Past and Prospective Energy Transitions in the UK

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Outline

- Can we learn from past energy transitions & policies?
  - The first & second British industrial revolutions
- Prospects and problems of a third, low-carbon industrial revolution
  - The challenges for low-carbon innovation
  - General Purpose Technologies & the Sailing Ship Effect
  - Relative prices and resources

Research on Energy System Transitions

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- Research on developing country and past & future UK transitions
- Long collaboration with Roger Fouquet (now C3B)
- Estimates for fuels, energy carriers & energy services, of
  - Prices, consumption, expenditure
- Publications include:
    - ‘One Thousand Years of Energy Use’ (En. Jnl.)
    - ‘Five Centuries of Energy Prices’ (World Econs.)
    - ‘Seven Centuries of Energy Services’ (Lighting) (En. Jnl.)
    - Chapter: ‘Long Run CO2 Emissions & Environmental Kuznets Curves’
    - Fouquet: *Heat, Power and Light: Revolutions in Energy Services*, Edward Elgar (2008)
- Now engaged with the *Transition Pathways to a low Carbon Economy* consortium (EPSRC/E.ON)

Data Sources

- Early centuries: data incomplete: broad trends only, so approach with caution
  - Data mostly from Southern England
  - Market town records (Rogers, 6 vols. 1865-86)
  - Oxford & Cambridge Colleges, Eton & Westminster schools, hospitals, the Navy… (Beveridge, 1894)
  - Several centuries of tax data
- National markets/transport developed gradually
- C18th national income data: ''controlled conjectures' (Mokyr)
- C19th/20$^{th:}$ data range/quality grows
  - Companies/local authorities
  - Official enquiries (Parliamentary Papers – see website)
  - Official government data series

Britain's 1st 'Industrial Revolution': C16th-C19th Energy Transitions

- From a traditional agricultural economy, with limited
  - Productivity of scarce land
  - For food, clothing, housing & **energy flows**
- To new regime: growth/ welfare transformed by using
  - fossil **stock** (coal) for larger energy flows (Wrigley)
- With innovations including
  - Steam engine
  - Cotton mills & technologies
  - Substitution of coal/coke for wood in metal manufacture
  - Other social, political, institutional & technological changes
- Which helped drive & were driven by mechanisation, urbanisation & Britain's first 'Industrial Revolution'

Fig.1a: UK Final Energy Consumption, 1500-1800 (TWh)

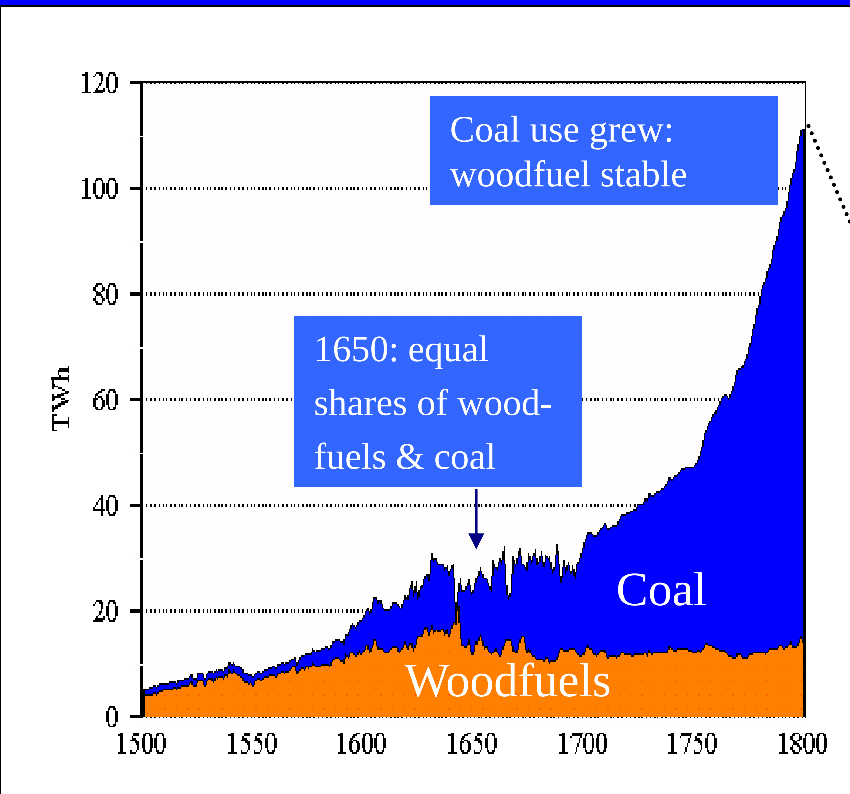
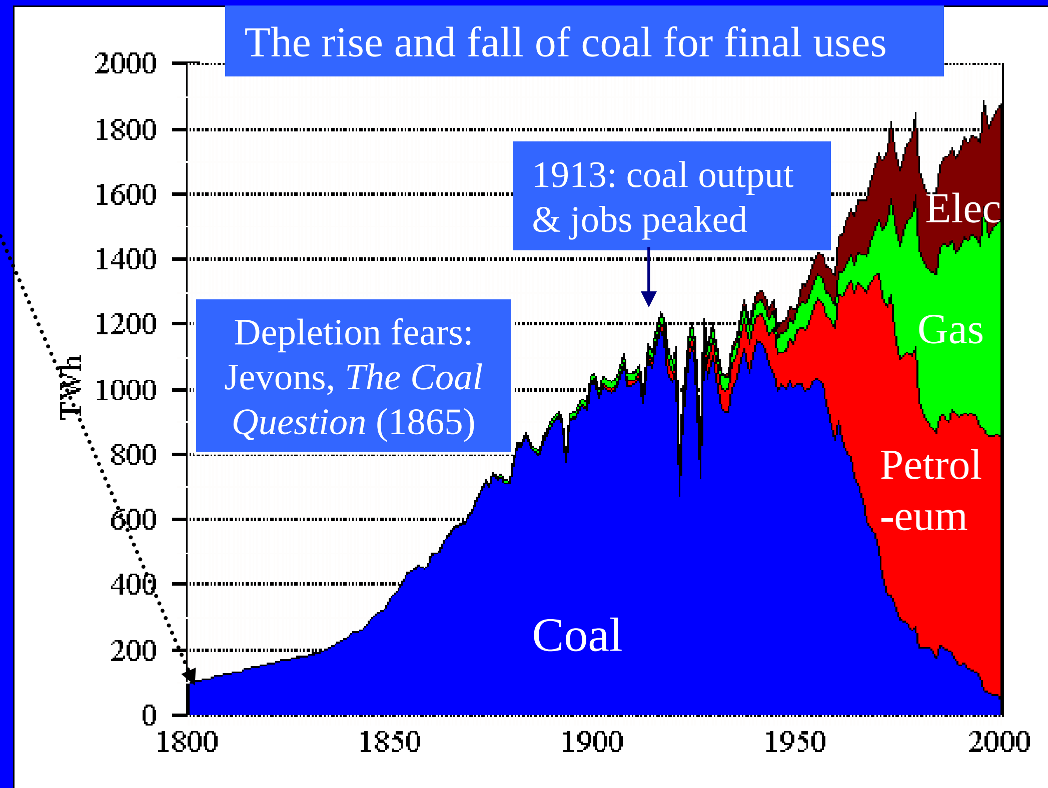


Fig. 1b: UK Final Energy Consumption, 1800-2000 (TWh)

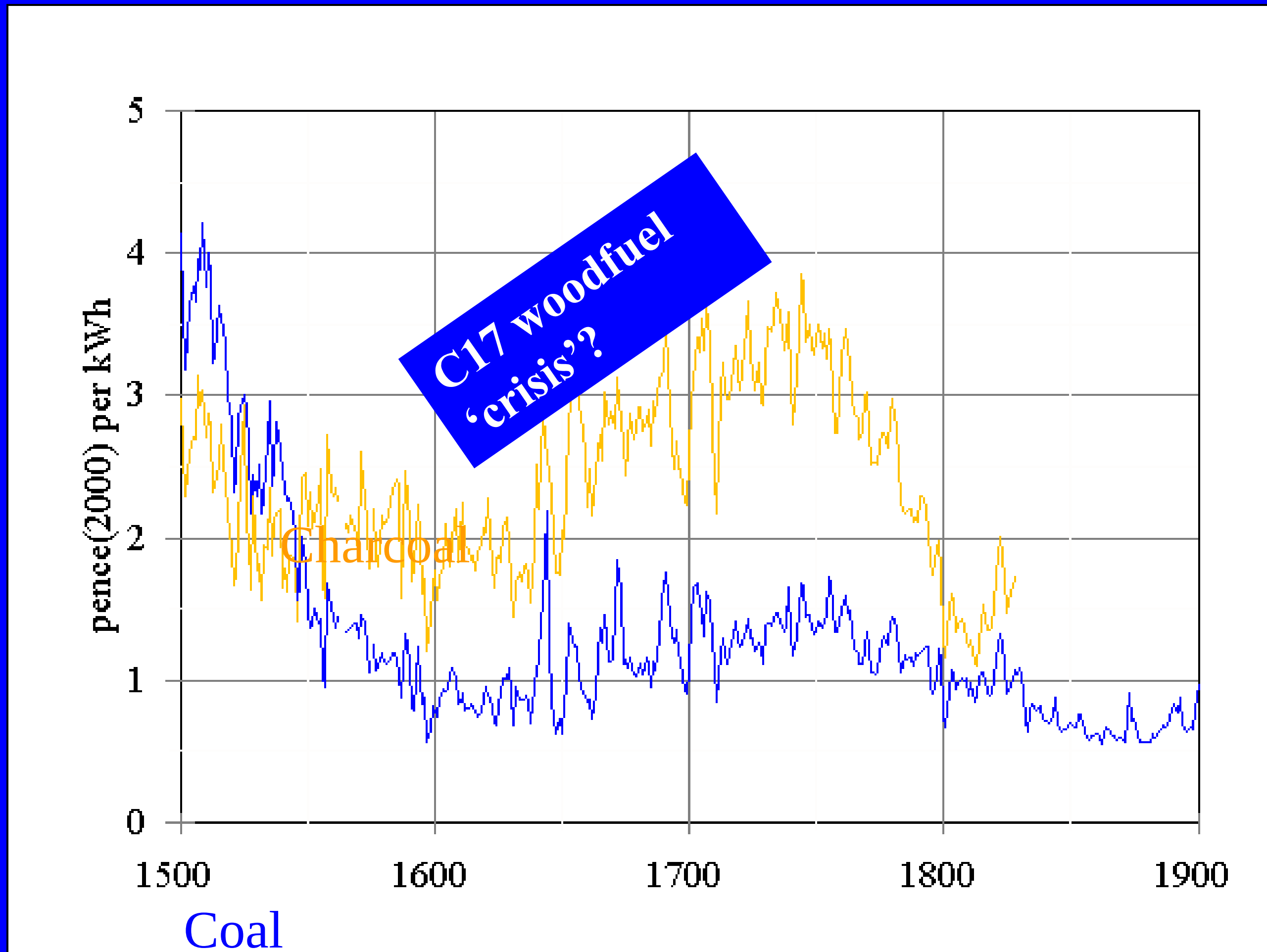


Fouquet & Pearson (2003) *World Economics*, 4(3)

- **Allen, 2009: why a British Industrial Revolution? Wages high relative to energy & capital costs, compared with other European & Asian countries**
- **Innovations in steam engines & cotton mills & substitution of coal/coke for wood in metal manufacturing were uniquely profitable in Britain**

Fouquet & Pearson (2003) World Economics, 4(3)

Fig. 2: Real consumer fuel prices,1500-1800 (p/kWh)



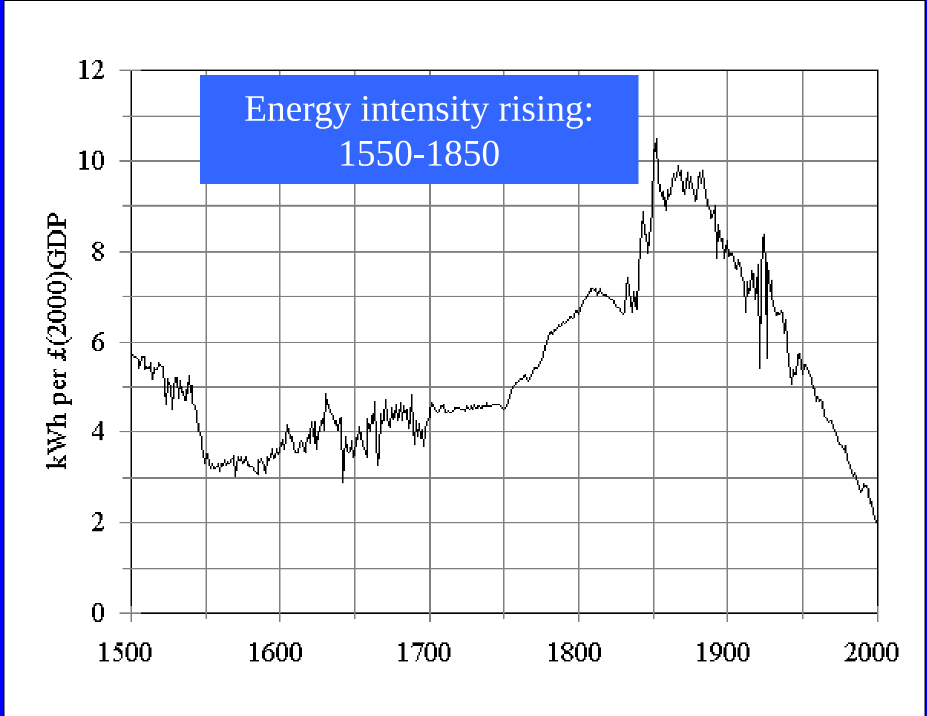
- **Rising charcoal/ coal price differential around 1650-1750 encouraged coal use**
- **Along with innovations in domestic & other uses of coal**

Fouquet & Pearson (2003) *World Economics*, 4(3)

Fig. 3: Energy intensity & prices

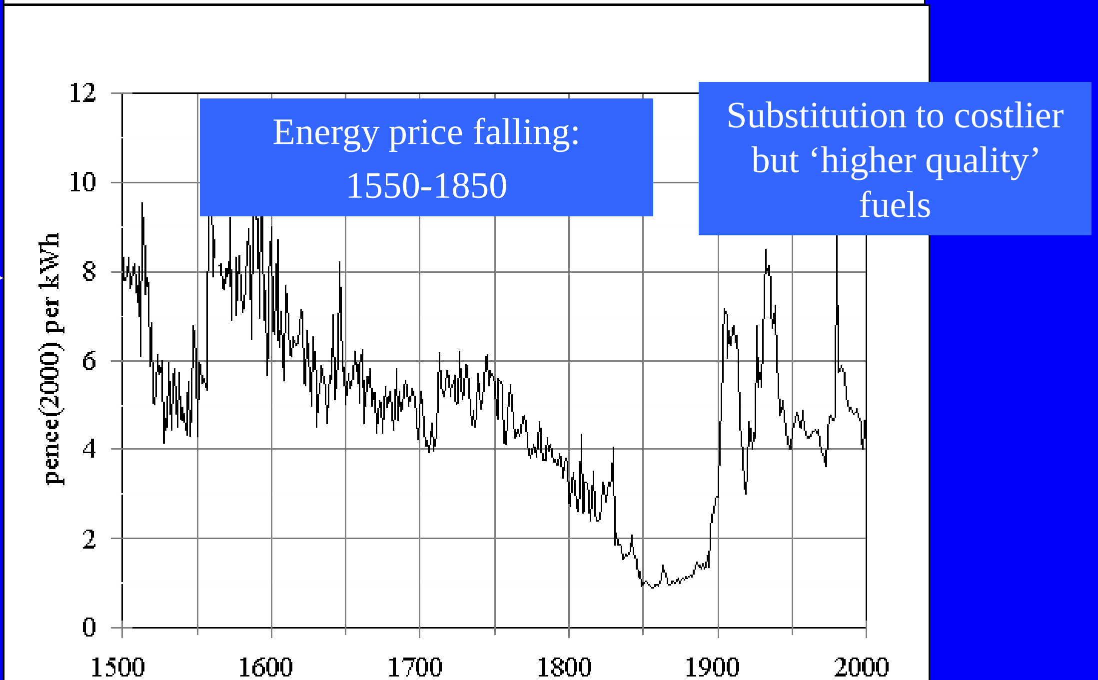
Inverse relationship between:

UK energy intensity (E/GDP) →



and

Real energy prices (p/kWh) →



Fouquet & Pearson (2003) *World Economics*, 4(3)

We created an 'average price of energy' series from estimates of individual fuel prices & expenditure weights

Coal & New Steam Technologies in C18

- Engines pumped water from coal, copper & tin mines
  - Savery's patent (1698-1733), Newcomen's 'atmospheric engine' (1710-12)
  - By 1733, 110 Newcomen engines in 7 countries
  - Engines also linked to water wheels (rotary power)
- Watt's separate condenser patent (1769-1800)
  - raised efficiency & royalties (B & W defended their patent…)
- Watt, Murdoch (1782) et al. - rotary steam power; engines smaller & could drive machines
- By 1805: gas lighting in cotton mills (safer, cheaper; longer work day…)
- But only 2200 steam engines in mining & manufacturing by 1800

Fig.4: Steam Engine Developments

- Thompson's Atmospheric Beam Engine
  - Size of a house
  - Ran 127 years, pumping water in Derbyshire coal mines (1791-1918)

- Bell Crank Engine (Rotary Power)
  - Patented 1799 by William Murdoch
  - 75 built by Boulton & Watt, 1799-1819
  - This one ran 120 years (1810-1930)

- Both in Science Museum, London

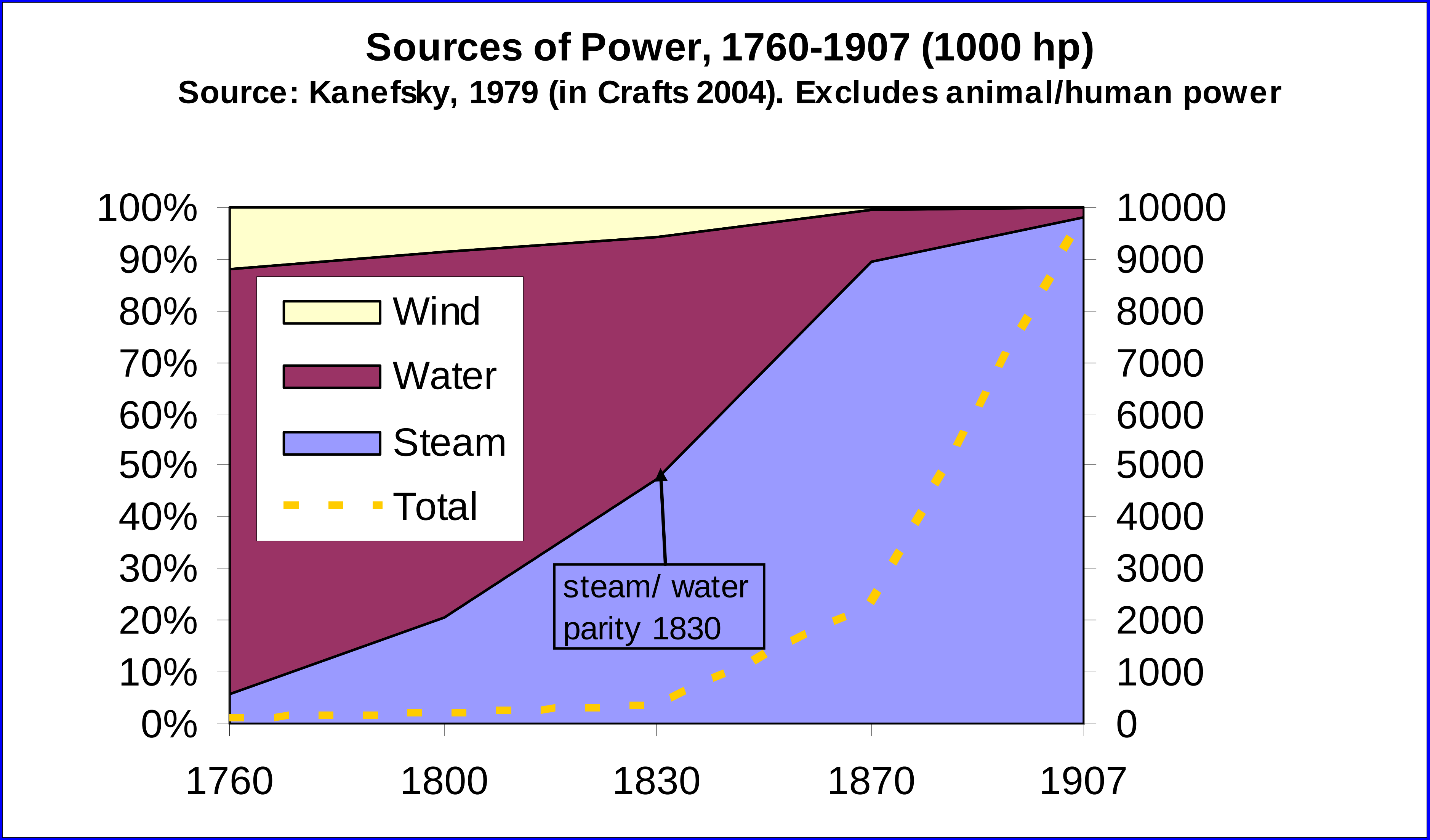
Long Run Perspective: Steam Power Development & Diffusion

- High steam/water power price differential gradually overcome
  - By steam's mobility advantage
  - More engine efficiency & control, from
    - Higher pressure & compound boilers (Cornwall; Woolf, McNaught - 1840s); Corliss valves (1860s)
    - Parity in power shares ca. 1830
- Steam let production move from water/ wind power sites
  - Helped develop the factory system
  - Especially textiles: e.g. Manchester - 'Cottonopolis'
- Railways & then ships (niches first) & trade
  - Developed national & international transport & markets

Fig 5: Sources of Power, 1760-1907 (shares/ total)

(L.h.s. axis: % shares)

(R.h.s. axis: total: 1000 hp)



Why was the Industrial Revolution British? Allen (2009):

- British late C16-C18 trade success (wool textiles) => rural industrialisation & urban growth
- London's growth (1500-1800: 15,000 – 1 million) => woodfuel shortage => relieved by exploiting relatively cheaper coal. Coal gave Britain cheap energy
- Responsive agriculture raised food supply & labour productivity =>freeing labour for manufactures
- City & manuf. growth => higher wages & living standards (inc. diet: beef, beer & bread)
- Trade success also created UK's high wage economy
- High wages & cheap energy (coal) => demand for technology to substitute capital & energy for labour
  - Newcomen steam engines used more capital & coal to raise labour productivity
  - Cotton mills used machines to raise labour productivity
  - New iron-making technologies substituted cheap coal for expensive charcoal & mechanisation raised output/ worker

Fig. 6 : Price of labour relative to capital & energy in several countries (Allen, 2009)

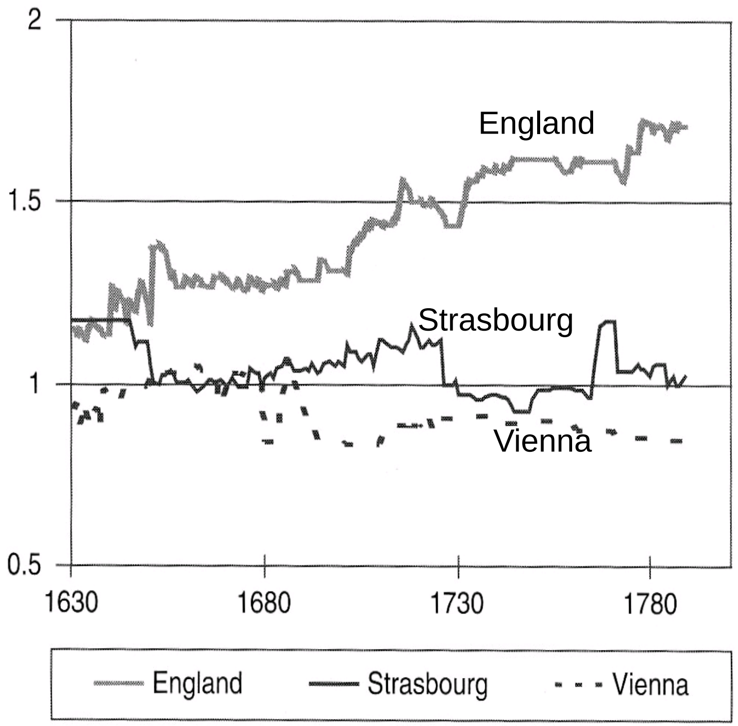


Figure 6.1 Wage relative to price of capital

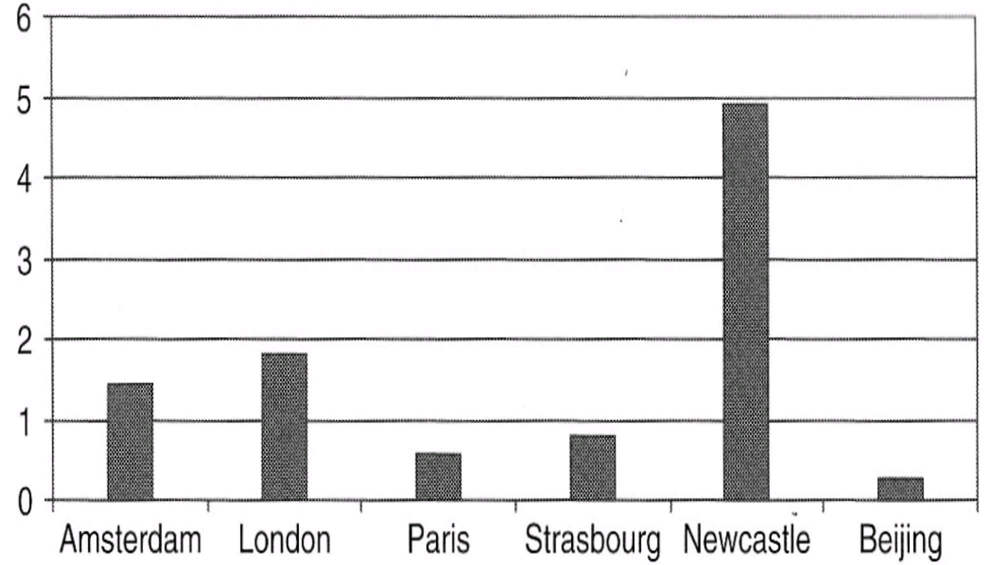


Figure 6.2 Price of labour relative to energy, early 1700s

Greater incentive to mechanise in Britain (ratio of building labourer's wage to index of rental price of capital - PPP adjusted).

Intense incentive to substitute fuel for labour in Britain (ratio of building wage rate to energy price in key cities in Europe & Asia - cheapest fuel in each city).

Allen (2009), cont.

- The engineering challenges of these (inefficient) 'macro-inventions' required 'micro-inventions' => growth of R & D, an important C18 business practice, supported by venture capital & use of patents to recoup development costs
- The high wage economy => demand for skills of literacy & numeracy & gave parents income to purchase them => supplied Britain with skills needed for the 'high-tech' revolution
- The inventions were tailored to British conditions & for years were unprofitable in countries with lower wages & costlier energy
- But local learning eventually led to neutral technical progress => British engineers raised efficiency & reduced use of all inputs:
  - E.g. steam engine coal consumption fell from 45 pounds/ horse power-hour in the early C18 to 2 pounds in the mid-C19
- By mid C19 the technologies could be profitably used in countries like France with expensive energy & India with cheap labour

Fig. 7: Pumping Engine Efficiency, 1727-1852 - Coal Consumption (Allen, 2009, 165)

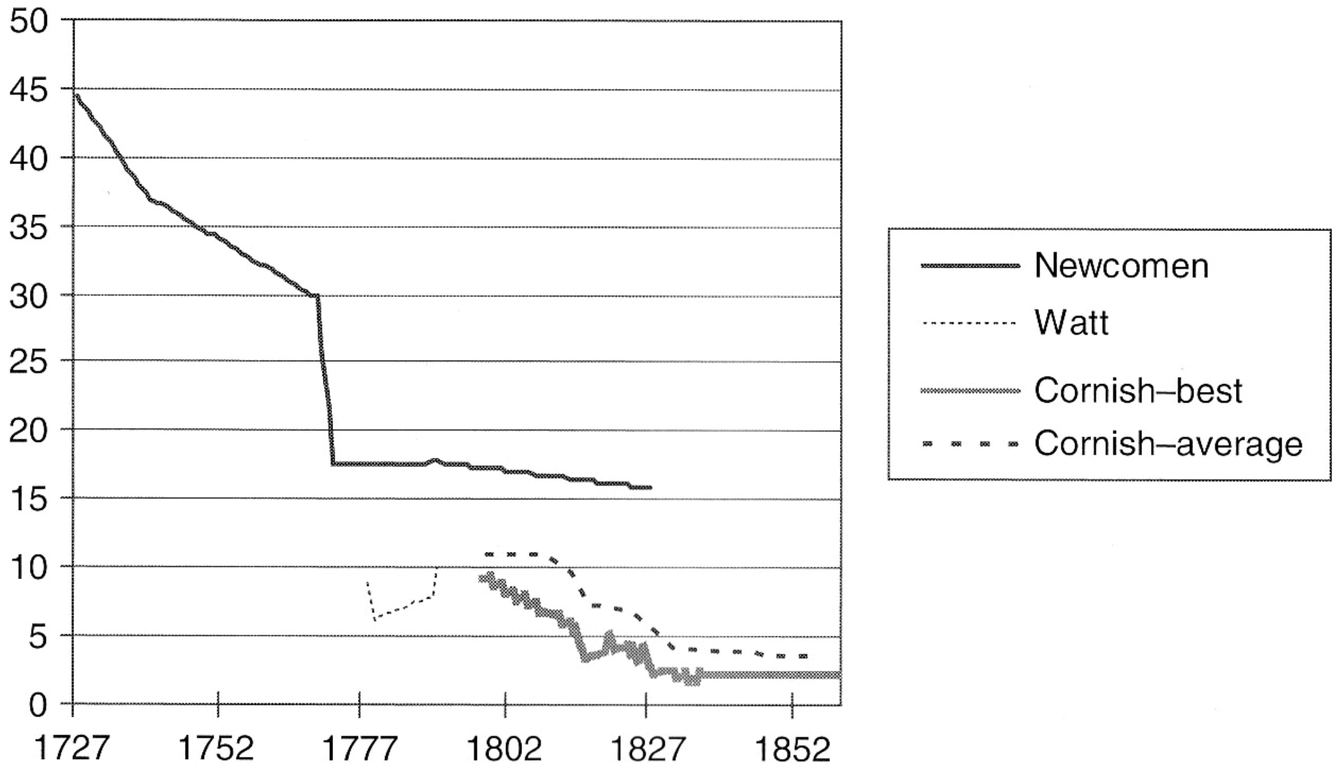


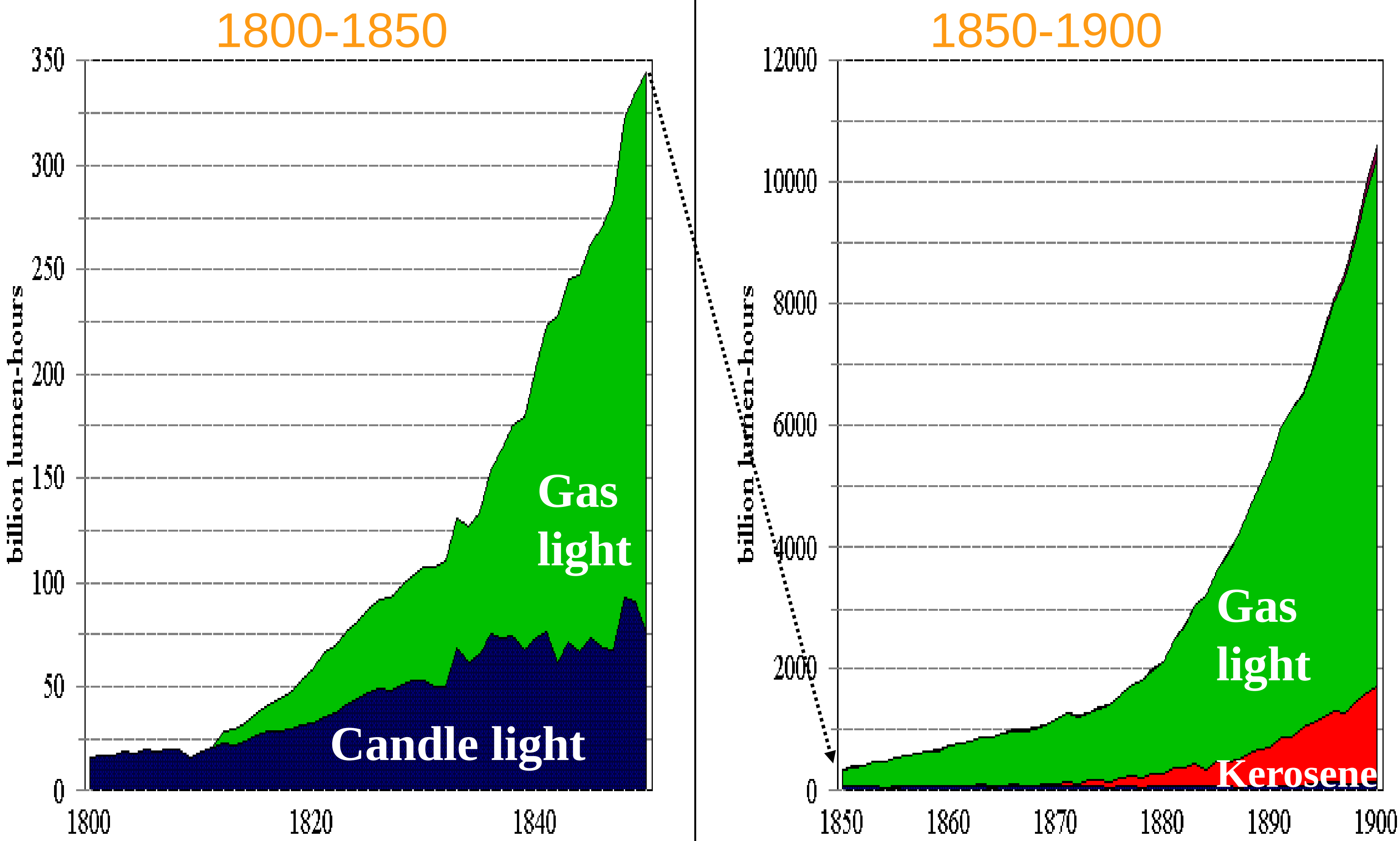
Figure 7.1 Coal consumption in pumping engines: pounds of coal per horsepower-hour

Sources: Hills (1989, pp. 37, 44, 88, 59, 111, 131), von Tunzelmann (1978, pp. 67–70), Lean (1839).

Energy Services: UK lighting experience

- The energy is for energy *services*
    - *illumination*, transportation, cooked meals, refrigeration, comfortable temperatures…
- Evidence: extraordinary potential of innovation to
    - – Reduce costs, enhance quality & raise welfare
- Example: UK lighting services (1300-2000)
    - – Innovation in fuels & technologies, infrastructures & mass production, mostly post-1800, cut costs & improved access
    - – With rising incomes, led to ‘revolutions’ in light use & quality

Fig. 8. UK Consumption of Gas, Kerosene & Candle Light (billion lumen-hours)



Fouquet & Pearson (2006) *Energy Journal*, Vol. 27(1)

Fig. 9. UK Consumption of Kerosene, Gas & Electric Light, 1900-2000 (billion lumen-hours)

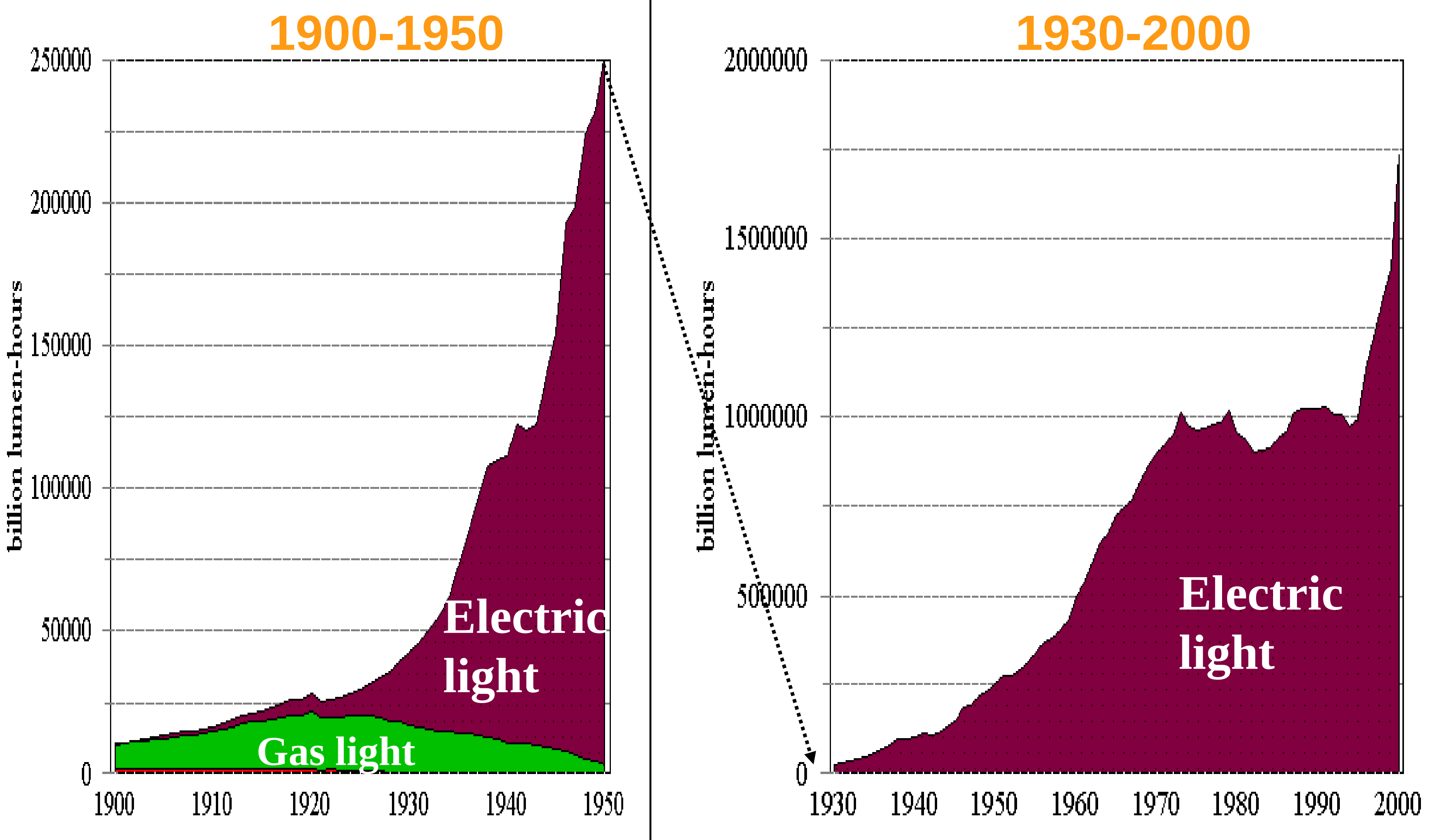


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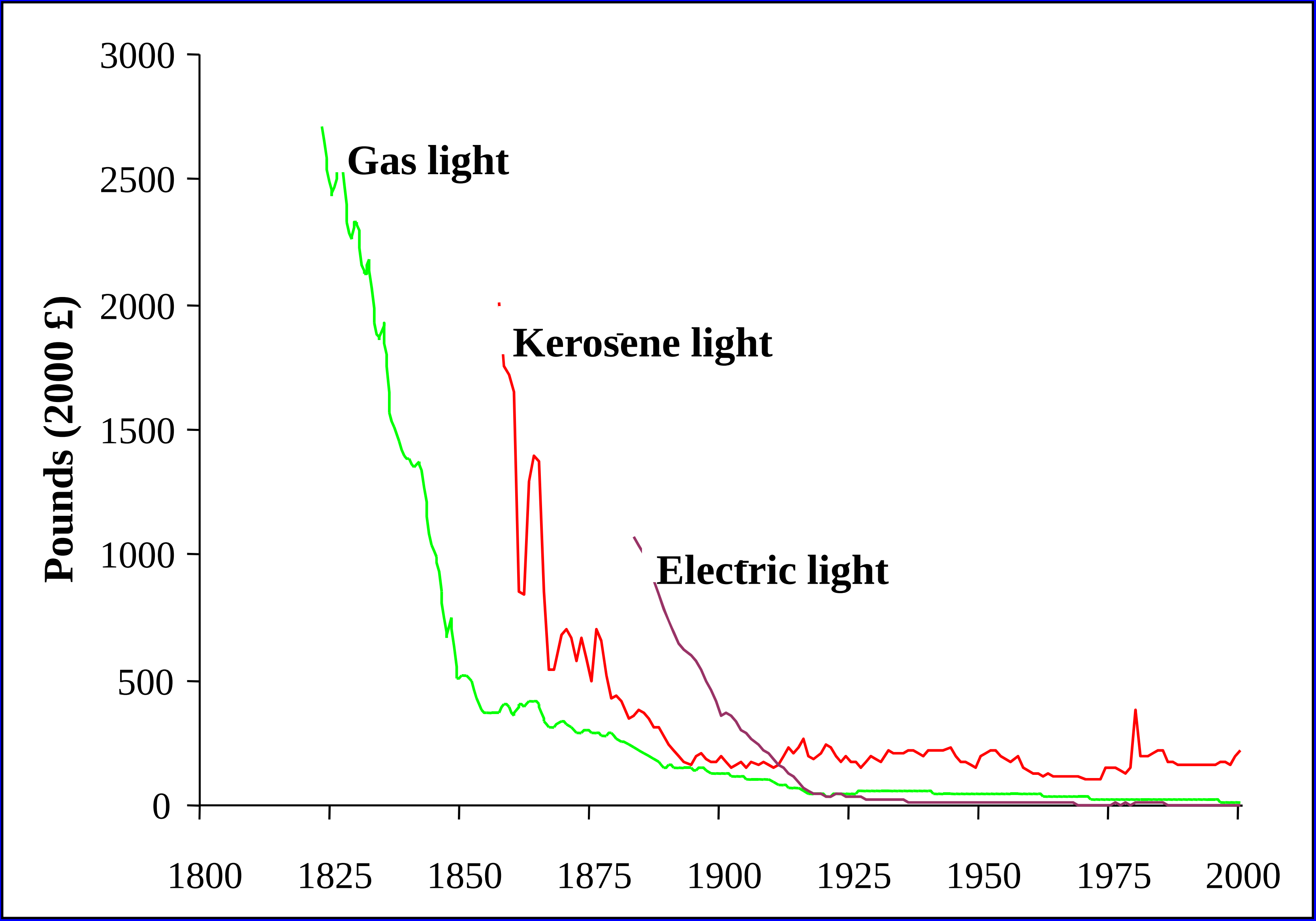
Fig.10. UK Cost of Lighting from Gas, Kerosene & Electricity (£ per million lumen hours, 1800 2000)



Source: authors' own estimates – see Sections II.1.3 -5 and II.3

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Fig. 11. UK Price Ratio of Lighting from Competing Energy Sources, 1820-1950

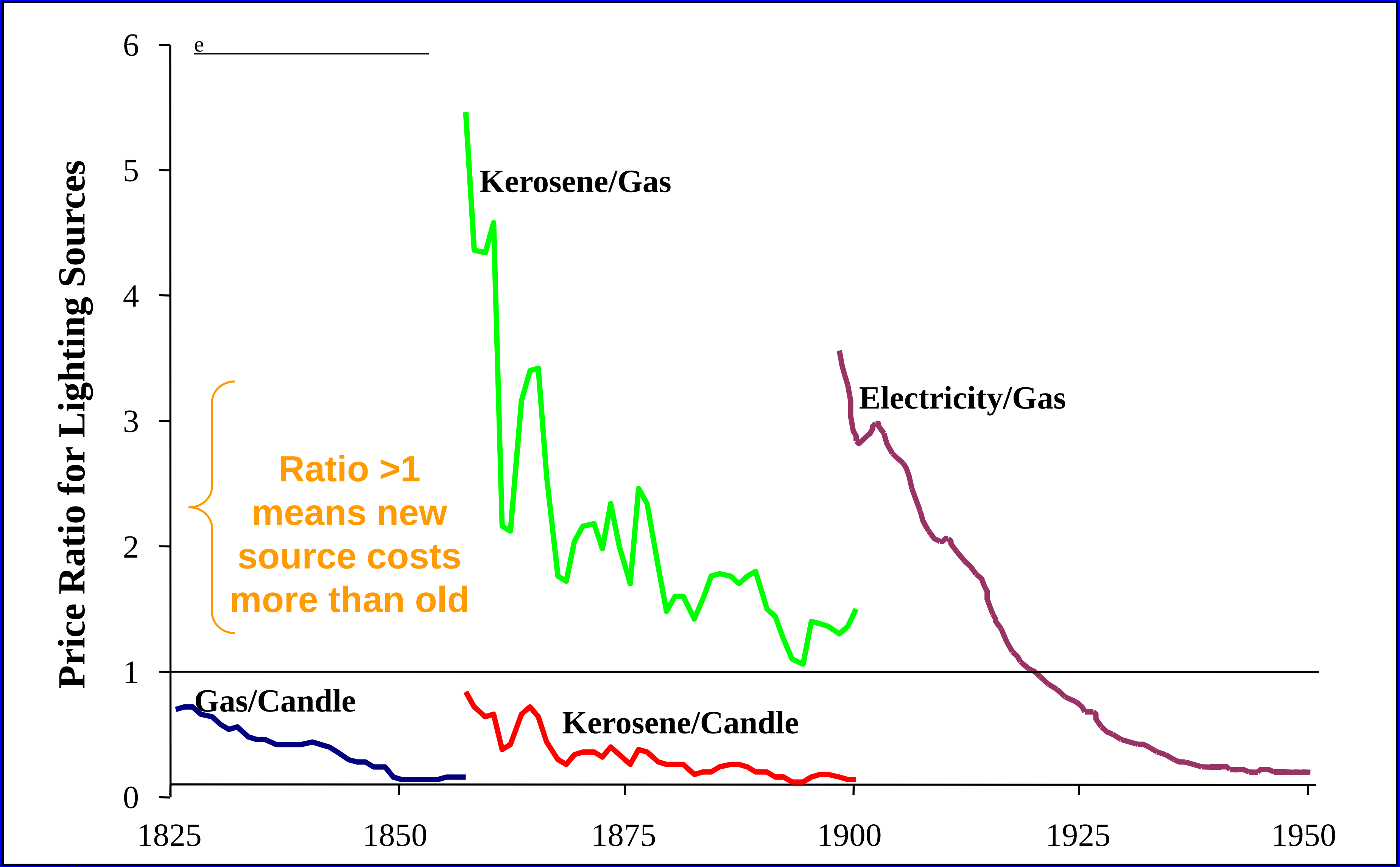

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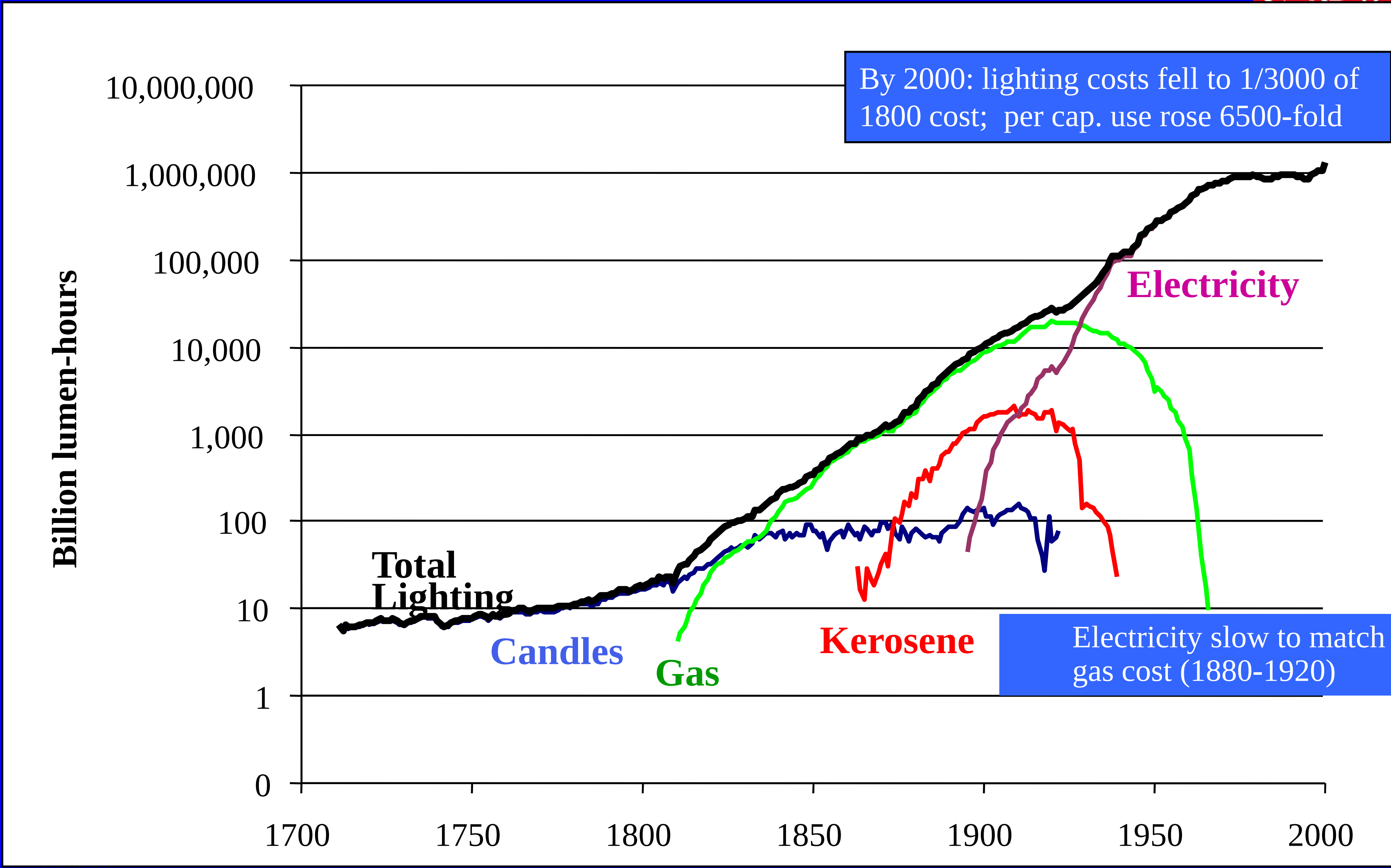
Fig. 12. UK Energy Service Transitions: Lighting – use of Candles, Gas, Kerosene & Electricity (1700-2000)



Source: authors' own estimates – see Sections II.2 and II.3

Billion: 10^9 (i.e. one thousand million)

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Energy Service Indices

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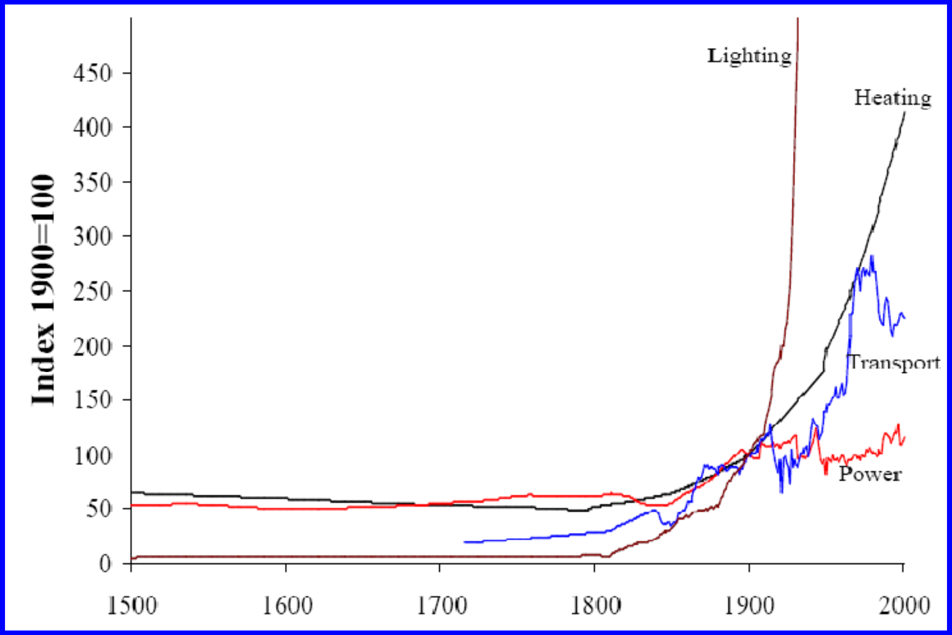
Fig. 13a. Efficiency of UK energy technologies, 1500-2000 (index: 1900=100)



Fouquet & Pearson (2007), IAEE conference, Wellington

Fig. 13b. Cost of consumer energy services, 1500-2000

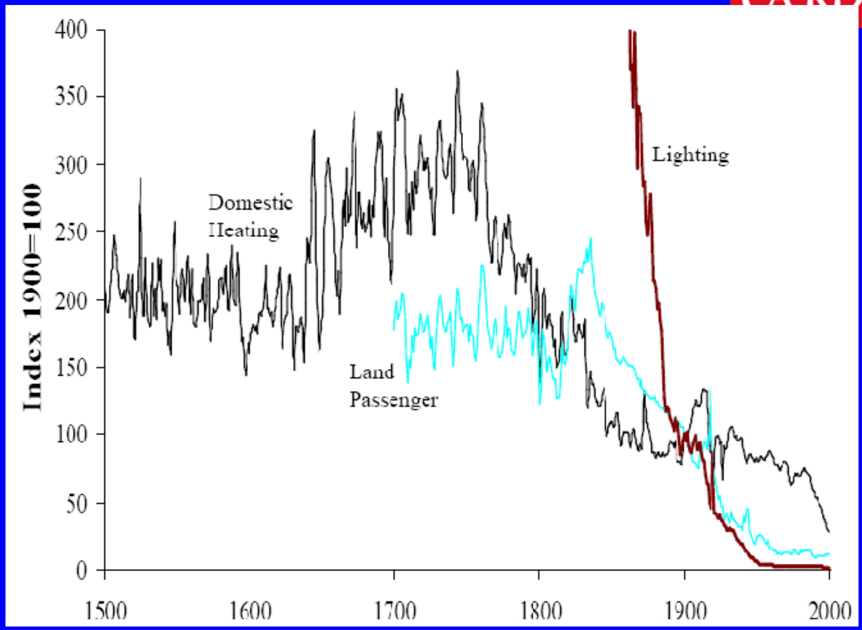
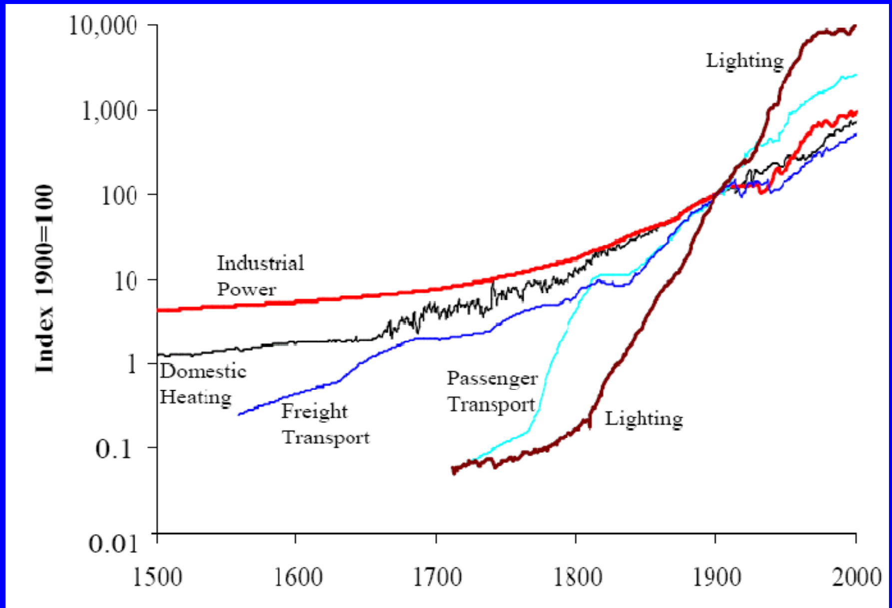


Fig. 13c. Energy services consumed, 1500-2000



'Industrial' includes all sectors except for the domestic sector

- Substantial rises also in efficiency & use for industrial power, transport & heat

See also: Fouquet (2008), *Heat, Power and Light*, E. Elgar

Long-Run Perspective on Energy System Transitions

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- Energy systems are complex evolutionary entities, so transitions mean interactions between
  - Fuels & energy converting technologies
  - Infrastructures (transport networks, pipes & wires…)
  - Institutions (markets, companies, finance…)
  - Policy regimes (institutions, bureaux, regulations…)
  - Economic variables (prices, income/output…)
  - Environment & resources
  - And people…

A Long-Run Perspective on UK Transitions

- New technology diffusion **took time**
  - Major productivity fx. of steam engines, locomotives & ships only observable after 1850 (Crafts…)
  - Few steam-intensive industries
    - 1800-1900: mining, textiles & metal manufactures accounted for >50% industrial steam power
- Not just steam: electric light slow to dominate gas (40 years: 1880-1920)
- Energy system inertia
  - First mover advantage & path dependence?
    - Mining & textile industries 1st with steam but slow with electricity in 2nd C19 Industrial Revolution
    - Relative to chemicals & engineering, shipbuilding & vehicles

Fig.14: Turning over the Capital Stock takes Time…

- Thompson's Atmospheric Beam Engine
  - Ran for 127 years (1791-1918) in coal mines

- B & W Bell Crank Engine
  - ran 120 years (1810-1930)

Some Lessons from UK Energy Transitions

- Transitions can have profound effects on economy, welfare & environment
- But Allen identified a combination of relative prices plus supply of cheap energy resources (coal) and physical, human & financial inputs as key conditions underlying the 1st industrial revolution
- But took multiple decades for measurable growth effects of steam power to appear
- Evidence shows government **can** make a difference
- But past transitions weren't managed
- Modern transitions *could* be **faster** – but still takes time
  - To build new enthusiasm, infrastructure & institutions
  - To escape the shackles of path dependence
  - Overcome 'lock-in' & turn over old capital stock

Challenges of Low Carbon Transitions

1. How to develop low carbon technologies & practices – what features should they have?
2. Adoption of these technologies & practices – do we pay enough attention to interactions between new & incumbent technologies

- These two questions lead towards
  - Macro/Micro Inventions & GPTs
  - The Sailing Ship Effect (SSE)/ Last Gasp Effect (LGE)
  - The issue of pre-conditions, such as those identified by Allen in his analysis of why the 1st industrial revolution happened in Britain
  - And the question, does the next industrial revolution have to happen in Britain

The Future for Low Carbon Energy Systems?

- Two previous UK Industrial Revolutions were about manufacturing
  - C18 revolution driven by textiles, iron & steam
  - end C19 2nd revolution: electricity, chemicals, petroleum & mass production
- Improved technology (e.g. energy & ICT), *might* help break link between energy services, fuel demands & CO2 emissions
  - Energy & ICT e.g. in smart grids) as *General Purpose Technologies*
  - *Could* enhance macro-level productivity
- A third and low carbon 'Industrial Revolution'?
  - But could be expensive & take time'
  - Remember, very few people enjoyed the fruits of the first Industrial Revolution until it was nearly over (Joel Mokyr')'

General Purpose Technologies

- Three key features:
  - *Pervasiveness:* have a broad range of general applications/purposes
  - *Technological Dynamism:* continuous innovation in the technology - costs fall/quality rises
  - *Innovational Complementarities:* innovation in application sectors – users improve own technologies, find new uses
- The penetration of a GPT in an economy involves a long acclimatization phase
  - In which other technologies, forms of organization, institutions & consumption patterns adapt to the new GPT
- Steam engines, ICE, electrification & ICT often given as examples
  - raised productivity growth - but took decades

Two Reviews: (i) Castaldi & Nuvolari (2003)

- Reviews GPT by applying it to 19th century steam power development
- Economic impact of stationary steam technology not significant until mid-19th century
- The GPT model has some limitations.
  - Doesn't capture the "local" aspect of accumulation of technological knowledge
  - Doesn't take into account the interdependency among different technological trajectories (because it focuses on one particular technology as opposed to "constellations of major technical innovations").

Two Reviews: (ii) Edquist and Henrekson (2006)

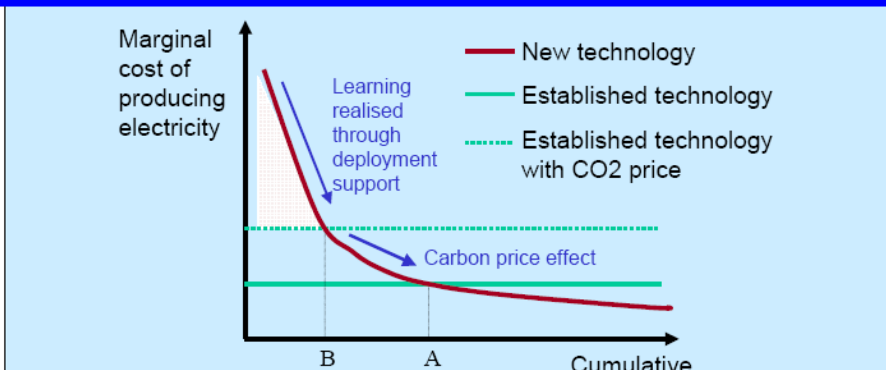
- Explore the impact of the steam engine, electrification & ICT – on productivity growth
- Finds that major technological breakthroughs do affect aggregate productivity growth
  - but slowly: 140 years for the steam engine, 40-50 years for electrification & ICT
- Each technological breakthrough offers a different lesson
- There is a complex interdependence between different technologies
  - ICT presupposed an extensive electricity network
  - Steam was used as a primary source for producing electricity.

The hypothesis of the *Sailing Ship Effect*

- Hypothesis: the advent of a competing new technology may stimulate innovation in an incumbent technology
  - for *some* mature technologies, in *some* circumstances
- This ‘Sailing Ship effect’/ ‘Last Gasp Effect’ makes the incumbent technology more efficient & competitive
- Before being ultimately superseded by the successor technology
- Cited SSE/LGE examples include:
  - Improvements in sailing ships after the late C19 introduction of the steam ship
  - The response of gas lighting, via the Welsbach incandescent mantle, to the 1880s arrival of the incandescent lamp and Jablochkoff candle
  - The response of carburettors to the introduction of electronic fuel ignition in the 1980s (Snow)

Figure 15: Experience Curves & Financing Learning

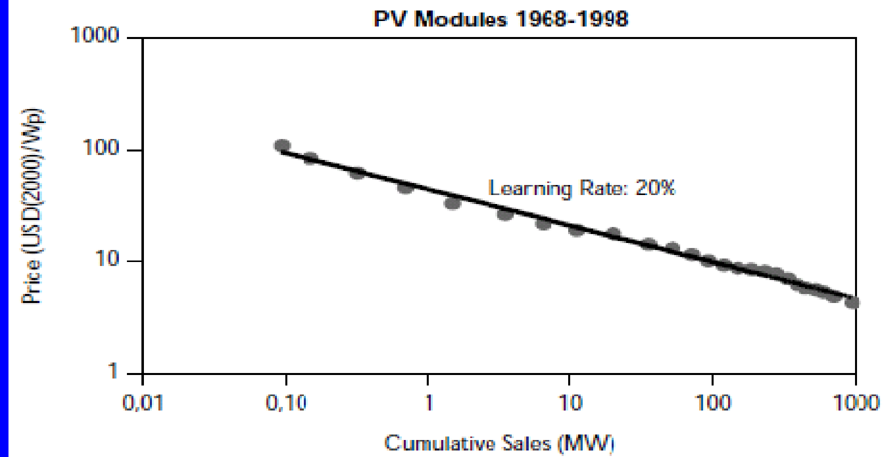
Stern Review



Source: Stern Review, Figure 16.6

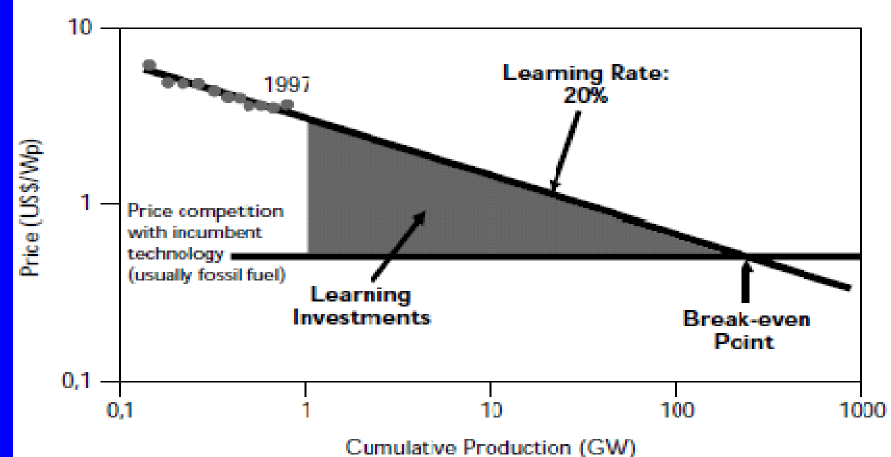
PV Modules

Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

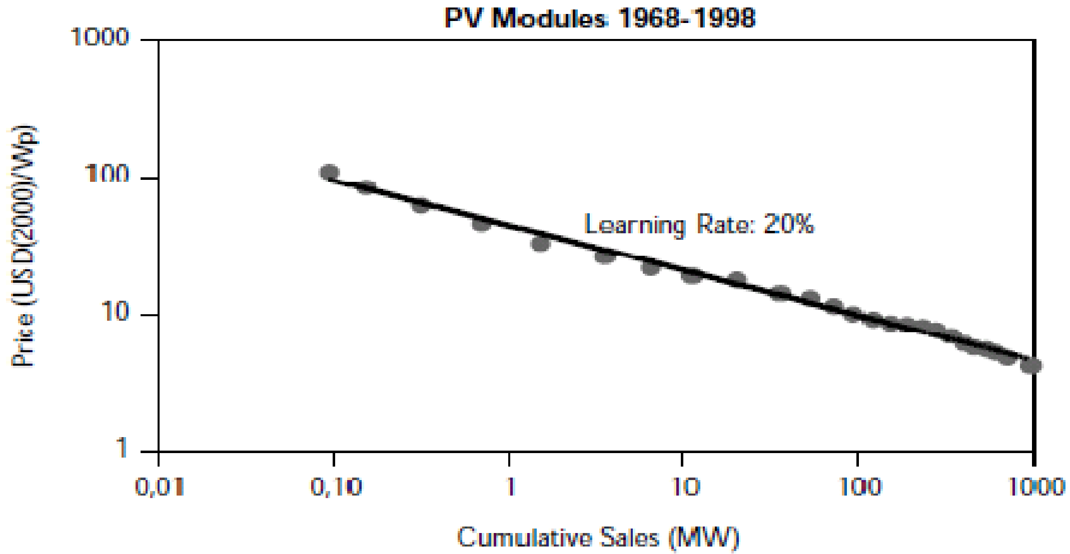
Figure 3.4. Making Photovoltaics Break Even



Source: OECD/IEA(2000).

Fig.16 SSE/ Last Gasp Effects?

Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

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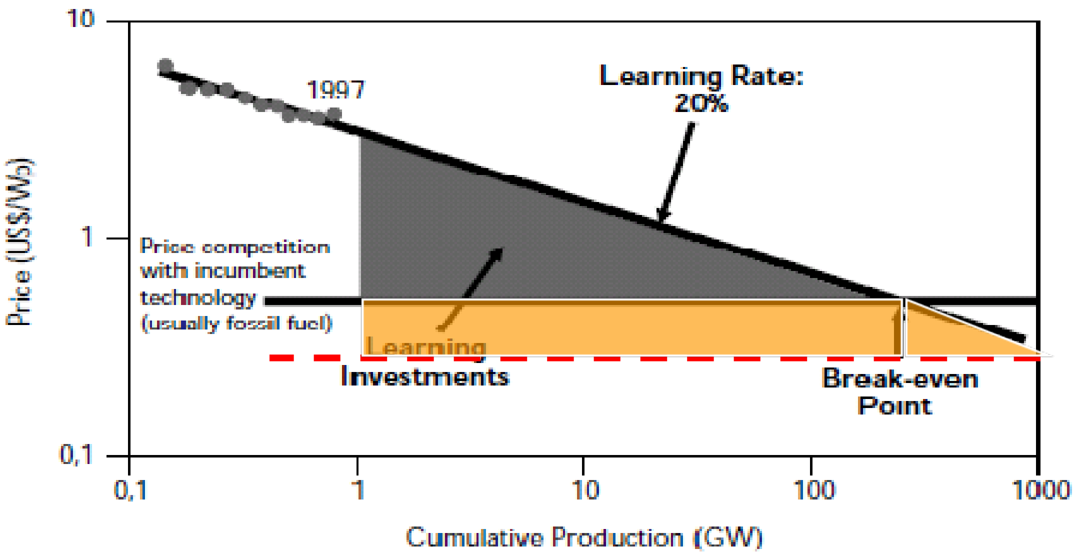

Source: OECD/IEA(2000).

- ❑But what if the incumbent's experience curve shifts downwards?
- ❑Through SSE/LGE and/or fossil fuel prices?
- ❑Bigger learning investment needed

Potential Significance of the SSE Hypothesis for Lower Carbon Transitions & Policy

- Significantly increased (price/quality) competitiveness of incumbents, through SSEs & fossil fuel price shifts, could :
  - Slow newcomers' sales
  - Delay their travel down experience curves
  - As they chase incumbents' shifting experience curves
  - Slowing the transition by restraining penetration rates (McVeigh et al.)
  - And raising policy costs via higher subsidies needed for competitive penetration
  - While forecasts that don't allow for SSEs could overestimate penetration
- So, appreciating SSEs/Last Gasps matters, where there are mature technologies and we seek radical innovation
- And suggests giving proper attention to dynamic interactions between new and incumbent technologies

A Third, Low-Carbon ‘Industrial Revolution’?

- Getting there from here
  - Means more than substituting a few low carbon technologies into *existing* uses & institutions
- Low carbon technologies need capacity:
  - To be widely used & diffused
  - For continuous innovation & cost reduction
  - To change what we do with them & how
- Hence to be somewhat like General Purpose Technologies?
  - E.g. ICT & energy combinations (like smart grids)
  - But GPTs take time to develop
  - May be slowed by path dependence, lock-in and Sailing Ship/Last Gasp Effects
  - So we need to be aware of and respond to interactions between new & incumbent technologies
  - GPTs are contested – empirically & theoretically
- Relative prices & resources
  - If Allen’s (2009) messages about 1st industrial revolution hold for this revolution, where are the relative prices & physical, human & financial resources needed for risky innovation?
  - Role of carbon prices here?
- But does the low carbon revolution have to start in Britain?

Thank you!

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