Past and Prospective UK Energy Transitions: Insights from Historical Experience

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Lessons from Historical Experience of Energy Transitions

EPSRC/ E.ON funded *Transition Pathways to a Low Carbon Economy* Project Workshop

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Outline

- The first British Industrial Revolution
  - What happened & why it happened here
- Energy services & their contribution to economic welfare
- Prospects & problems of a third, low-carbon industrial revolution
  - General Purpose Technologies
  - The Sailing Ship Effect & interactions between incumbent & new technologies
- Four scoping studies, with insights from past managed transitions

A Long-Run Perspective on Energy System Transitions

- 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…

Research on Energy System Transitions

- 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/20th: data range/quality grows
  - Companies/local authorities
  - Official enquiries/ Parliamentary Papers
  - 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 mechanisation, urbanisation & Britain's first 'Industrial Revolution'

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

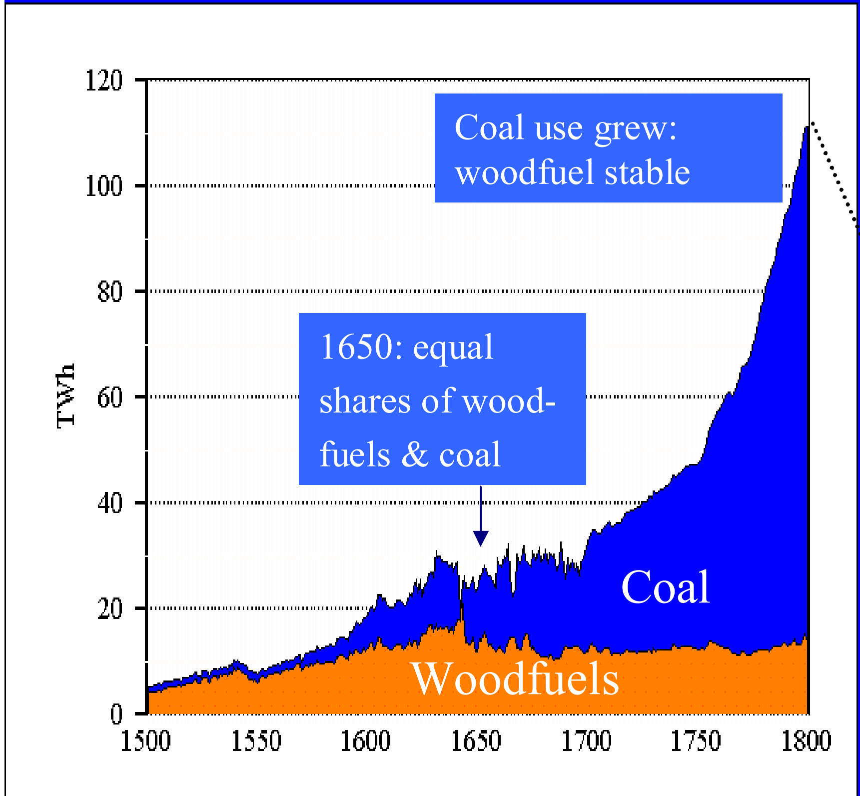
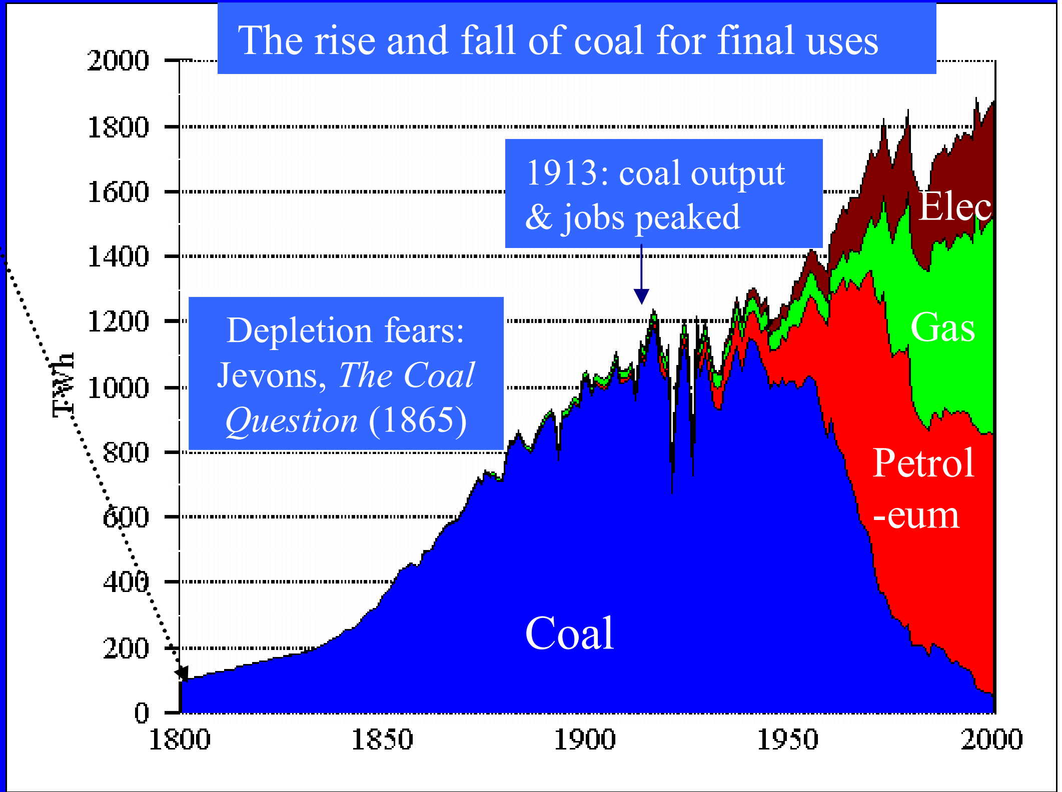


Fig. 1b: UK Final Energy Consumption, 1800-2000 (TWh)

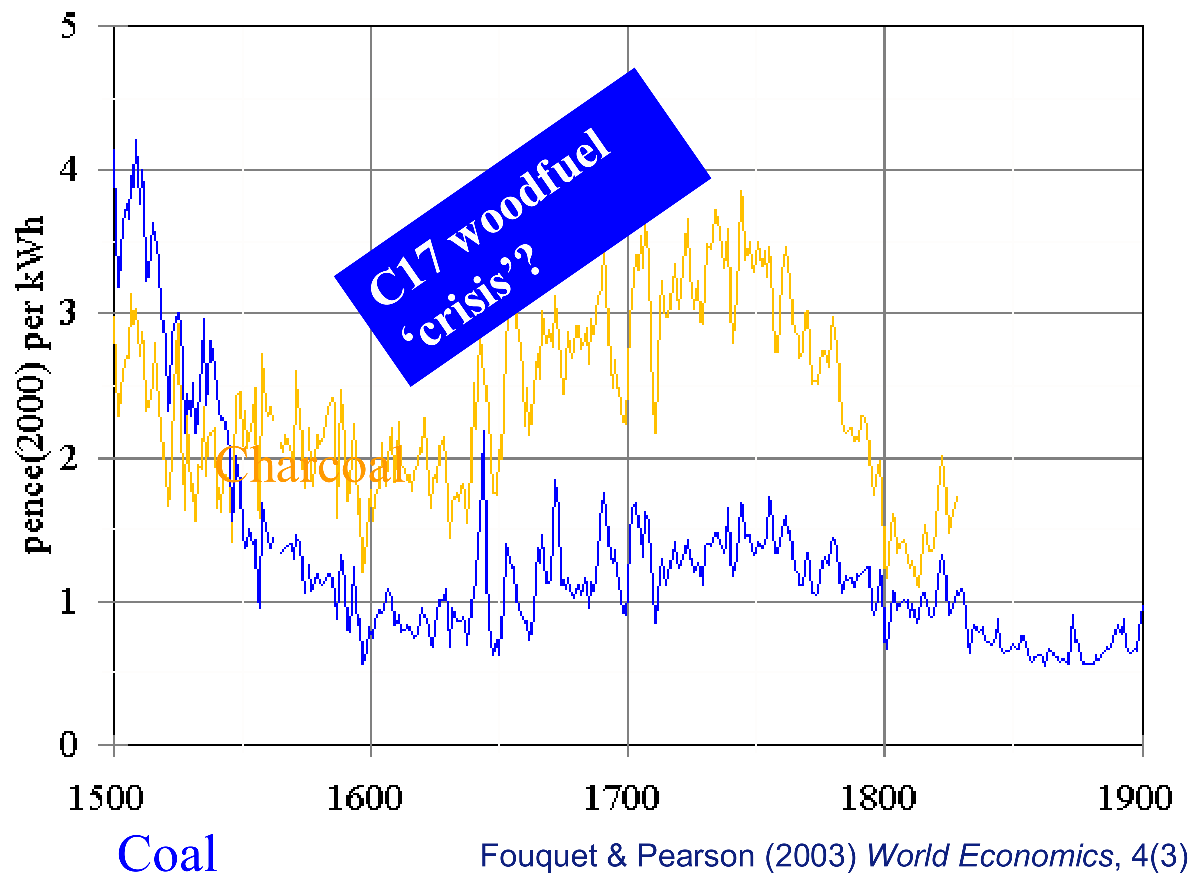


Fouquet & Pearson (2003) *World Economics*, 4(3)

- **Allen, 2009: why a *British* Industrial Revolution? Wages high relative to energy & capital costs, compared with other European & Asian countries, so that**
- **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)



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

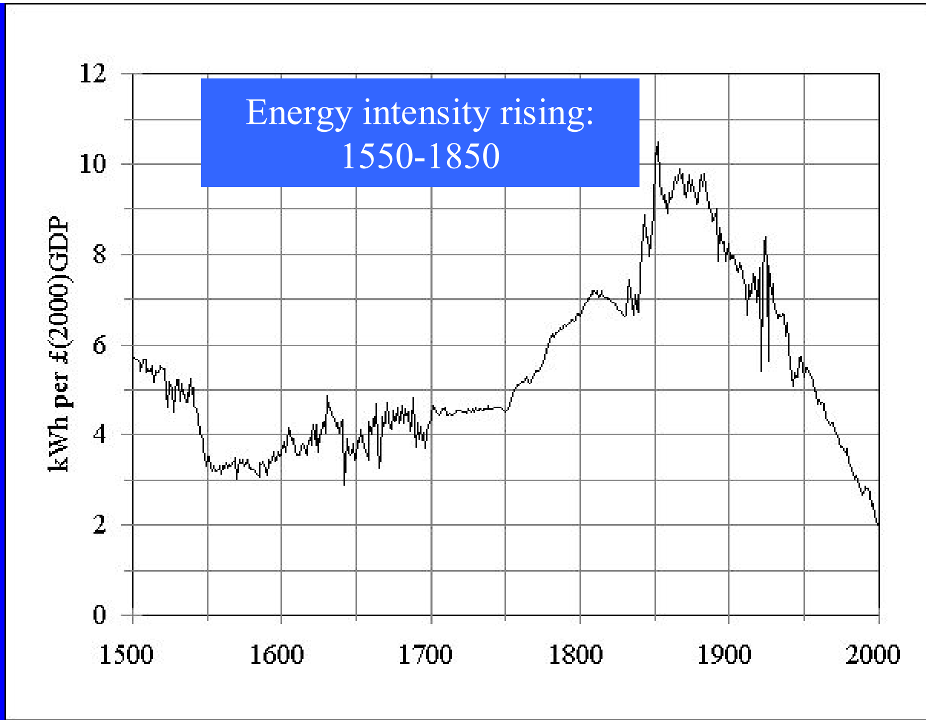
- Rising charcoal/ coal price differential around 1650-1750 encouraged coal use
- Along with innovations in domestic & other uses of coal

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

Fig. 3: Energy intensity & prices

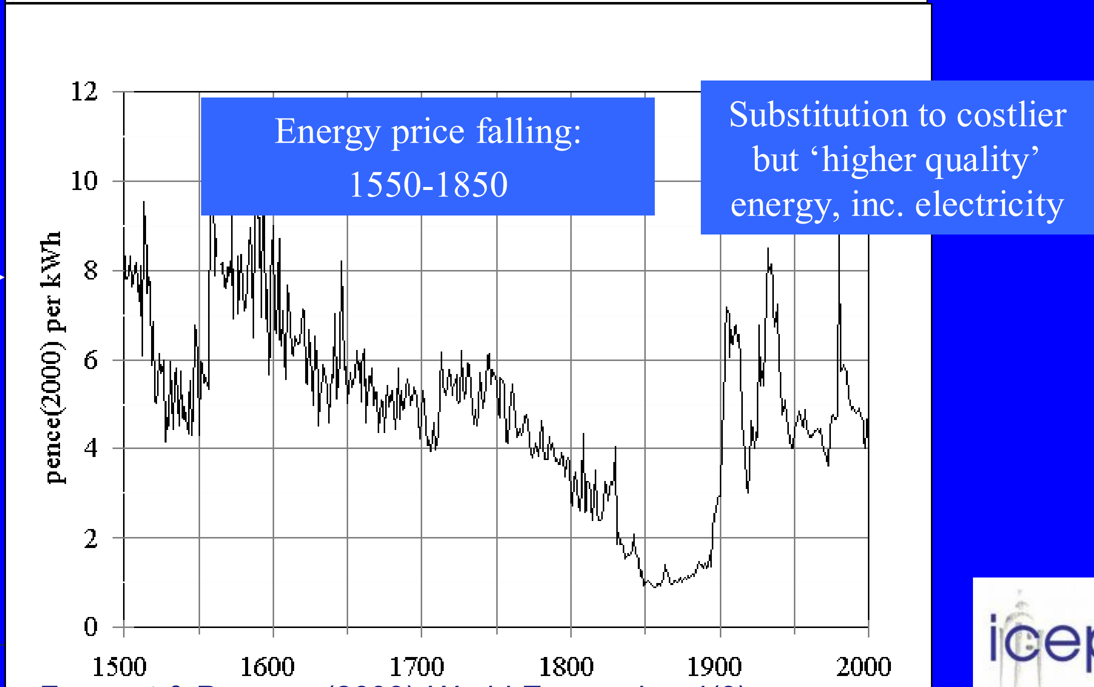
Inverse relationship between:

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

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- 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) & others: rotary steam power, engines smaller & now drove machines
- By 1805: gas lighting in cotton mills (safer, cheaper; longer work day…)
- But only 2200 steam engines in mining & manufacturing by 1800

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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)

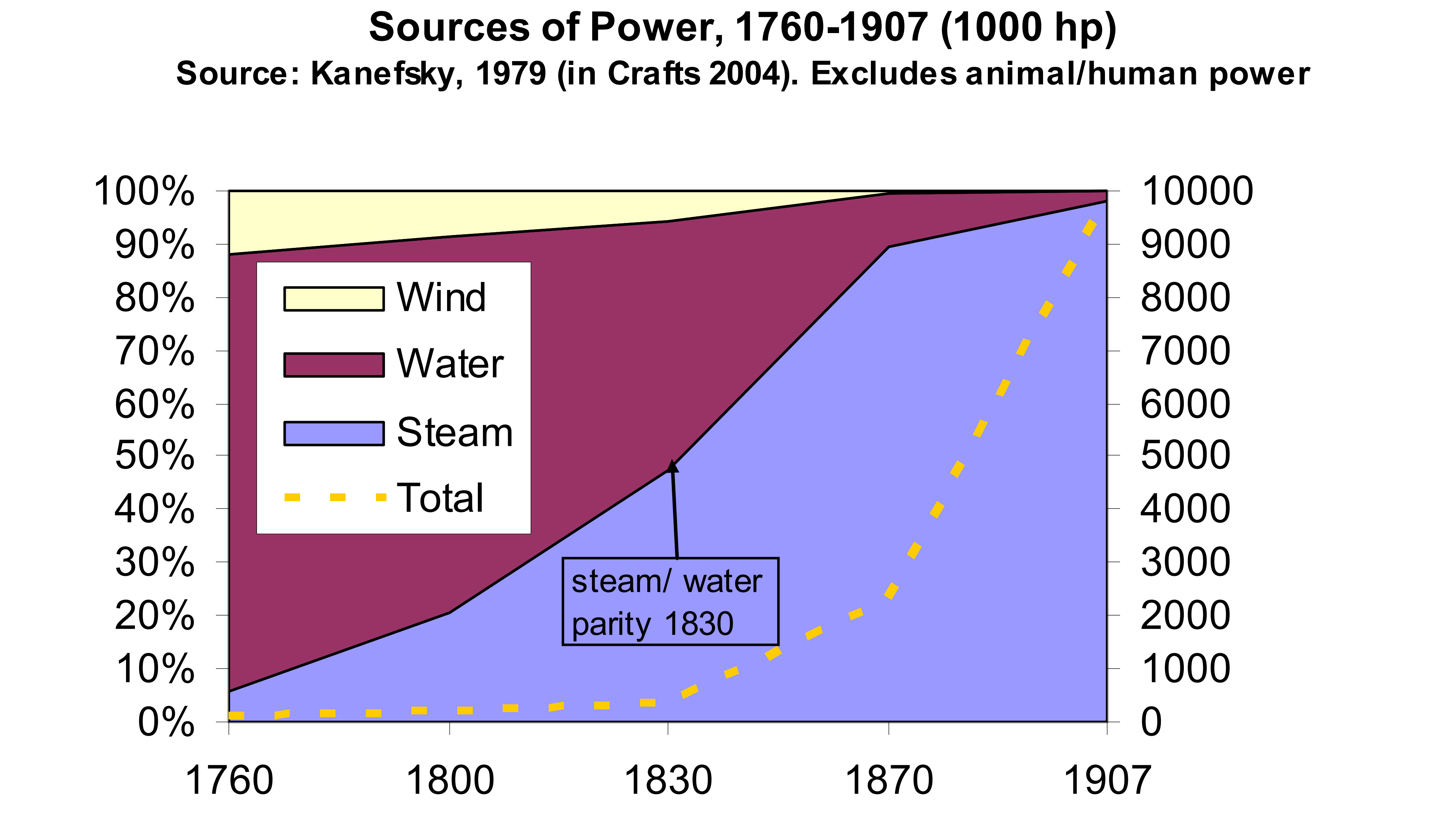
- Both in Science Museum, London

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); and 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 & marke[ts]

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

(L.h.s. axis: % shares) (R.h.s. axis: total: 1000 hp)



Why was the First 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)

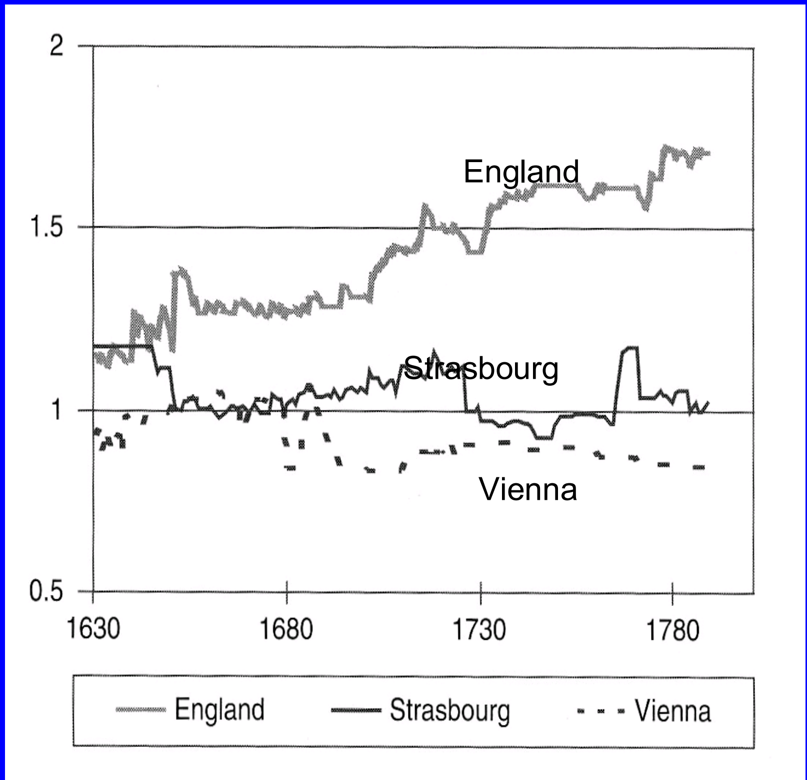


Figure 6.1 Wage relative to price of capital

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

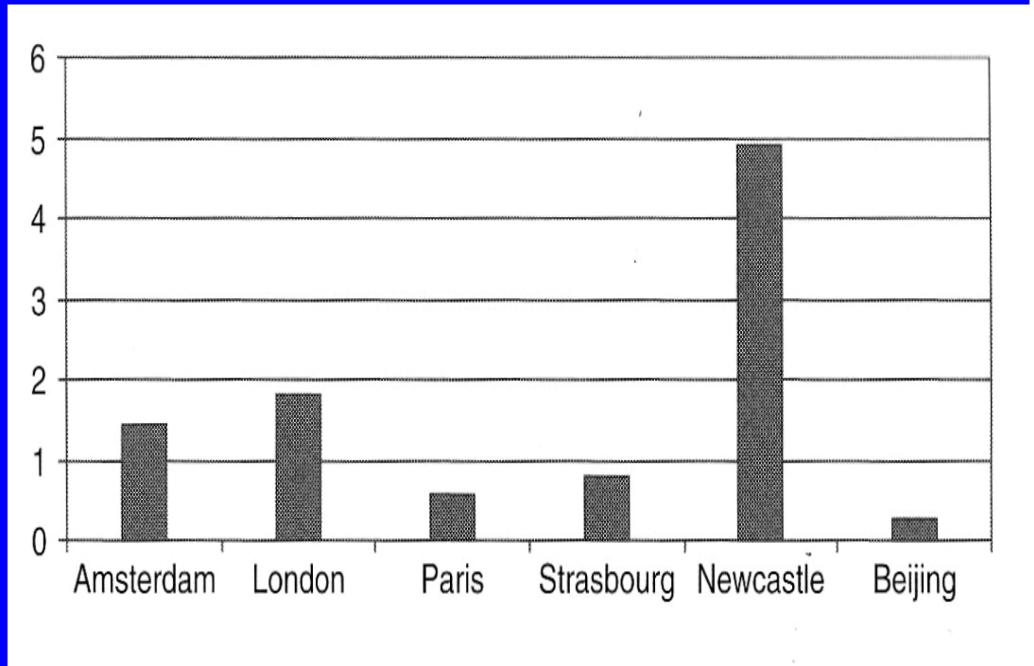


Figure 6.2 Price of labour relative to energy, early 1700s

Strong incentive to substitute fuel for labour in Britain (building wage rate/ 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 => rising demand for literacy & numeracy skills & gave parents income to purchase them => supplied Britain with skills for the 'high-tech' revolution
- The innovations 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 now profitable to use in countries like France, with expensive energy, & India, with cheap labour

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

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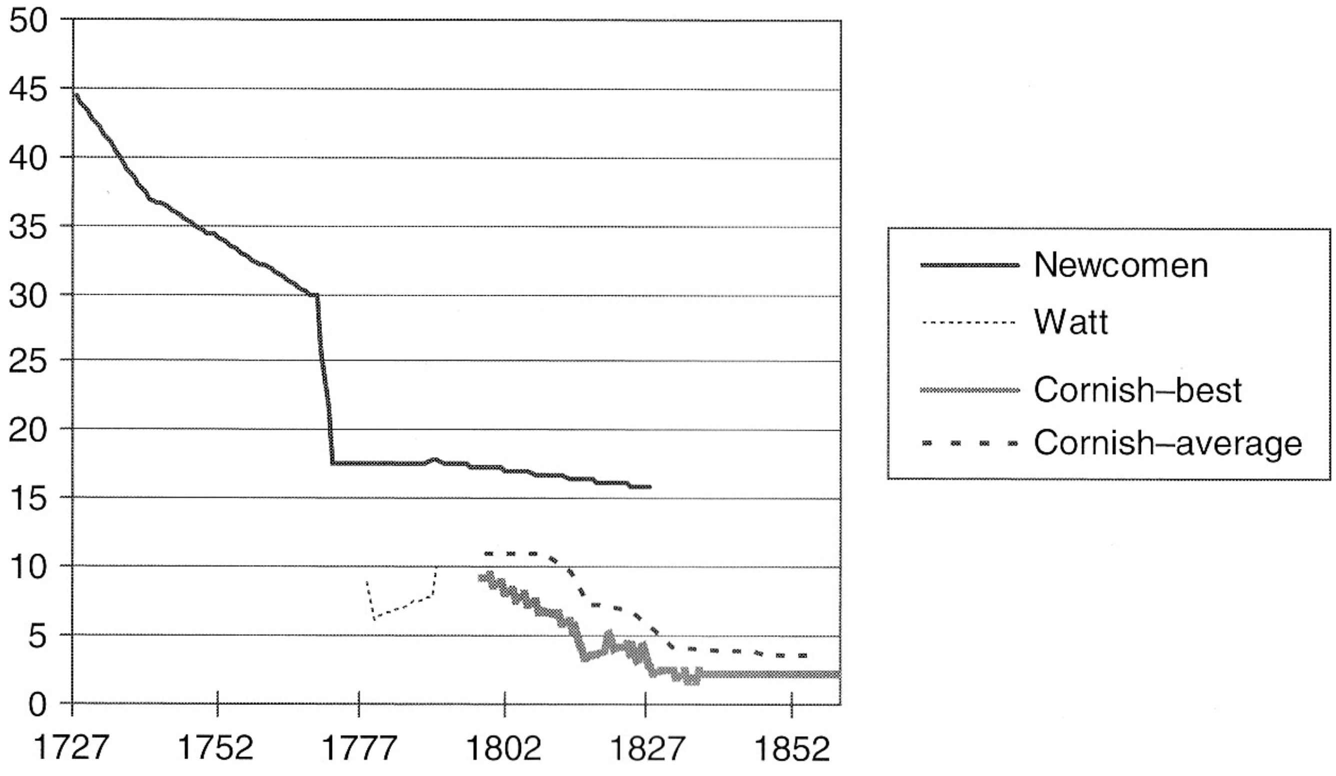

Figure 7.1 Coal consumption in pumping engines: pounds of coal per horsepower-hour

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

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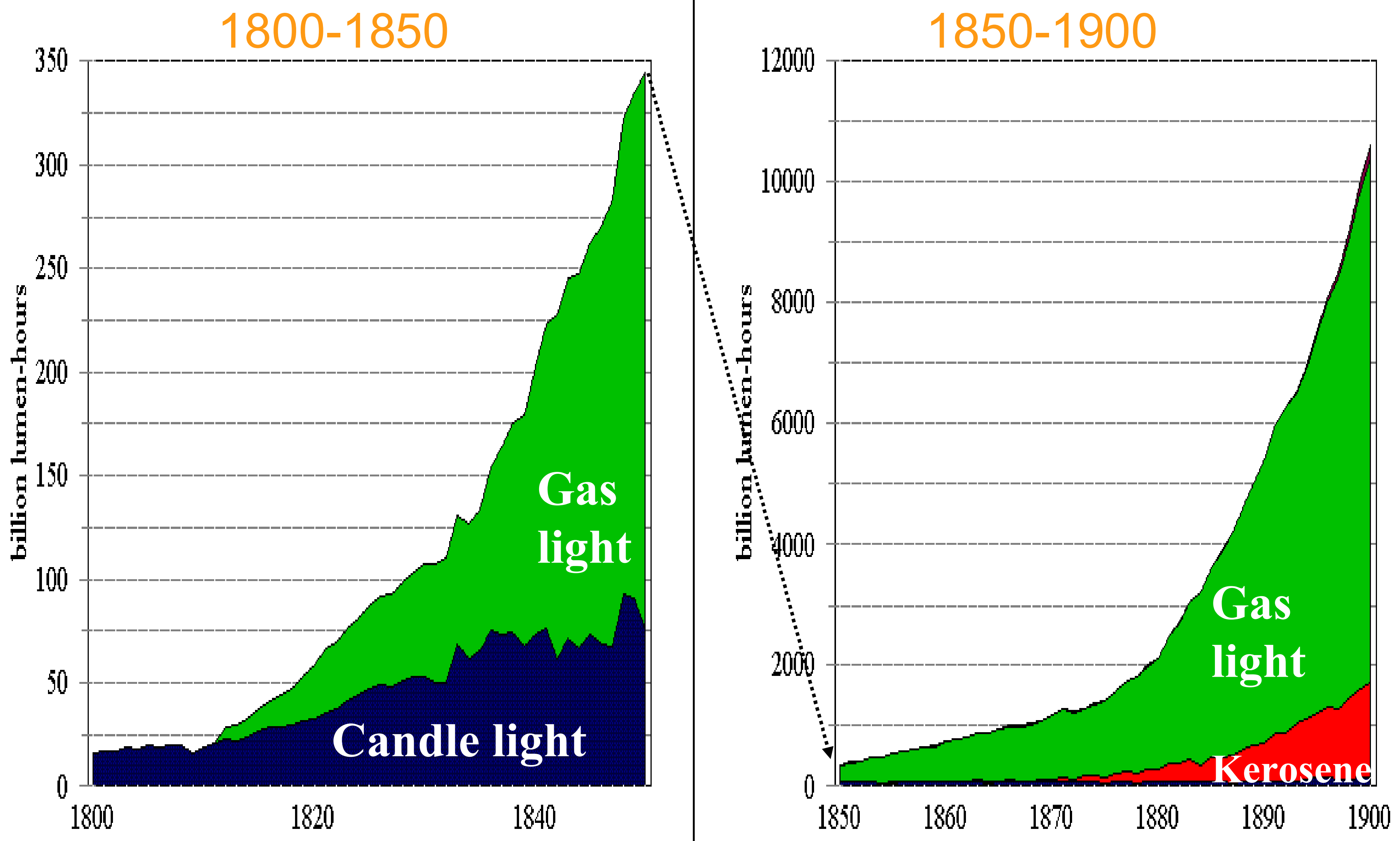
Energy Services: UK lighting experience

- 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)

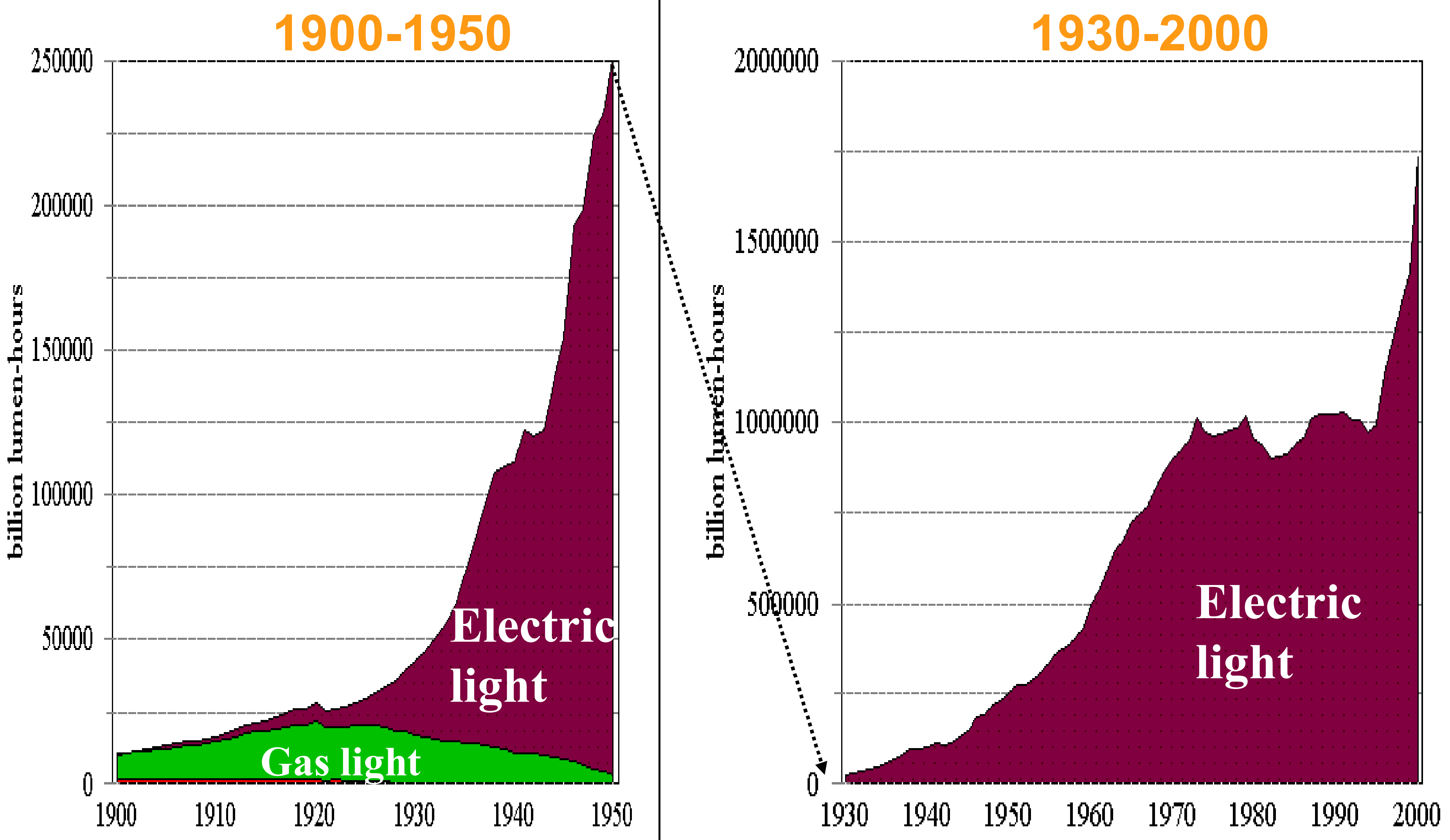


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Fig.10. UK Cost of Lighting from Gas, Kerosene & Electricity (£ per million lumen hours, 1800 2000)

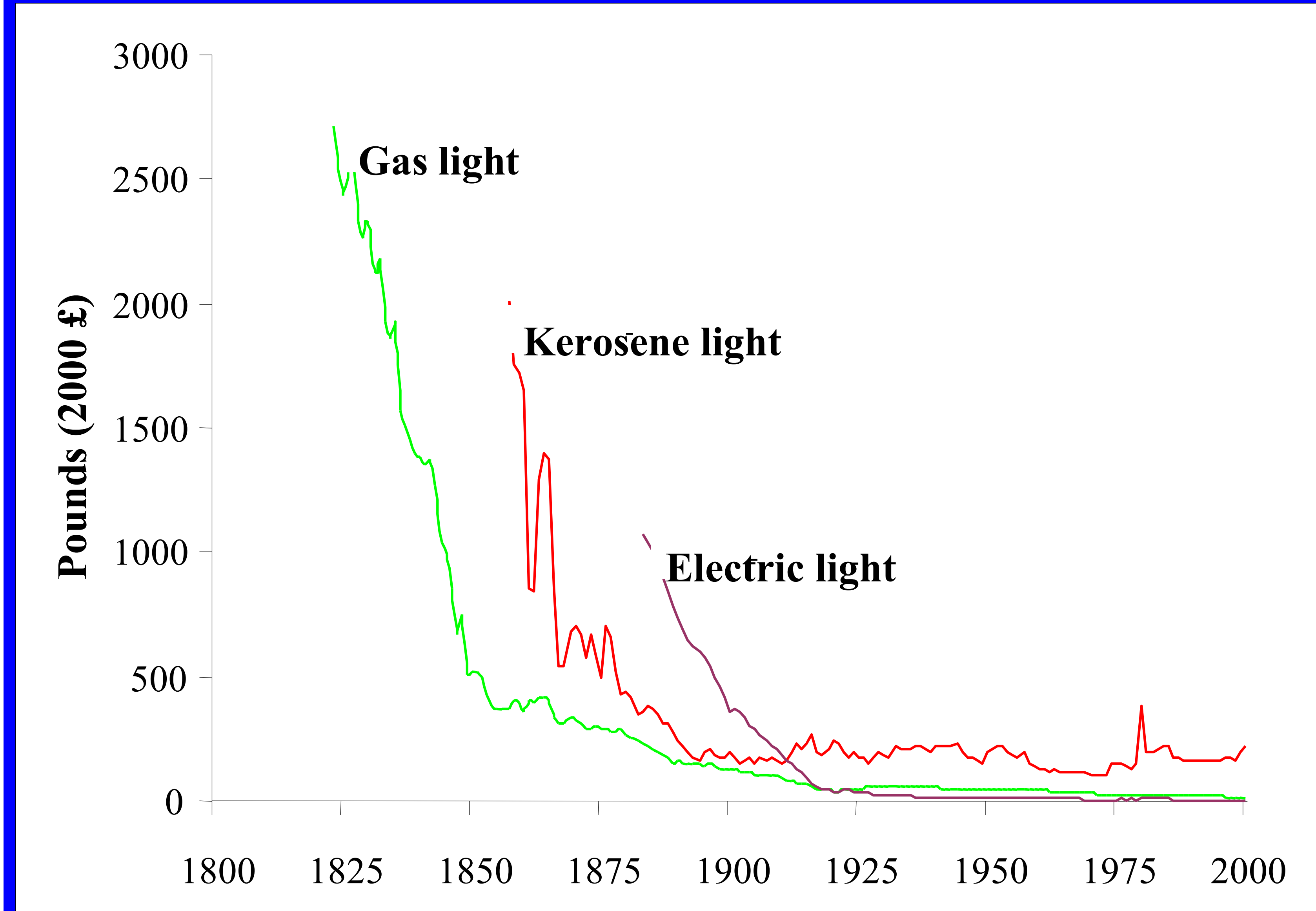

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Fig. 11. UK Price Ratio of Lighting from Competing Energy Sources, 1820-1950

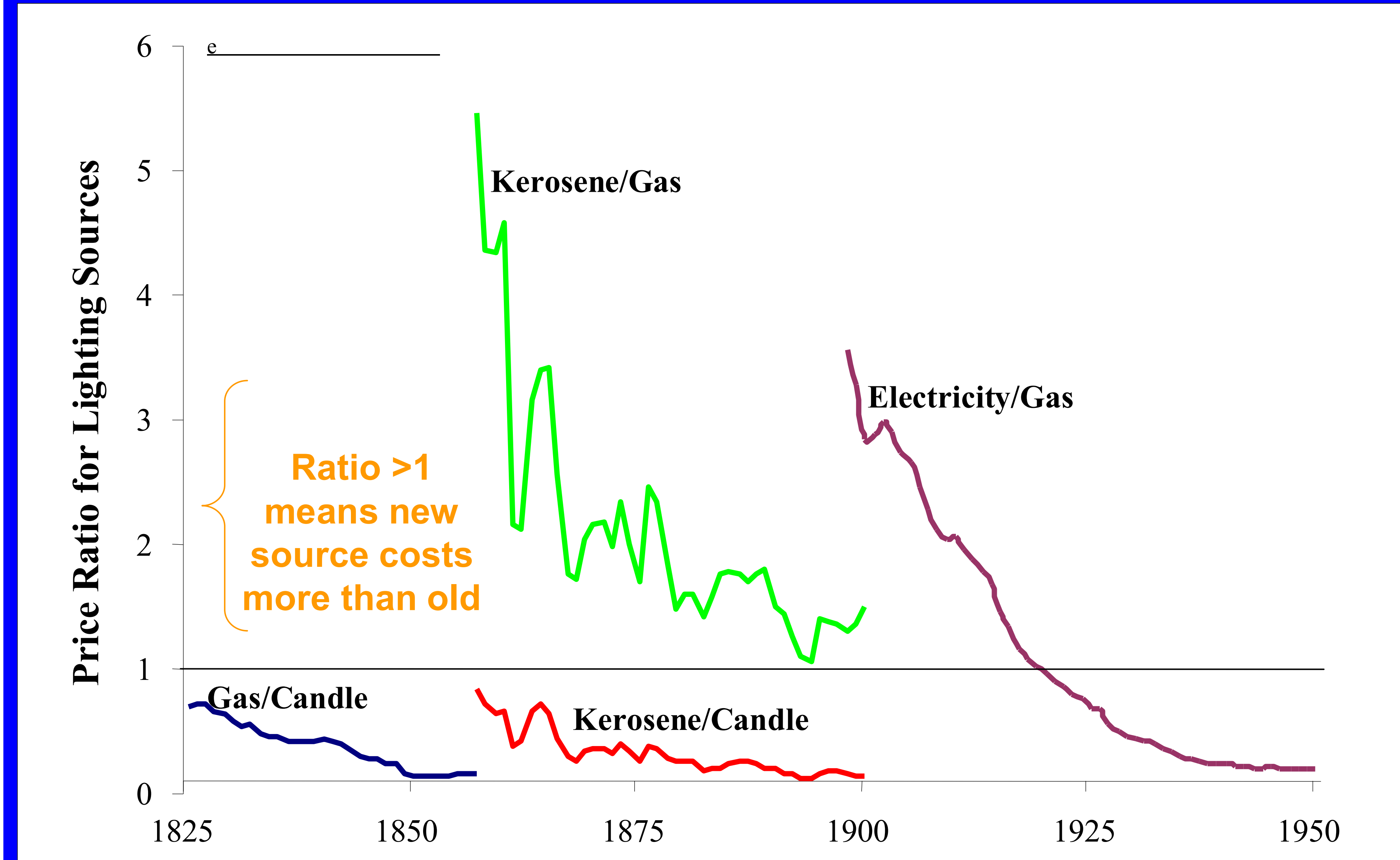

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Fig. 12. UK Energy Service Transitions: Lighting – use of Candles, Gas, Kerosene & Electricity (1700-2000)

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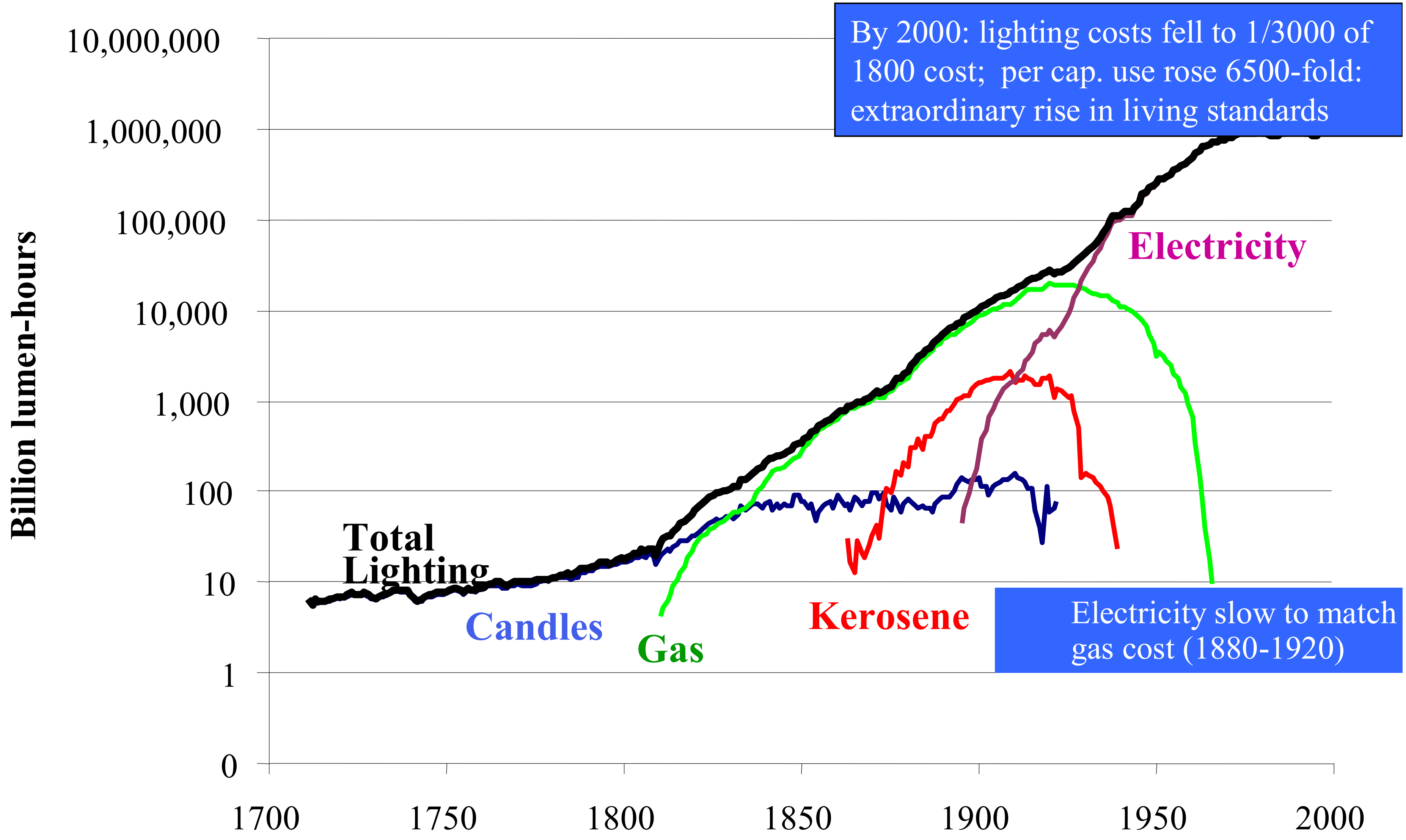
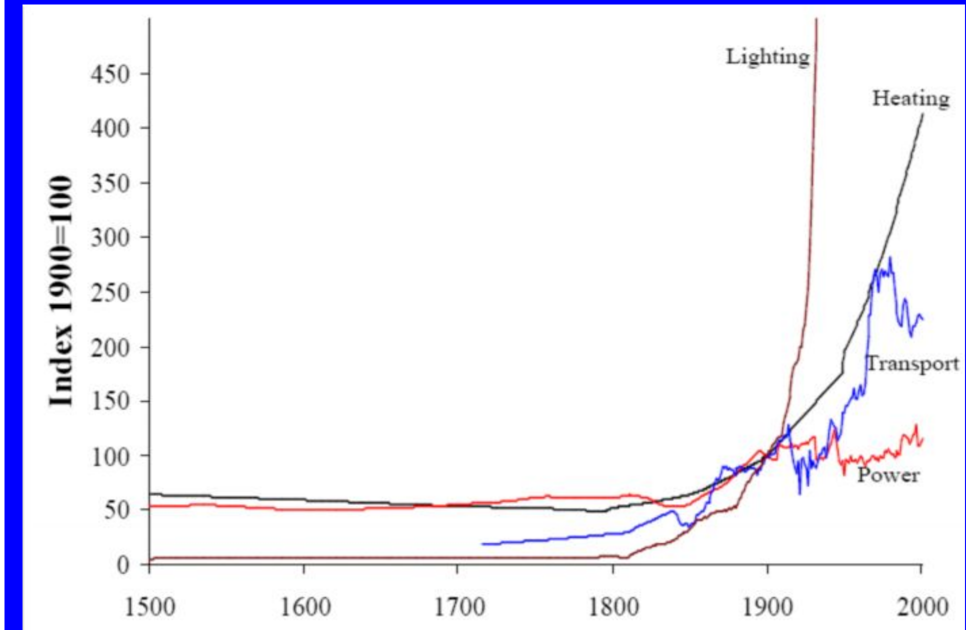


Source: authors' own estimates – see Sections II.2 and II.3 Billion: 10^9 (i.e. one thousand million)

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

Energy Service Indices

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

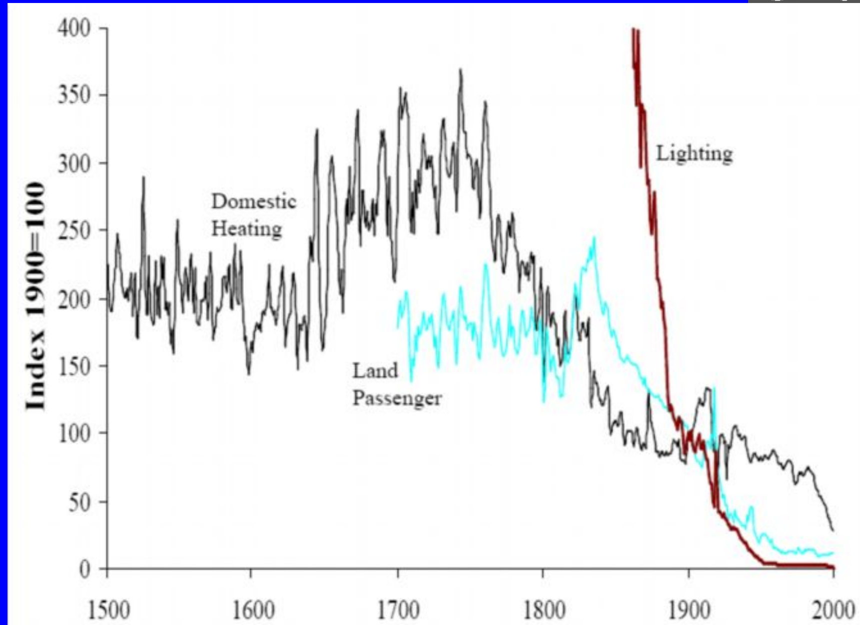
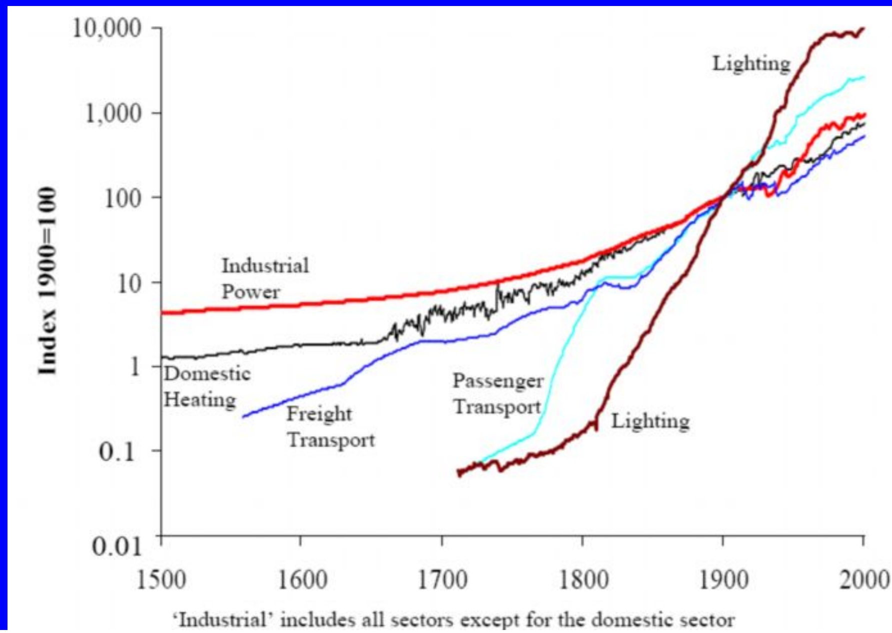


Fig. 13c. Energy services consumed, 1500-2000



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

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

A Long-Run Perspective on UK Transitions

- Transitions can yield remarkable improvements in welfare
- But 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 were first 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)

Challenges of Low Carbon Transitions

1. How to develop low carbon technologies & practices
   - What features should they have?
   - What lessons/ insights might we glean from past transitions?
2. Adoption of these technologies & practices
   - How do we get there from here?
   - Do we pay enough attention to interactions between new & incumbent technologies?

These questions lead towards

- The Sailing Ship Effect (SSE)/ Last Gasp Effect (LGE)
- Macro/Micro Inventions (Allen) & GPTs
- The issue of pre-conditions, such as those identified by Allen in his analysis of why the 1st industrial revolution happened in Britain

Some Lessons from UK Energy Transitions

- Transitions can have profound effects on economy, welfare & environment
- But Allen identified the combination of relative prices plus cheap energy resources (coal) & 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
- 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
- And although evidence shows government **can** make a difference
- Most past transitions weren't managed

The Future for Low Carbon Energy Systems?

- The first two 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' (Mokyr)

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:
  - Late C19 improvements in sailing ships after the arrival of the steam ship
  - The response of gas lighting in the 1880s, via the Welsbach incandescent mantle, to the arrival of the incandescent lamp and earlier arc lamps
  - The response of carburettors in the 1980s to the introduction of electronic fuel ignition (Snow)
- But the SSE is a contested and sometimes fuzzy concept

Figure 15: Experience Curves & Financing Learning

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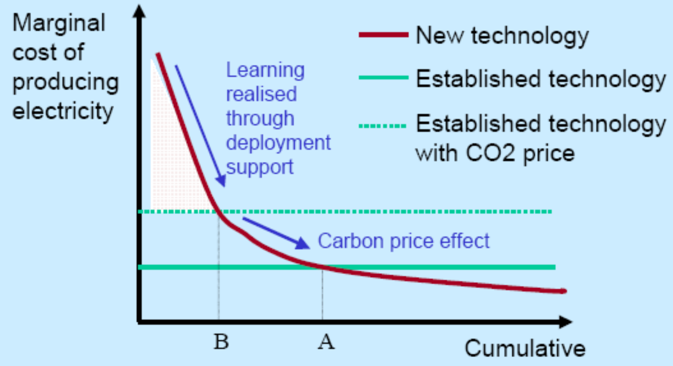
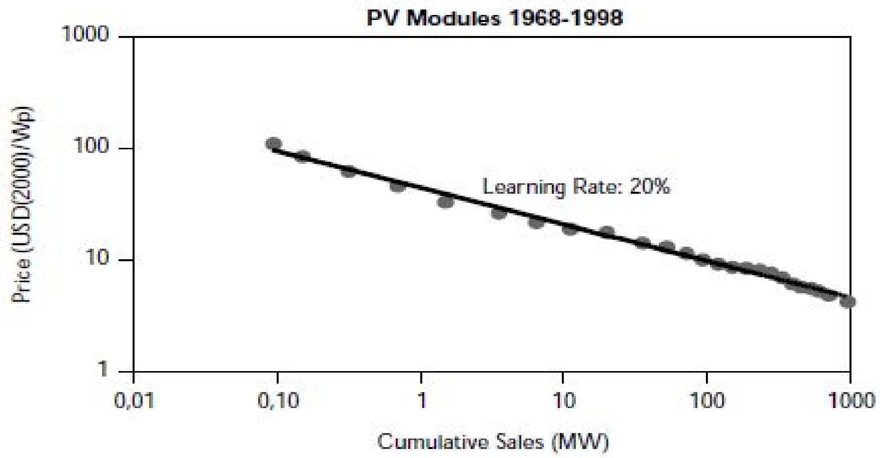
Stern Review



Source: Stern Review, Figure 16.6

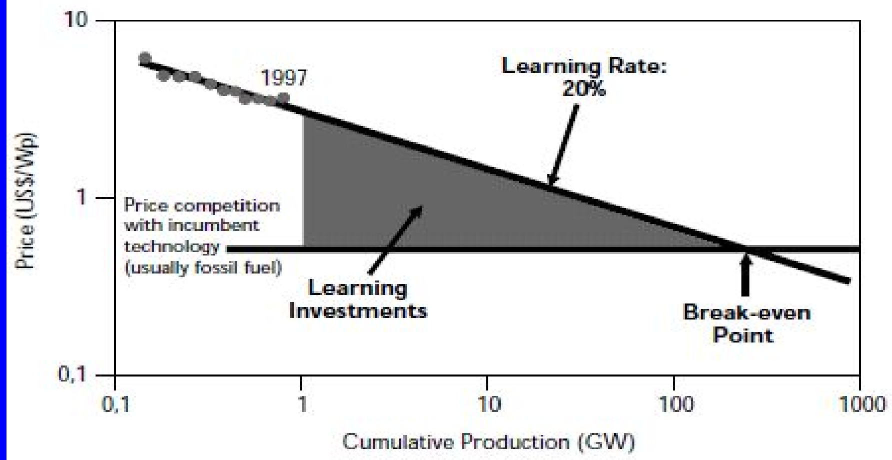
PV Modules

Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

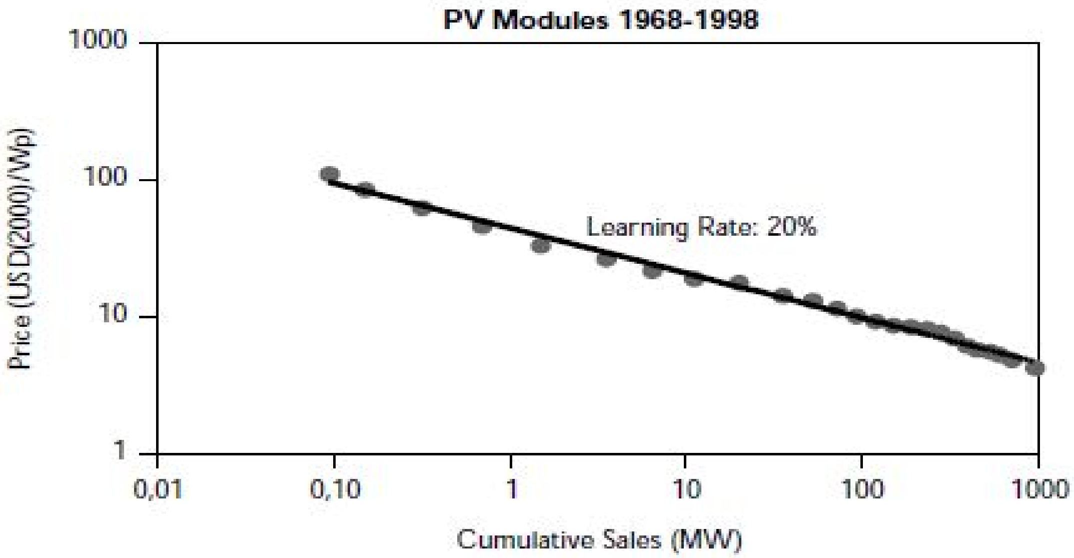
Figure 3.4. Making Photovoltaics Break Even



Source: OECD/IEA(2000).

Fig.16 SSE/ Last Gasp Effects?

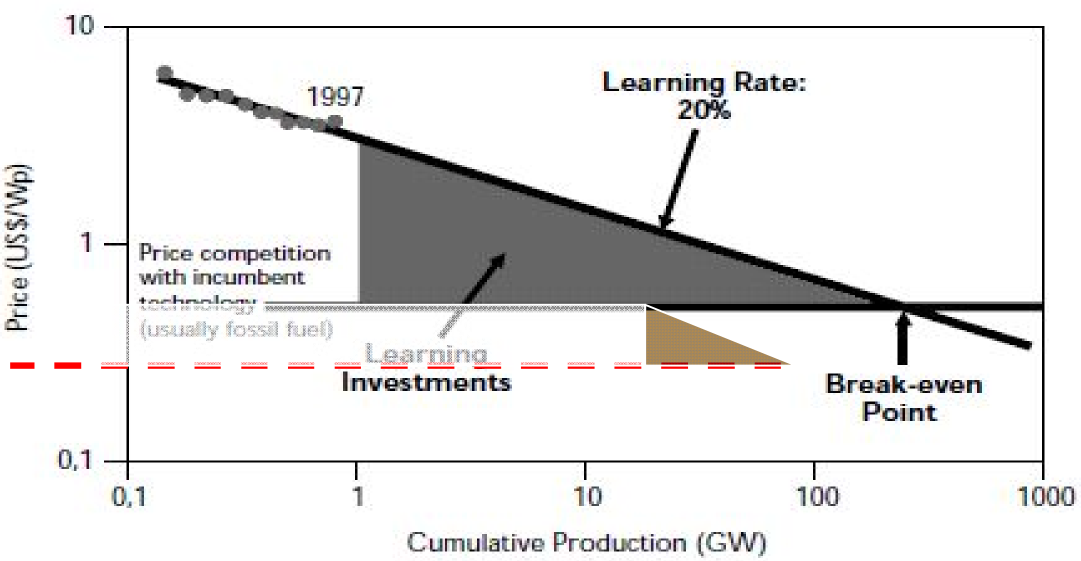
Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

- •But what if the incumbent's experience curve shifts downwards (orange shading added)?
- •Through SSE/LGE and/or fossil fuel prices?
- •Bigger learning investment needed

Figure 3.4. Making Photovoltaics Break Even



Source: OECD/IEA(2000).

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 & so delay their travel down experience curves
  - As they chase incumbents' shifting experience curves
  - Slowing the transition by restraining penetration rates (McVeigh et al.)
  - Raising policy costs via higher subsidies for competitive penetration
  - While forecasts that don't allow for SSEs could overestimate penetration
- So, appreciating SSEs/Last Gasps could matter, if there are mature technologies & we seek radical innovation
- Suggests giving proper attention to possible dynamic interactions between new & incumbent technologies

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 cited as examples

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 interdependence 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.

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 we know that GPTs take time to develop
  - May be slowed by path dependence, lock-in & Sailing Ship/Last Gasp Effects
  - So we need to be aware of & respond to interactions between new & incumbent technologies
  - And GPTs are contested – empirically & theoretically

A Low-Carbon 'Industrial Revolution'?

- 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?
- And does the low carbon revolution have to start in Britain? Other countries (China, India?) might be better placed
- But we *have* managed some past transitions

Some Examples of Managed Transitions

- UK
  - UK gas & electricity industries sought to shape & encourage energy uses & habits in C19 & C20
  - Petrol from ethanol (Distillers Co) & coal (Imperial Chemical Industries) in 1920s & 1930s
  - National Grid, 1930s
  - Nuclear plant development, post WWII
  - Scaling up electric power plant by CEGB & partners, 1960s
  - Transition from town gas to natural gas, 1960s
- Other countries
  - France: nuclear power, 1970s – post oil shocks
  - Brazil: Proalcool ethanol programme, 1970s – post oil shocks

Insights from Managed Transitions: Four Scoping Studies

In this workshop, we'll hear about four scoping research studies that explore four previous UK transitions and the insights they might offer for low carbon transitions

- The postulated responses of an incumbent energy industry, especially end-C19 gas lighting, to the threat of new competition, i.e. the Sailing Ship Effect (Suzanne Wallis)
- The scaling up & rolling out of electric power plant by CEGB & partners, 1960s (Paul Reynolds)
- The transition/conversion from town gas to natural gas, 1960s (Scott Laczay)
- How the UK gas & electricity industries sought to shape & encourage energy uses & habits in C19 & C20 (Maria Gradillas)

Thank you!

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