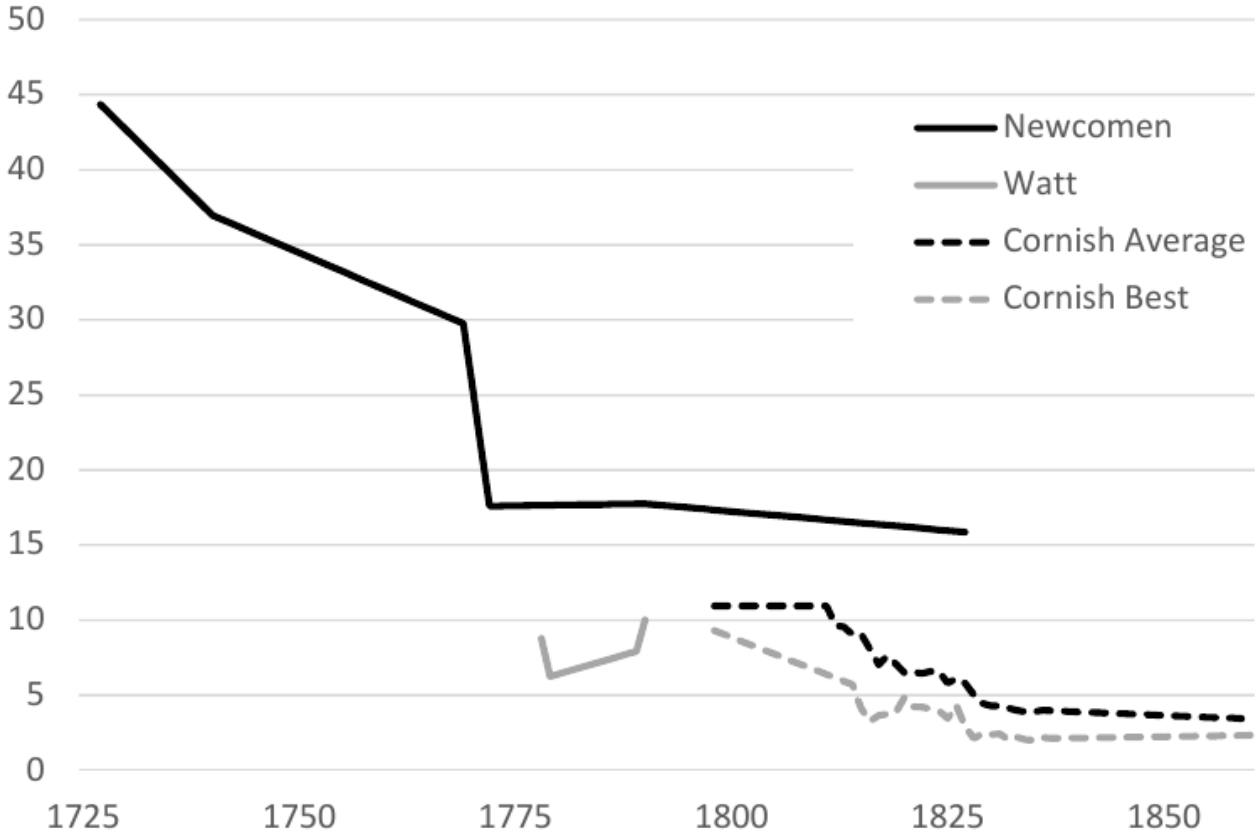


Figure 14: Coal Consumption of Pumping Engines

Table 9: Stationary Power Sources in Great Britain

	1760	1800	1830	1870	1907
Steam	5,000	35,000	160,000	2,060,000	9,659,000
Water	70,000	120,000	160,000	230,000	178,000
Wind	10,000	15,000	20,000	10,000	5,000
Total	85,000	170,000	340,000	2,300,000	9,842,000

Notes: This table replicates Table 7.1 in Allen (2009).

Aided by Low Cost of Energy in Northern England

- Cost of energy was very low in Northern England due to coal industry
- Huge difference versus other locations
- No wonder industrialization occurred in Northern England (Manchester)

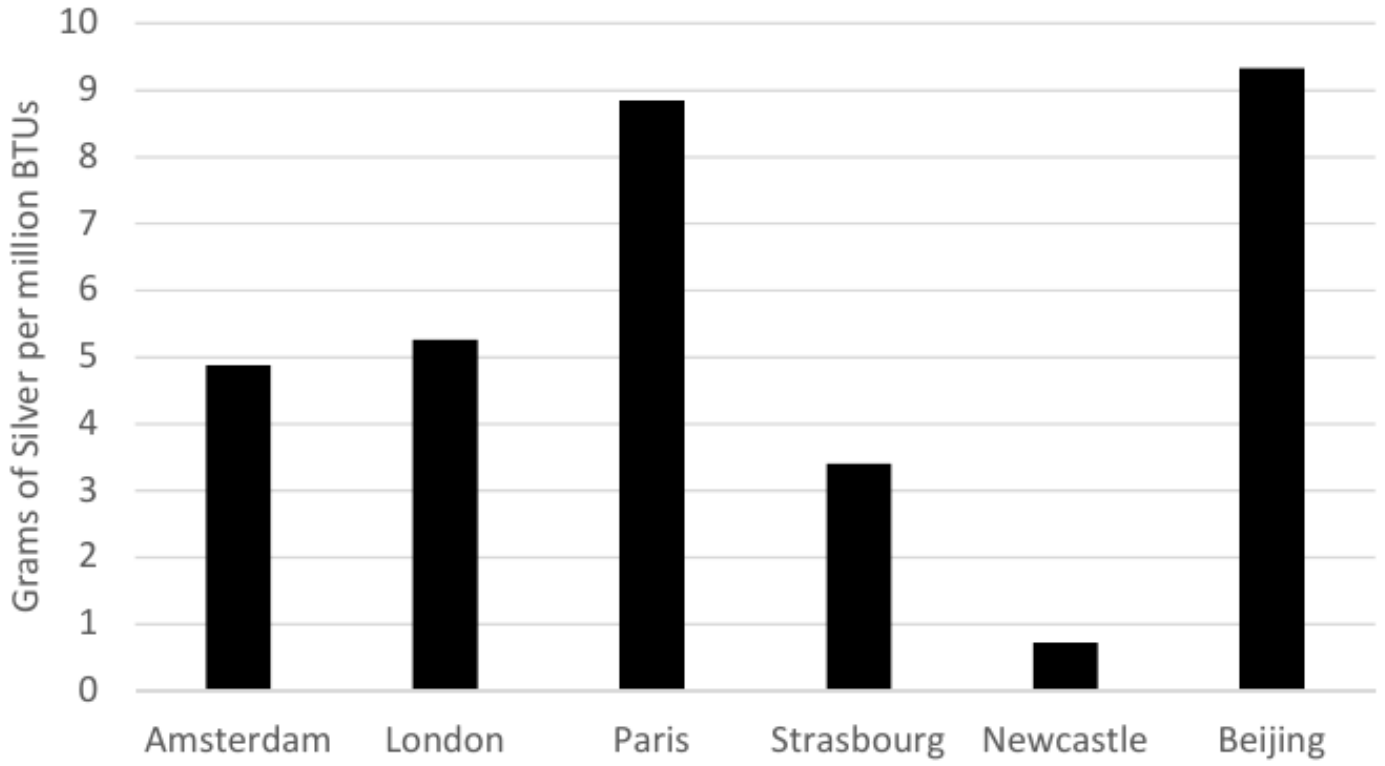


Figure 13: Price of Energy in the Early 1700s

Cotton: The Marvel of the Industrial Revolution

- British cotton industry grew by 2200% from 1770 to 1815
- Productivity growth of 2.6% per year
- 25% of all productivity growth in British economy over this period
- Resulted in massive fall in relative price of cotton cloth

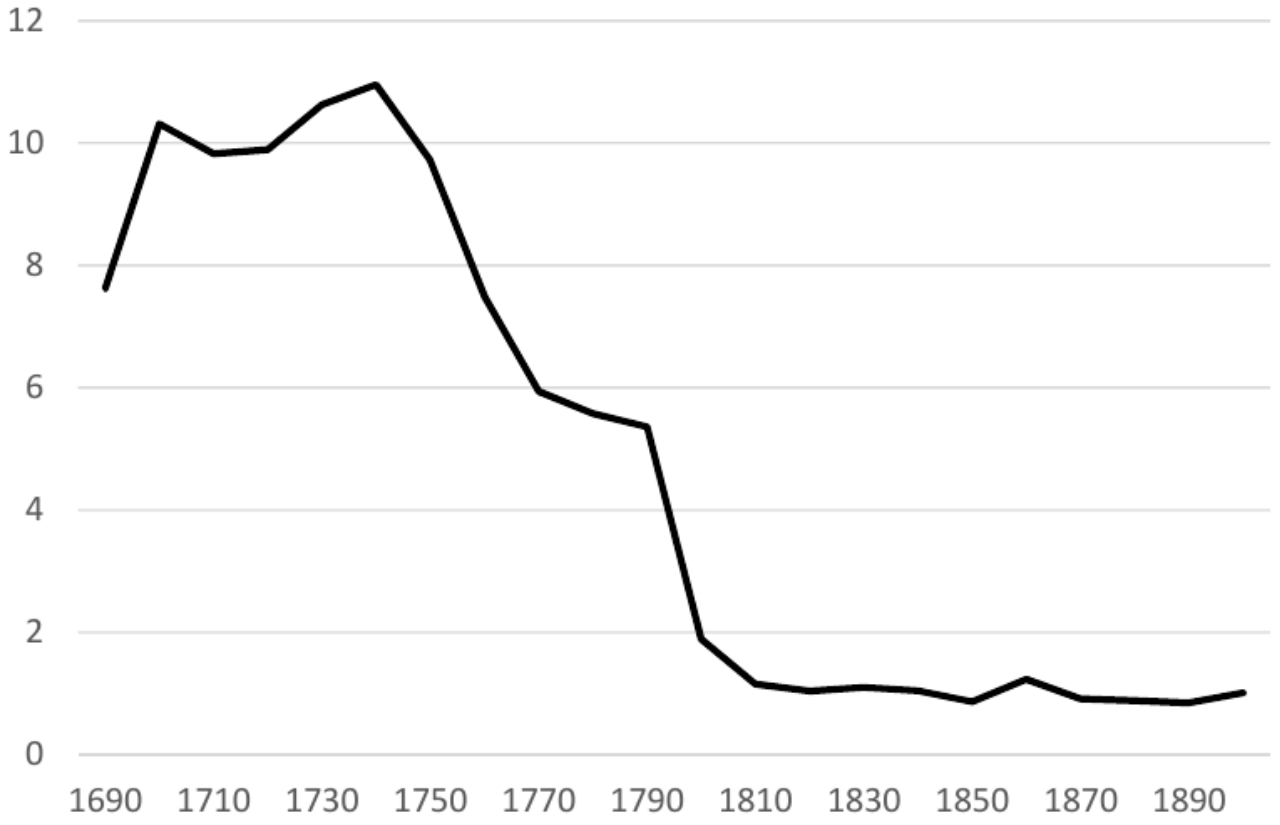


Figure 15: Prices of Cotton (or Linen) Cloth Relative to Bread in England

Miracle of Labor-Saving Technology

- Cotton spinning was hugely labor intensive (labor share of value added: 95%)
- High wages spurred labor-saving technical change
- Labor share of value added fell to 53%
- Incentive to mechanize much smaller in France/Italy

Table 10: Real Cost of Cotton Yarn (16 count)

	Hand Method	24-Spindle Jenny	Arkwright Mill	Glasgow Mill
	1760	1775	1784	1836
Labor:				
Cleaning and Carding	7.00	7.00	2.69	0.16
Spinning	7.00	2.33	2.57	0.34
Reeling, bundling, etc.	0.47	0.47	2.19	0
Administrative	2.72	2.72	0.41	0.02
Total Labor	17.19	12.52	7.86	0.52
Materials:				
Raw Cotton	16.88	16.88	16.88	16.70
Other	0	0	1.20	0.53
Capital	0.93	1.88	2.00	0.47
Total Cost	35.00	31.28	27.94	18.22
Labor Share of Value Added	95%	87%	80%	53%

Notes: Costs are reported pence per pound at 1784 prices. The data are from Table 8.1 of Allen (2009). The "count" of cotton yarn measures the number of hanks (770m) of yarn that make one pound of yarn. The higher is the count, the finer the yarn. 16 count yarn is relatively coarse, similar to the yarn used for modern jeans.