Lecture 5
Technology

Matti Sarvimäki

Economic History
2 April 2018

Outline of the course

1. Yesterday: Introduction, fundamental causes of growth
   - 1.1 Introduction and the Malthusian Model
   - 1.2 Luck, Geography and Culture
   - 1.3 Institutions I
2. Today: fundamental (con't), Innovations and crises
   - 2.1 Institutions II
   - 2.2 **Technology**
   - 2.3 Finance
3. Tomorrow: Unleashing talent
   - 3.1 Geographical and social mobility
   - 3.2 Marriage, family and work

Sources of growth

Mokyr (1990, Ch. 1)

Growth can occur through four distinct processes

1. investment (accumulation of capital)
2. trade (specialization)
3. population growth (specialization, public goods)
4. technology and institutions

This lecture is about **technological progress**:

- Mokyr's definition: "change in the application of information to the production process in such a way to increase efficiency"
- "application of information" deliberate: innovation does not necessarily require invention

Antiquity
Mokyr (1990, Ch. 2)

Technological progress in Antiquity often considered limited

- there were not many important innovations in agriculture, metallurgy, mining, shipping, machinery...

May be overly harsh: in the areas that mattered to *them*, the Greeks and Romans achieved huge success

- e.g. construction and architecture, literature, science, mathematics, political organization
- we may also have a biased sample, because tools and devices made of wood or leather may not have survived

Antiquity

Mokyr (1990, Ch. 2)

Technological innovations that had economic impact

- Lever and the screw (Greeks)
- Cement masonry (Romans)
- Waterwheel (Romans)

Antiquity
Mokyr (1990, Ch. 2)

Technological innovations that had economic impact

- Lever and the screw (Greeks)
- Cement masonry (Romans)
- Waterwheel (Romans)

Much of the technological progress served the public sector

- paved streets, sewage disposal, water supply, fire protection, war machines, road network...

Antiquity
Mokyr (1990, Ch. 2)

Technological innovations that had economic impact

- Lever and the screw (Greeks)
- Cement masonry (Romans)
- Waterwheel (Romans)

Much of the technological progress served the public sector

- paved streets, sewage disposal, water supply, fire protection, war machines, road network...

Some impressive technologies used only as gadgets

- steam engine (used to open temple doors)
- an analog computer (the Antikythera mechanism designed to calculate the movements of stars and planets)

Antiquity

Mokyr (1990, Ch. 2)

"[...] classical civilizations had the intellectual potential to create complicated technical devises. The question remains why so little of this potential was realized and translated into economic progress"

"This is not to say that the ancient economy was primitive, poor, or incapable of growth. But its growth derived from [...] organization, trade, order, the use of money, and law"

Middle Ages, 500–1500

Mokyr (1990, Ch. 3)

For most of the Middle Ages, European technology lagged behind the Islamic World and the Orient

- but Europe adopted many innovations made elsewhere
- in comparison to the Antiquity, medieval Europe managed many important technological breaktroughs
- in comparison to the rest of the world, Europe caught up and started to push the technological frontier by 1500

Middle Ages, 500–1500

Mokyr (1990, Ch. 3)

For most of the Middle Ages, European technology lagged behind the Islamic World and the Orient

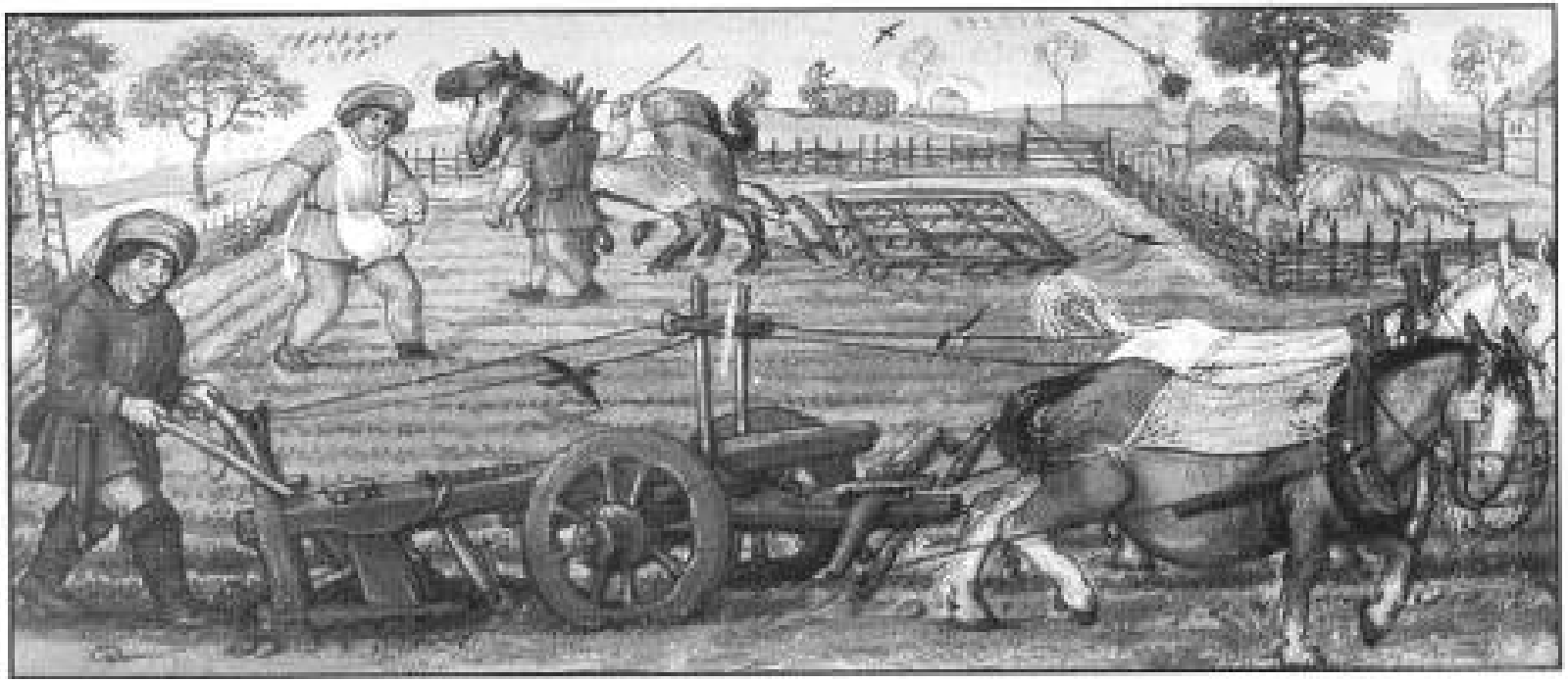
- but Europe adopted many innovations made elsewhere
- in comparison to the Antiquity, medieval Europe managed many important technological breaktroughs
- in comparison to the rest of the world, Europe caught up and started to push the technological frontier by 1500

This progress is quite surprising as conditions usually associated with innovation were largely absent

- low literacy and urbanization rates
- lots of conflict, little trade
- infrastructure declined
- (all particularly true during the early Middle Ages)

Heavy plow, three-field system, new horse collar

Mokyr (1990, Ch. 3)



This picture presents several important innovations of the Middle Ages. The first is the heavy plow that allowed effective cultivation of the soils north of the Alps. The second is the horseshoe and the new kind of horse collar (those used in the Antiquity choked the horse and lost up to 80% of horse's efficiency). The third is the three-field system under which fields rotated between fallow, winter and spring crops.

Innovations of the Middle Ages

Mokyr (1990, Ch. 3)

Blast furnance, cake of soap, cam, canal lock, galleon, cast-iron pot, chimney, cole-fueled fire, cog boat, compass, crank, cross-staff, distilled liquors, eyeglass, flywheel, glass window, grindstone, hops in beer, marine chart, overshoot water wheel, printing press, ribbed ship, shingle ski, spinning wheel, suction pump, spring watch, treadle loom, water-driven bellows, weight-driven clock, wheelbarrow, whippletree, windmill...

Mokyr: "useful tools and ideas that reduced the daily toil and increased the material comfort of the masses"

- concentrated largely in the private sector
- preceeded the beginning of European science

Renaissance and beyond, 1500–1750

Mokyr (1990, Ch. 4)

The period between 1500–1750 is better know for its scientific achievement than big technological innovations

- however, many important microinventions, adjustements and discoveries from abroad greatly increased productivity
- during this era Europe emerged as the technological frontier

The lack of macroinventions is not due to lack of brilliant ideas

- but constrainted by what could be implemented
  (think of all the wonderful mechanical ideas of Leonardo da Vinci)
- much of the progress that eventually solved these practical problems was done during this era

Renaissance and beyond, 1500–1750

Mokyr (1990, Ch. 4)

"New husbandy" probably the most important innovation

- gradual expansion of new agricultural practices
- new crops, elimination of fallowing, stall feeding of cattle
- inventions mainly capital- or land-saving (i.e. labor intensive)

Examples of other lines of progress

- more efficient windmills
- more widespread use of peat and coal
- major improvements in blast furnances and mining
- emergence of technical literature
- improvements of the spinning wheel

Renaissance and beyond, 1500–1750

Mokyr (1990, Ch. 4)

The defining feature of this age was the geographic discoveries

- exposure effects, in which technological change primarily took the form of observing alien technologies and crops and transplanting them elsewhere
- discoveries may also have been a substitute for pushing the technological frontier

Particularly, the discovery of the New World provided many agricultural "innovations"

- potato, maize, tobacco, sweet potates, cassava, tomatoes, chili peppers, cacao, peanuts, pineapples...

... as well as the exchange of ideas, diseases and populations

- see Nunn, Qian (2010): The Columbian Exchange, JEP 24(2):163–188 for an excellent overview

Renaissance and beyond, 1500–1750

Mokyr (1990, Ch. 4)

The age of discoveries was also one of instruments

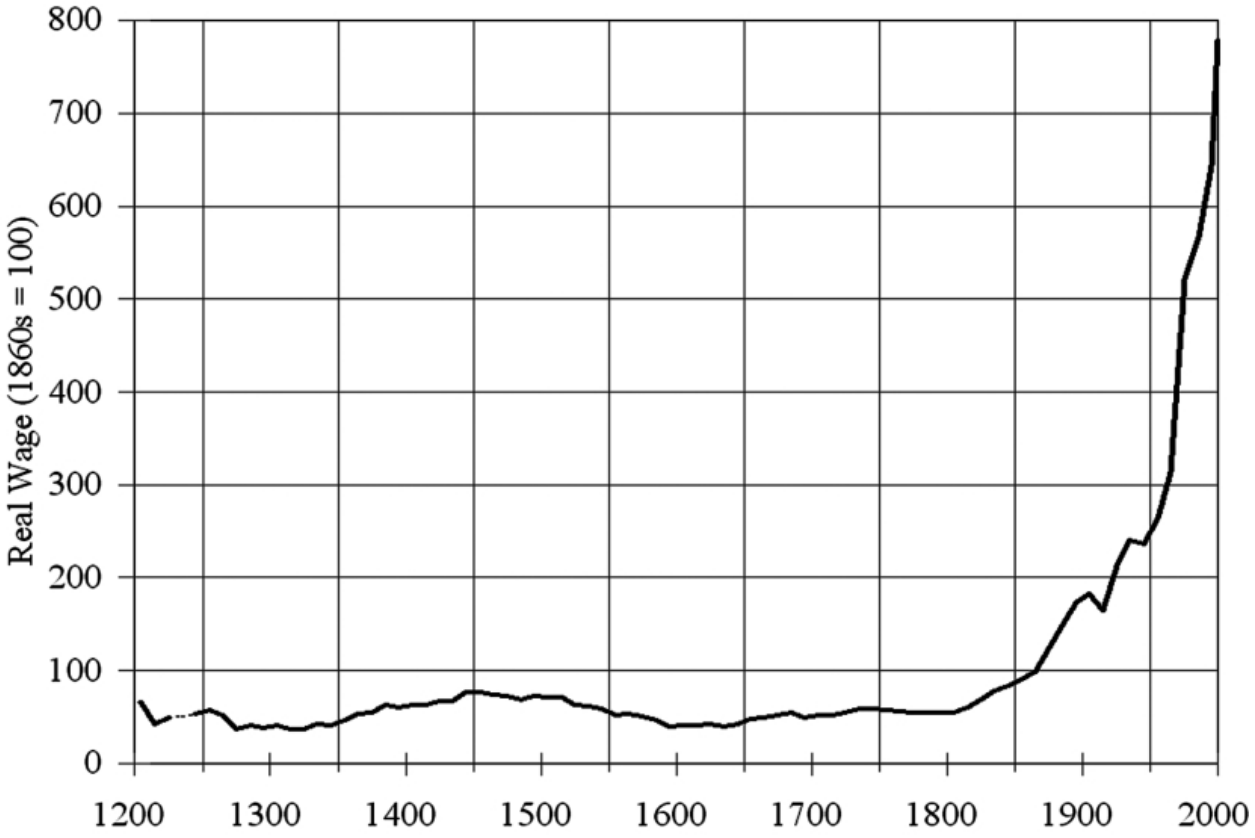
- largely driven by the clock-making industry, but also military (precise guns), commerce (precise scales), optics...

The precision instrument industry had important spill-over effects for manufacturing

- mostly realized during the Industrial Revolution

Coalbrookdale by Night, Philip James de Loutherbourg, 1801

Real wages of English building workers
(Clark 2005)



Mokyr (1990, 81): "In two centuries daily life changed more than it had in the 7,000 years before. The destablising agent in this dizzying tale was technology, and Western technology alone. Of course, technological progress did not start in 1750, and the difference between the period after 1750 and the period before it was one of degree; but degree was everything"

Industrial Revolution, 1750–1830

Mokyr (1990, Ch 5)

The Industrial Revolution

- typically dated between 1750–1830
- and located in Britain (though other European countries and, later, the United States also were sources of innovations)

Was it a "revolution"?

- per capita income did not improve much initially
- but production technologies changed dramatically

Industrial Revolution, 1750–1830

Mokyr (1990, Ch 5)

Huge technological progress in some industries

- power, metallurgy, textiles, high-precision machinery tools...

Little progress in in other industries

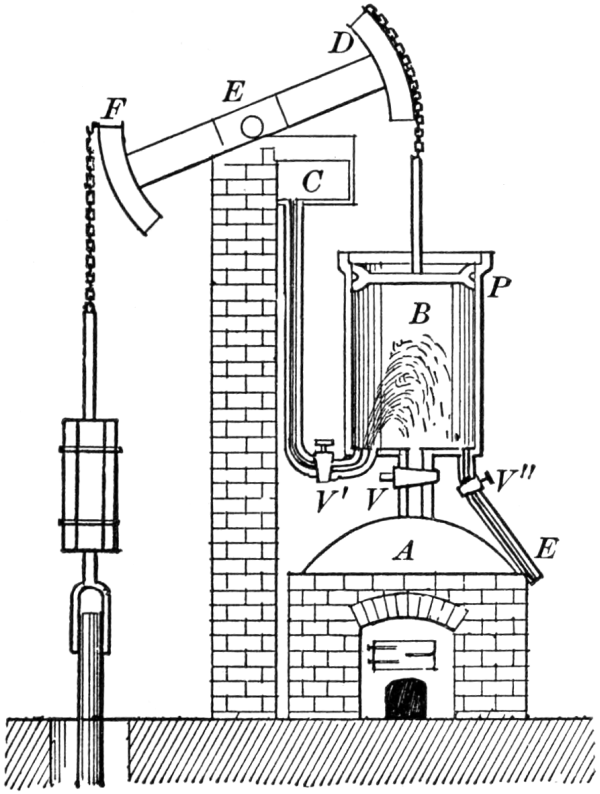
- service, construction, food processing, apparel making

Innovation was not particularly scientific

- though *scientists* made many important innovations
- Mokyr: "A typical innovator in those years was a dextoreous and mechanically inclined person who became aware of a technical problem to be solved and guessed approximately how to go about solving it"

Power technology
Mokyr (1990, Ch 5)

Newcomen's engine

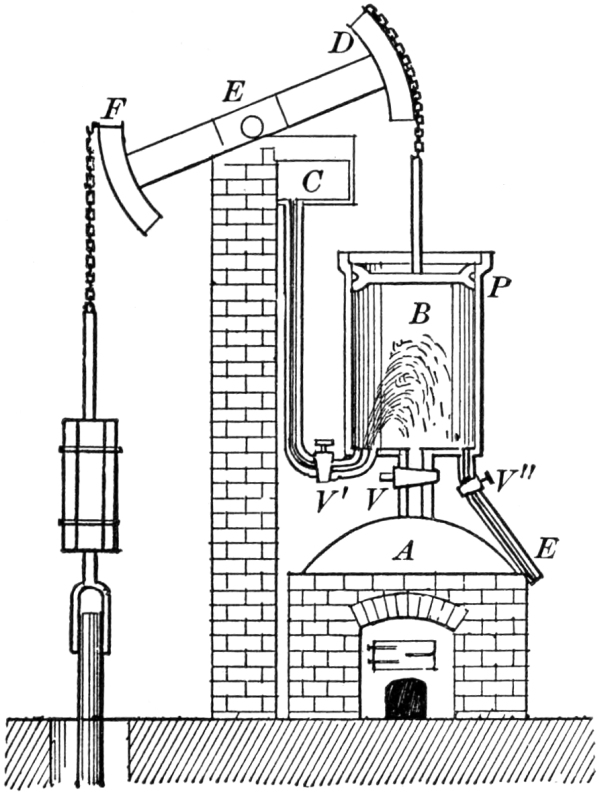


Boiler (A) produces steam into the cylinder (B) and the steam is then condensed with cold water, creating a "partial vacuum", and the pressure differential with the atmosphere then drives the piston (P) down.

Power technology

Mokyr (1990, Ch 5)

Newcomen's engine



Boiler (A) produces steam into the cylinder (B) and the steam is then condensed with cold water, creating a "partial vacuum", and the pressure differential with the atmosphere then drives the piston (P) down.

Steam engine's "scientific" background

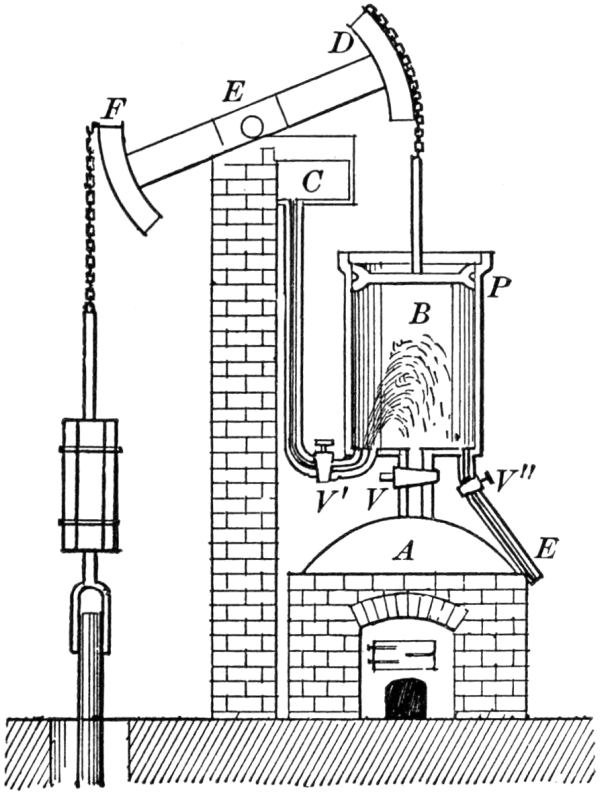
- realization that an atmosphere exists
- thermodynamics developed much later (started in 1824 with Sadi Carnot's work that explained why steam engines work)

Newcomen's engine first economically succesful one (installed in a coal mine in 1712)

Power technology

Mokyr (1990, Ch 5)

Newcomen's engine



Boiler (A) produces steam into the cylinder (B) and the steam is then condensed with cold water, creating a "partial vacuum", and the pressure differential with the atmosphere then drives the piston (P) down.

Steam engine's "scientific" background

- realization that an atmosphere exists
- thermodynamics developed much later (started in 1824 with Sadi Carnot's work that explained why steam engines work)

Newcomen's engine first economically succesful one (installed in a coal mine in 1712)

Watt designed important improvements that greatly increased efficiency

- "his mind ran upon making engines *cheap* as well as *good*" (autobiography)

Trevithick: high-pressure machine, 1802

- smaller and more economical
- fitted boats and horseless carriages

Waterpower: breast wheel, turbine

Other innovations

Mokyr (1990, Ch 5)

Metallurgy

- coke replaces charcoal in iron smelting → allows building bigger and more efficient blast furnaces → high quality and cheap wrough iron

Other innovations

Mokyr (1990, Ch 5)

Metallurgy

- coke replaces charcoal in iron smelting → allows building bigger and more efficient blast furnaces → high quality and cheap wrough iron

Textiles

- between 1760–1800 "a feverish wave of inventions focused on the manufacturing of cotton" → made all-cotton clothing possible → cotton industry grew in unprecedented pace

Other innovations

Mokyr (1990, Ch 5)

Metallurgy

- coke replaces charcoal in iron smelting → allows building bigger and more efficient blast furnaces → high quality and cheap wrough iron

Textiles

- between 1760–1800 "a feverish wave of inventions focused on the manufacturing of cotton" → made all-cotton clothing possible → cotton industry grew in unprecedented pace

Other

- productive innovations high-precision machine tools, chemical industry, lighting, ceramics and glass, papermaking...

Other innovations

Mokyr (1990, Ch 5)

Metallurgy

- coke replaces charcoal in iron smelting → allows building bigger and more efficient blast furnaces → high quality and cheap wrough iron

Textiles

- between 1760–1800 "a feverish wave of inventions focused on the manufacturing of cotton" → made all-cotton clothing possible → cotton industry grew in unprecedented pace

Other

- productive innovations high-precision machine tools, chemical industry, lighting, ceramics and glass, papermaking...
- symbolic: flying
  (Montgolfier brothers' balloon, 1783)

Why 18th century Britain?

One of the key questions in economic history

- why didn't these breakthroughs occur earlier?
- and why did they take place in Europe, particularly Britain?

The field remains very active, recent books include:

- Robert C. Allen's *The British Industrial Revolution in Global Perspective* (2009), Gregory Clark's *A Farewell to Alms: A Brief Economic History of the World* (2007), Jan de Vries's *The Industrious Revolution: Consumer Demand and the Household Economy, 1650 to the Present* (2008), Deirdre McCloskey's *Bourgeois Dignity: Why Economics Can't Explain the Modern World* (2010), Joel Mokyr's *The Enlightened Economy: An Economic History of Britain 1700–1850* (2010), Jan Luiten van Zanden's *The Long Road to the Industrial Revolution* (2009), E. A. Wrigley's *Energy and the English Industrial Revolution* (2010)

A broad categorization of the explanations:

1. Ideas (macro-inventions, science, culture)
2. Incentives (institutions, prices)

Ideas 1: Genius and luck

Hypothesis

- radical new ideas (macroinventions) appear "from nowhere"
- Mokyr (1990): "[macro-inventions] do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous economic variables. Many of them resulted from strokes of genius, luck or serendipity"

Ideas 1: Genius and luck

Hypothesis

- radical new ideas (macroinventions) appear "from nowhere"
- Mokyr (1990): "[macro-inventions] do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous economic variables. Many of them resulted from strokes of genius, luck or serendipity"

Criticism

- why would 18th century Britain have more genius and/or luck than other countries and time-periods?
  - but: maybe Britain just was particularly lucky
- a substantial R&D period typical for the big inventions
- many of the inventors appear to have been motivated by profit

Ideas 2: Science

Hypothesis

- technological breakthroughs were applications of scientific discoveries that were not made for economic reasons
- Scientific Revolution: advances in physics, astronomy, biology, chemistry, anatomy in the 16th and 17th centuries

Ideas 2: Science

Hypothesis

- technological breakthroughs were applications of scientific discoveries that were not made for economic reasons
- Scientific Revolution: advances in physics, astronomy, biology, chemistry, anatomy in the 16th and 17th centuries

Criticism

- little sign of productivity advance between 1540–1760
  - but: who knows how long it "should" take
- little evidence of the inventors drawing from scientific results

Ideas 3: Scientific culture

Hypothesis: "Industrial Enlightenment"

- scientific, experimental *methods* applied to technology
- belief that the universe could be apprehended by science
- idea that science and technology would improve human life
- increase in literacy rates, printed material

Ideas 3: Scientific culture

Hypothesis: "Industrial Enlightenment"

- scientific, experimental *methods* applied to technology
- belief that the universe could be apprehended by science
- idea that science and technology would improve human life
- increase in literacy rates, printed material

Criticism

- Enlightenment was not a particularly British movement
- ... and it started about a century "too early"
  - but again: how could we know how long it "should" take
- inventors were craftsmen had limited formal education

Incentives 1: Institutions

Hypothesis

- the institutional structure following the Glorious Revolution of 1688 made the Industrial Revolution possible
- Acemoglu, Robinson (2012): "a fundamental reorganization of economic institutions in favor of innovators and entrepreneurs, based on the emergence of more secure and efficient property rights"

Incentives 1: Institutions

Hypothesis

- the institutional structure following the Glorious Revolution of 1688 made the Industrial Revolution possible
- Acemoglu, Robinson (2012): "a fundamental reorganization of economic institutions in favor of innovators and entrepreneurs, based on the emergence of more secure and efficient property rights"
- another version: the British elite were landowners and thus did not need to oppose innovations in manufacturing

Incentives 1: Institutions

Hypothesis

- the institutional structure following the Glorious Revolution of 1688 made the Industrial Revolution possible
- Acemoglu, Robinson (2012): "a fundamental reorganization of economic institutions in favor of innovators and entrepreneurs, based on the emergence of more secure and efficient property rights"
- another version: the British elite were landowners and thus did not need to oppose innovations in manufacturing

Criticism

- timing: the Glorious Revolution took place eight decades before the start of the Industrial Revolution
  - yet again: we really don't know how long it should take
- insecurity of property prior to 1688 contestable
- ... and many other countries also had secure property rights
- patents were costly, sometimes had counterproductive effects

Incentives 2: Prices

Hypothesis

- British labor was uniquely expensive and energy uniquely cheap $\rightarrow$ it paid to invent labor saving technology in Britain
  - British wages were higher than those of its competitors
  - high wages translated into higher living standards
  - wages were high relative to capital prices
  - ... and relative to energy prices (in some British areas)

Incentives 2: Prices

Hypothesis

- British labor was uniquely expensive and energy uniquely cheap $\rightarrow$ it paid to invent labor saving technology in Britain
  - British wages were higher than those of its competitors
  - high wages translated into higher living standards
  - wages were high relative to capital prices
  - ... and relative to energy prices (in some British areas)

Criticism (Mokyr 2011, The Enlightened Economy)

- "factor prices might have determined the *direction* of technological change, but the *power* and *intensity* of improvement were a function of technological capabilities and motives that had deeper causes"

Why were British wages and prices unique?
Allen (2006, 2009)

Geography

- Britain had vast and readily worked coal deposits
- inexpensive coal raised wage/energy price ratio
- ... and reduced the price of capital (production of metals and bricks)

Why were British wages and prices unique?
Allen (2006, 2009)

Geography

- Britain had vast and readily worked coal deposits
- inexpensive coal raised wage/energy price ratio
- ... and reduced the price of capital (production of metals and bricks)

International trade

- late 16th-century: 'new draperies' made in East Anglia and exported to the Mediterranean through London
- 17th century onwards: imperialism
- 1500–1800: population living in cities/town 7% $\rightarrow$ 29%, agriculture labor force share 75% $\rightarrow$ 35%

Why were British wages and prices unique?
Allen (2006, 2009)

Interaction between geography and trade

- 16th century: London's population exploded → demand for fuel increased → prices of charcoal, firewood increased
- now worthwhile to figure out how to substitute coal for wood
- and to set up large scale mining business in northern England

Why were British wages and prices unique?
Allen (2006, 2009)

Interaction between geography and trade

- 16th century: London's population exploded → demand for fuel increased → prices of charcoal, firewood increased
- now worthwhile to figure out how to substitute coal for wood
- and to set up large scale mining business in northern England

Luck (a.k.a. why not the Netherlands?)

- the Duch cities were also growing, close to vast coal deposits

Why were British wages and prices unique?
Allen (2006, 2009)

Interaction between geography and trade

- 16th century: London's population exploded → demand for fuel increased → prices of charcoal, firewood increased
- now worthwhile to figure out how to substitute coal for wood
- and to set up large scale mining business in northern England

Luck (a.k.a. why not the Netherlands?)

- the Duch cities were also growing, close to vast coal deposits
- Duch peat initially used to meet growing energy demand → transport on the Ruhr not improved
- once industry established in Newcastle, coal could be delivered as cheaply to Amsterdam and London

Why did international price differences matter?
Allen (2006, 2009)

Product innovations

- trade with Asia brought new products to Britain
  (cotton fabrics, Chinese porcelain, coffee, tea)
- Britain's high wages → a broad market for these products → British manufacturers started to produce cotton, porcelain...
- Industrial revolution was largely import substitution

Why did international price differences matter?
Allen (2006, 2009)

Product innovations

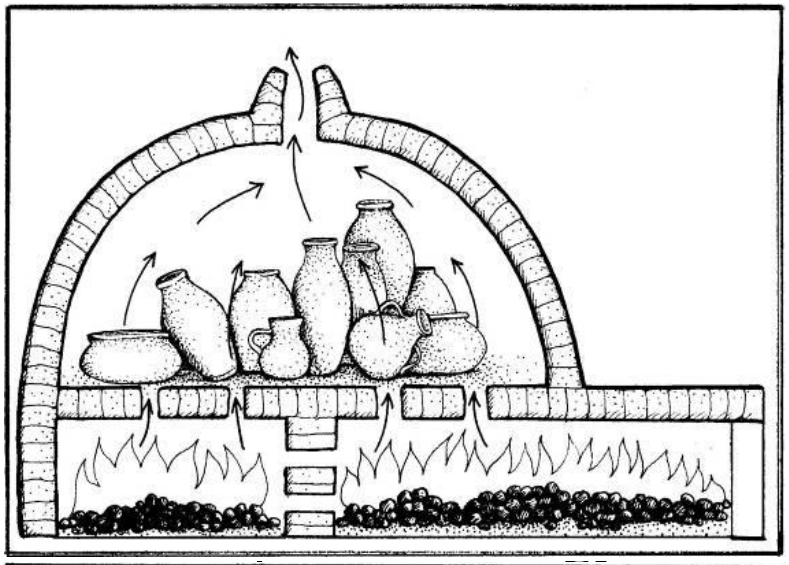
- trade with Asia brought new products to Britain (cotton fabrics, Chinese porcelain, coffee, tea)
- Britain's high wages → a broad market for these products → British manufacturers started to produce cotton, porcelain...
- Industrial revolution was largely import substitution

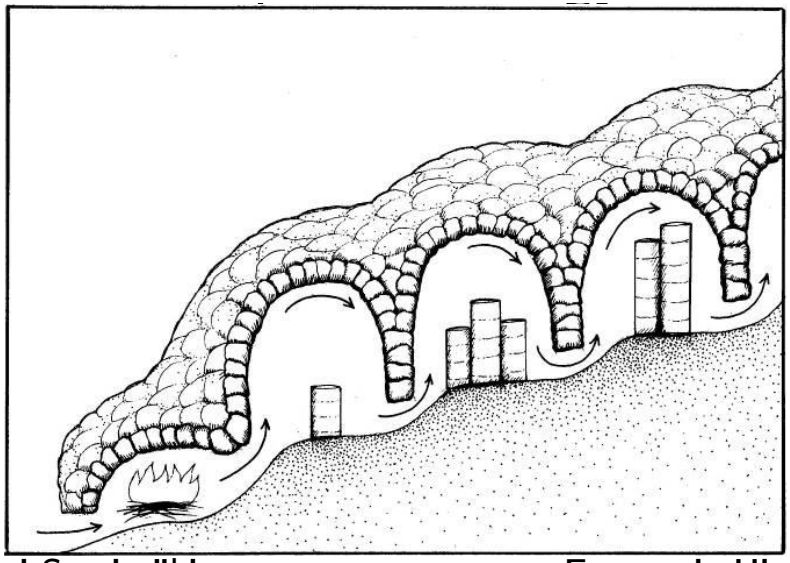
Process innovations

- British inventions were labour saving, energy/capital intensive
- thus these inventions were adopted in Britain and not on the (low wage, costly energy) continent
- the necessary R&D behind the invention was profitable under British conditions but unprofitable elsewhere
- new technology was being improved and once it was sufficiently effective, it spread across the continent

Example: English and Chinese kilns

Allen (2009)





In Britain, pottery was fired in round, up-draft kilns (top picture). These were cheap to build but did not use energy efficiently (much heat escaped from the holes in the top).

In China, kilns were designed to conserve energy. A common design was the 'down-draft climbing kiln' build in hill slopes (bottom picture).

That is, the Chinese *were* inventive, but they invented tecnologies that were optimal for their factor prices

Industrial Revolution: Summary

Technology shifted the supply curves

- prices decreased (e.g. cotton price decline by 85% between 1780–1850)
- completely new goods were created
- the quality of many old goods greatly improved

Consumers slid down their demand curves (bought more)

- note, though, that initially living standards improved slowly

Industrial Revolution: Summary

Technology shifted the supply curves

- prices decreased (e.g. cotton price decline by 85% between 1780–1850)
- completely new goods were created
- the quality of many old goods greatly improved

Consumers slid down their demand curves (bought more)

- note, though, that initially living standards improved slowly

Why did it happen in 18th century Britain?

- many alternative explanations
- not necessarily mutually exclusive
- hard to test, but can examine consistency with data

Papers for essays

Nunn, Qian (2011): The Potato's Contribution to Population and Urbanization: Evidence from a Historical Experiment, *QJE* 126(2): 593–650

- exploits regional variation in suitability for cultivating potatoes and find that the introduction of the potato accounts for at least one-quarter of the growth in Old World population and urbanization 1700–1900.

Jia (2014): Weather Shocks, Sweet Potatoes and Peasant Revolts in Historical China. *Economic Journal*

- shows that exceptional droughts more than doubled the probability of peasant revolts in historical China. This effect was dramatically reduced after the introduction of (drought resistant) sweet potatoes.

Papers for essays

Pascali (2017): The Wind of Change: Maritime Technology, Trade, and Economic Development. *AER*, 107(9): 2821-54.

- Examines the impact of the introduction of the steamship on international trade. Finds a major impact on patterns of trade that benefited a small number of countries characterized by more inclusive institutions.

Donaldson (2018): Railroads of the Raj: Estimating the Impact of Transportation Infrastructure. *AER, 108(4): 899-934*

- Uses archival data from colonial India to investigate the impact of India's vast railroad network. Finds that railroads increased trade and real income.

Appendix

Data

Allen (2006, 2009)

Database combining hundreds of price histories

- typically based on the archives of an institution that lasted for hundres of years (e.g. colleges, hospitals)
- records of quantities and prices of everything bought or sold
- typical items: agricultural and food stuffs, cloth, fuel, candles, building materials, implements, wages, salaries

Tables of the annual averages available now for many cities

- while many gaps remain, these data make international comparisons possible and redefine our understanding of economic history (see a data archieve here)

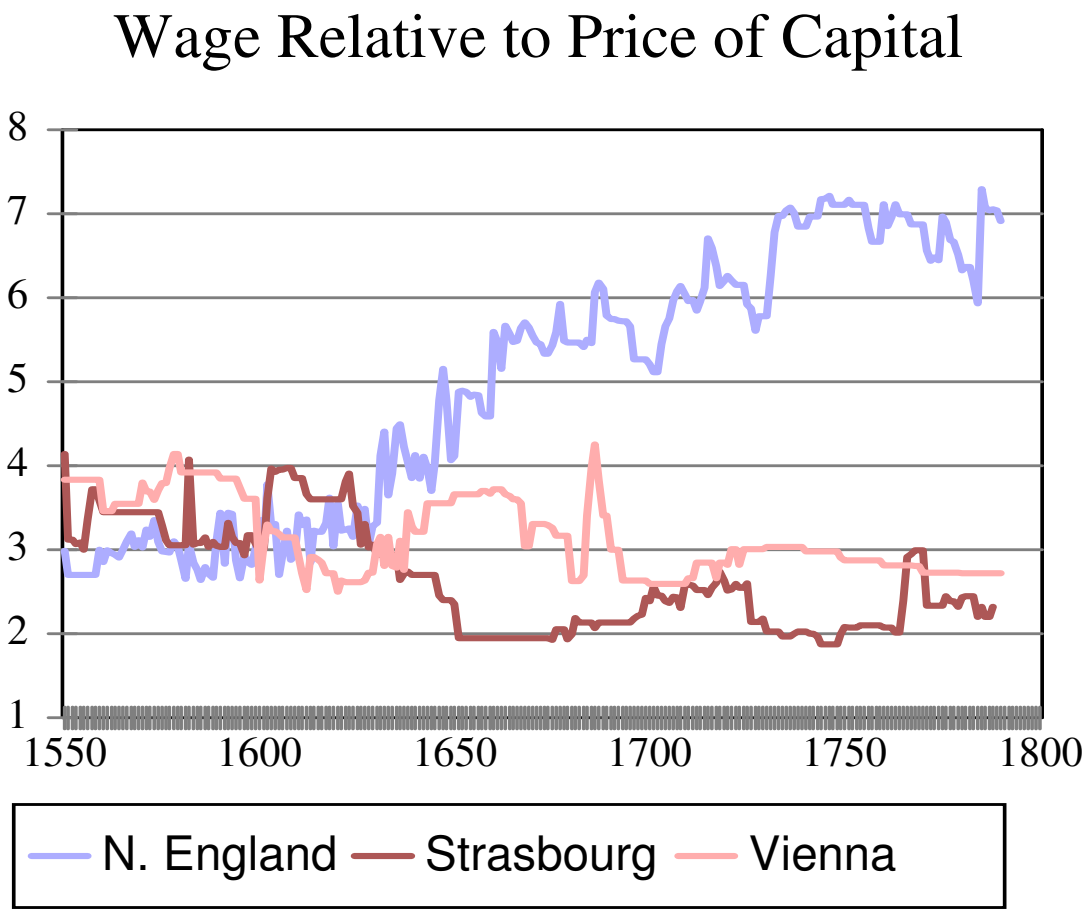
Nominal wages

Allen (2006, 2009)

Nominal wages for building workers were very similar in the European cities during the Middle Ages. In 1550–1620, wages in eastern Europe remained stagnant, while they rose in western Europe. Thereafter, there was a three way split with silver wages falling in southern Europe, levelling out in the Low Countries, and continuing to rise in London.

Price of labor vs. capital

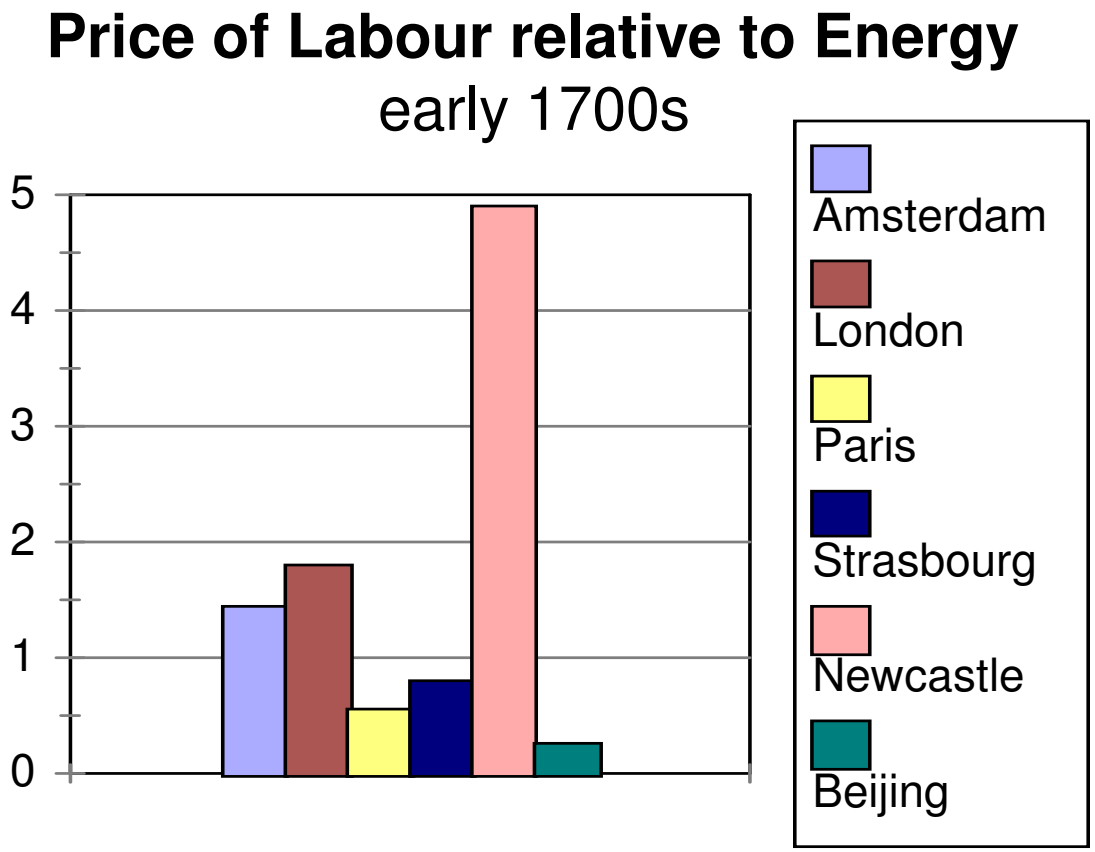
Allen (2006, 2009)



The ratio of a building labourer's daily wage relative to an index of the rental price of capital (average of price indices for iron, nonferrous metals, wood, and brick multiplied by an interest rate plus a depreciation rate). Strasbourg and Vienna chosen since long data series are available, and their data look comparable to those of most of Europe apart from the Low Countries. The series are 'PPP adjusted' so that we can compare across space as well as over time.

Price of labor vs. energy

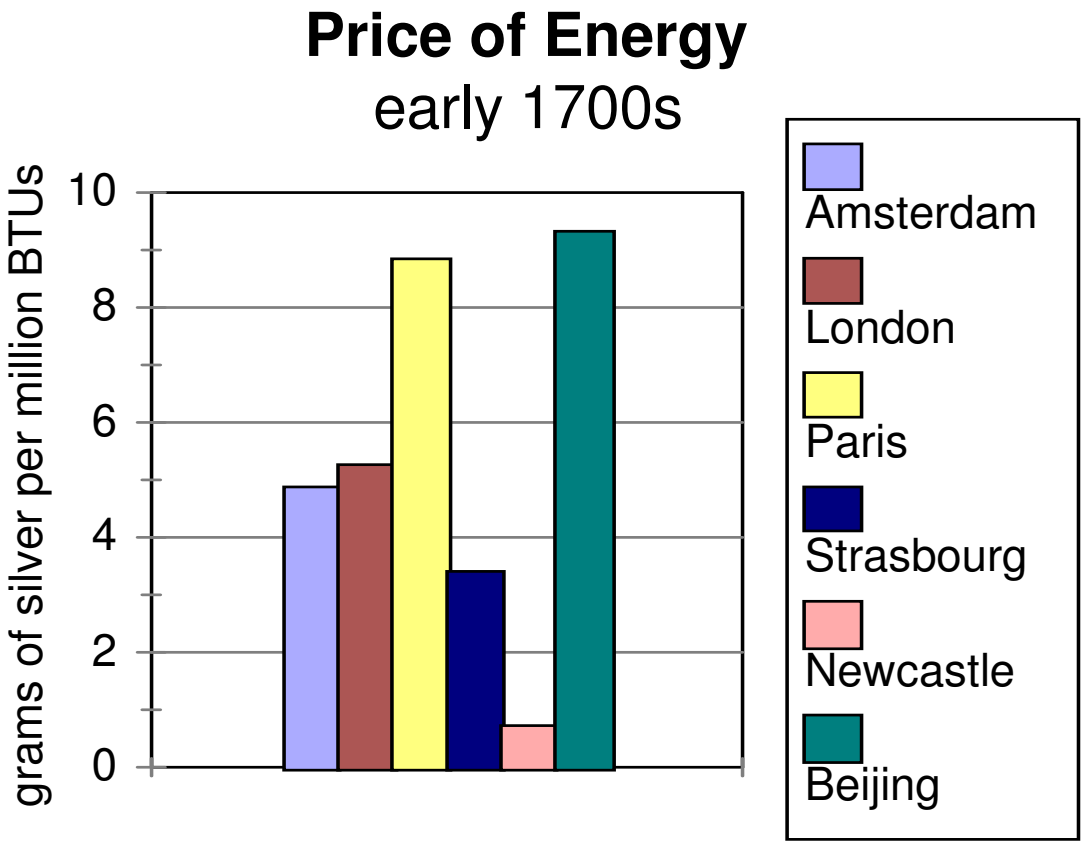
Allen (2006, 2009)



Ratio of the building wage rate to the price of energy in the early eighteenth century in important cities in Europe and Asia. In this ratio, the price of a kilogram of fuel was divided by its energy content, so energy prices are expressed as grams of silver per million BTUs. The ratio is calculated for the cheapest fuel available in each city–coal in London and Newcastle, peat in Amsterdam, charcoal or fire wood in the other cities.

Energy prices

Allen (2006, 2009)



London did not have particularly cheap fuel at that time; Newcastle, however, did. The difference in the energy price between the two cities equals the cost of shipping the coal from the Tyne to the Thames. Coal prices at other cities in northern and western Britain were similar to those in Newcastle–at least once canal improvements brought down internal shipping costs. Except perhaps for southern Belgium, no region anywhere in the world had the same combination of large population and cheap energy. Belgian coal output, however, was only 3% of Britain's in 1800.