Insights & Questions from Past UK Energy Transitions

Peter Pearson
Low Carbon Research Institute (LCRI)
Cardiff University

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and Graduate Schools
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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…)
  - Social & cultural variables
  - Environment & resources
  - And people & human behaviour…

Background: Research on Energy System Transitions

- A history of research on developing country & past & future UK transitions, including
  - A long collaboration with Prof. Roger Fouquet (now C3B)
  - Our work has produced estimates of prices, consumption, expenditure for fuels, energy carriers & energy services, over several centuries
- Now engaged with the *Transition Pathways to a low Carbon Economy* consortium (EPSRC/E.ON funded)
  - http://www.lowcarbonpathways.org.uk/lowcarbon/
- – recent & forthcoming research & workshops on historical transitions:
- And a new UKERC CCS consortium exploring historical analogies

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

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

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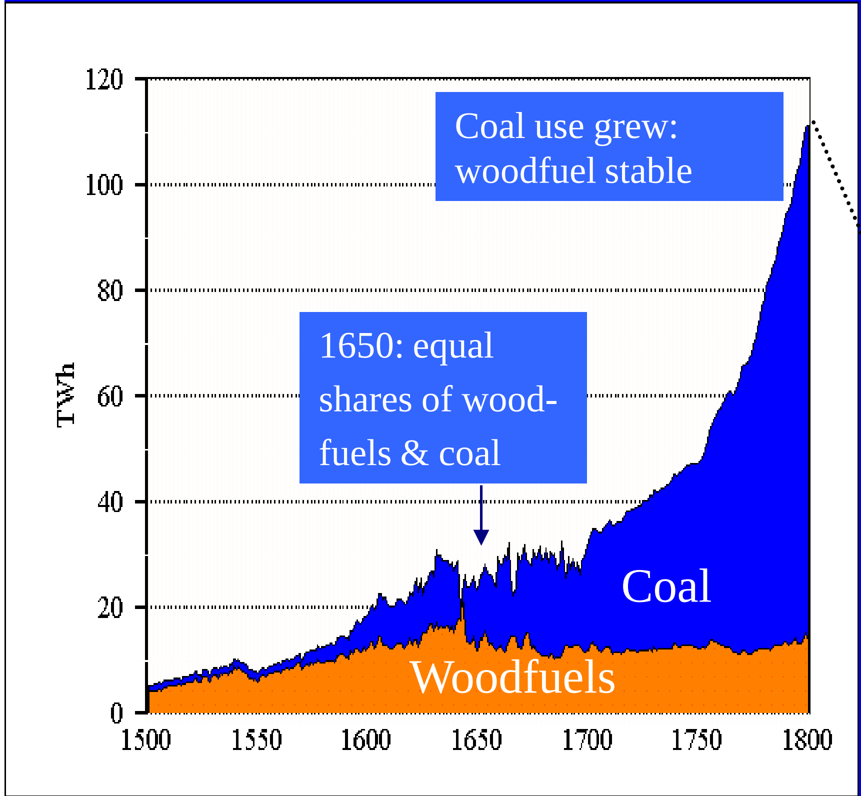
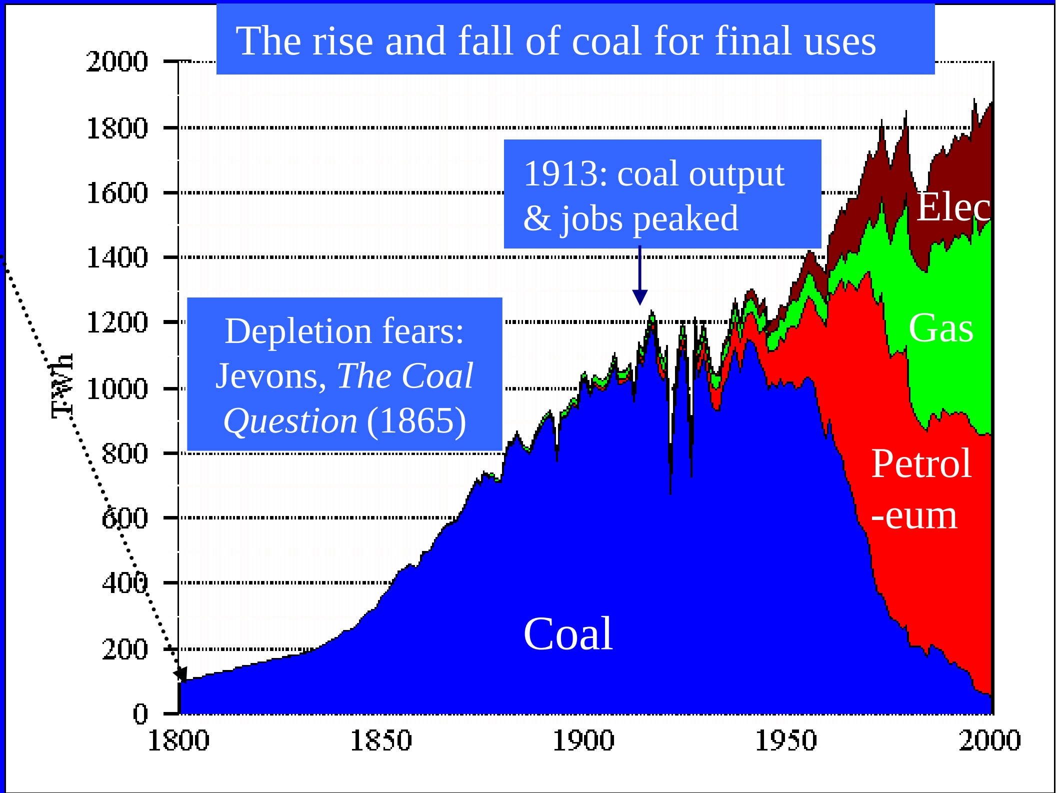
Fig.1a: UK Final Energy Consumption, 1500-1800 (TWh)

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

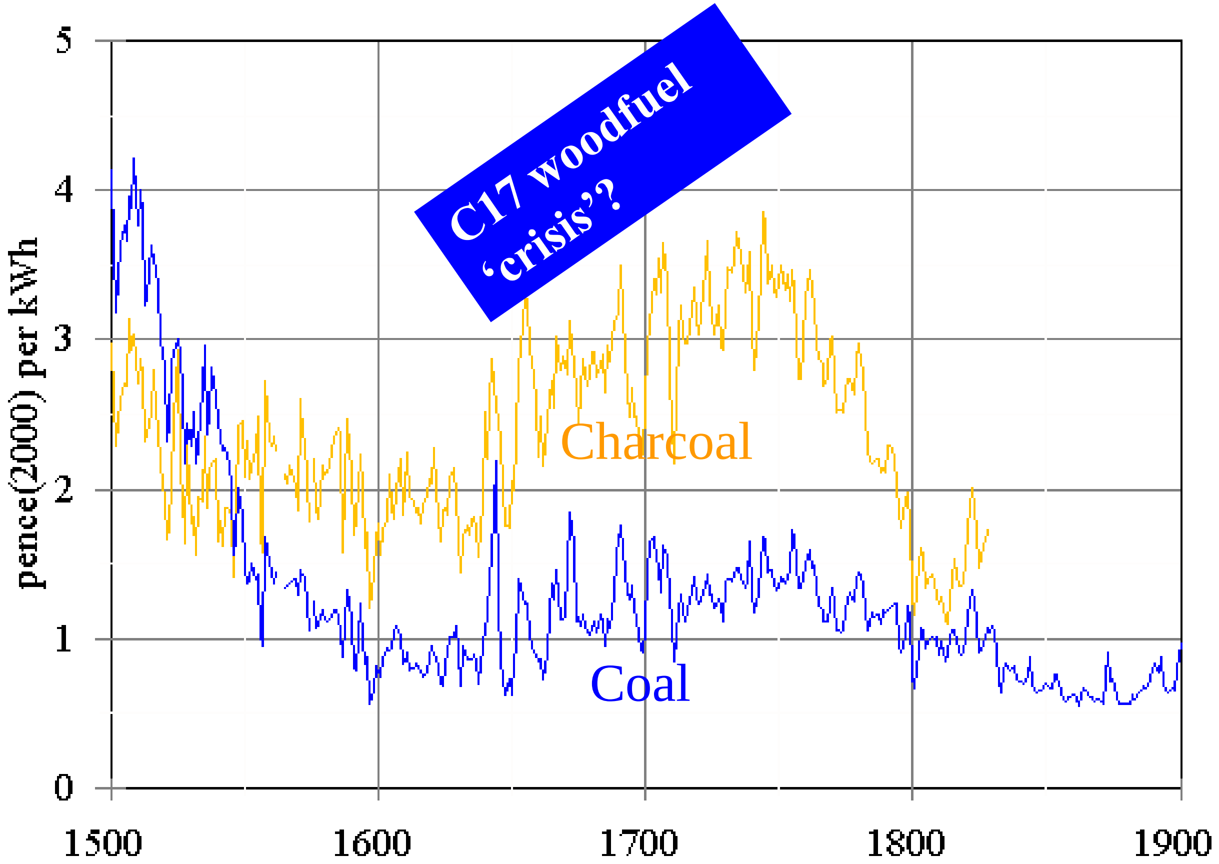




Fouquet & Pearson (2003) *World Economics*, 4(3)

- **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 uniquely profitable in Britain**

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

'It may have been the cost of the quantity of labour needed to produce charcoal that was the main reason for the attempts made to replace it as a fuel' (Palmer, 2001, ix).

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

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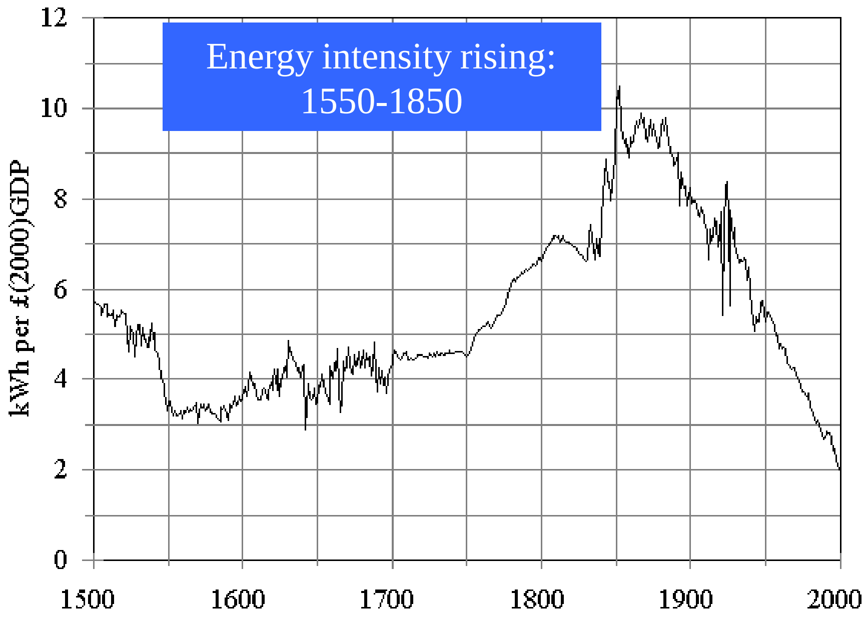
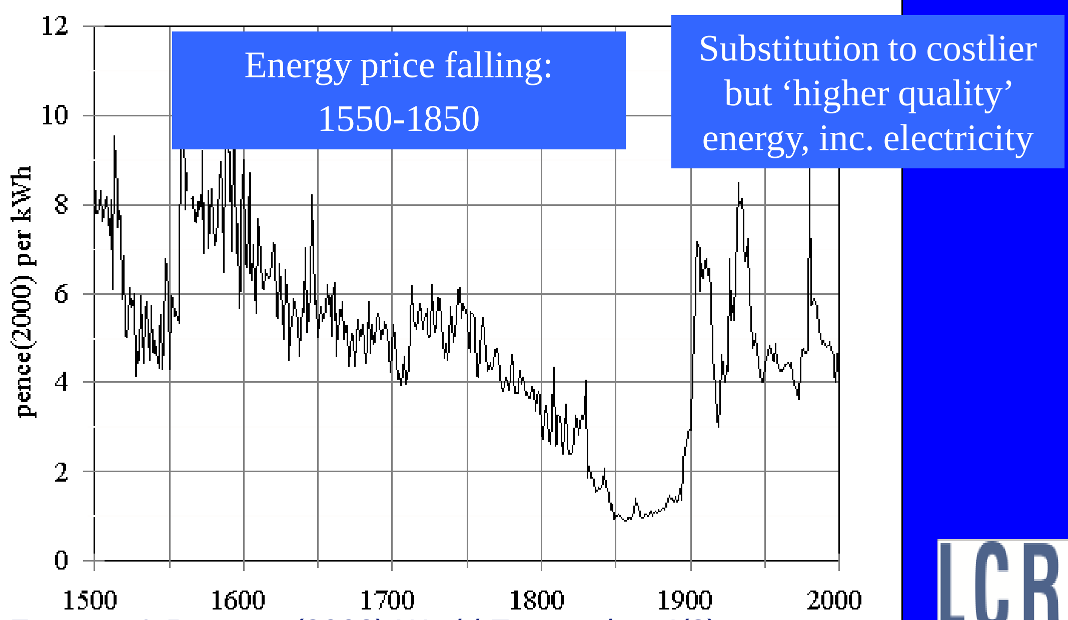
Fig. 3: Energy intensity & prices - Inverse relationship between:

UK energy intensity: Energy use/GDP



and

'Real' (inflation-adjusted) average energy prices: p/kWh



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

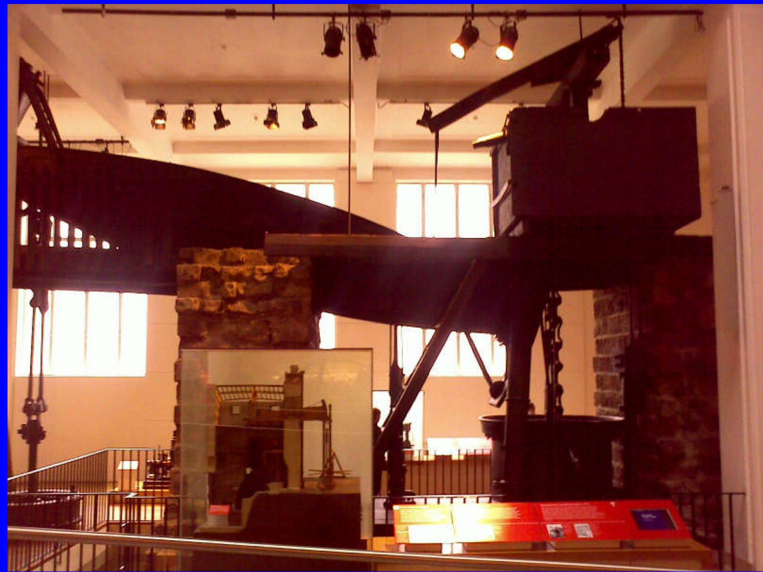
We created an 'average price of energy' series from estimates of individual fuel prices & expenditure weights

Coal & New Steam Technologies in C18

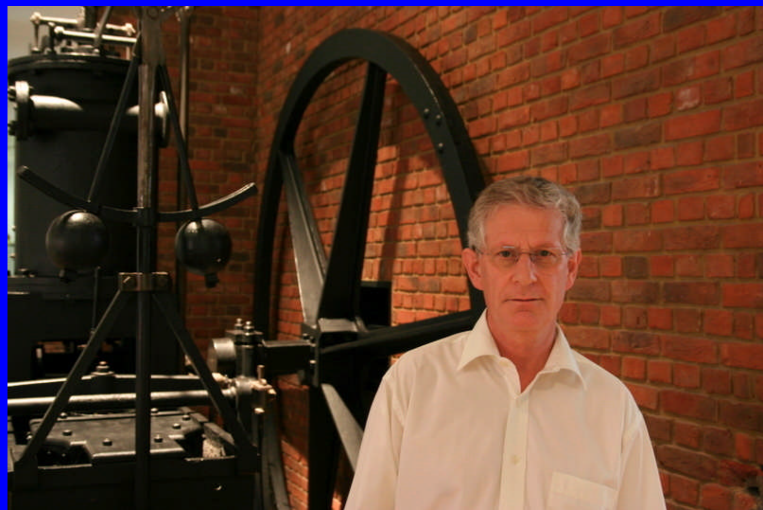
- Engines pumped water from coal, copper & tin mines
    - Savery's patent (1698-1733), Newcomen's 'atmospheric engine' (1710-12)
    - Engines also linked to water wheels (to maintain rotary power)
- Watt's separate condenser patent (1769-1800)
    - raised efficiency & royalties (B & W defended their patent…)
- Watt, Murdoch (1782) & others: *rotary* steam power, engines smaller & now drove machines (Fig. 4)
- 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 from 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)

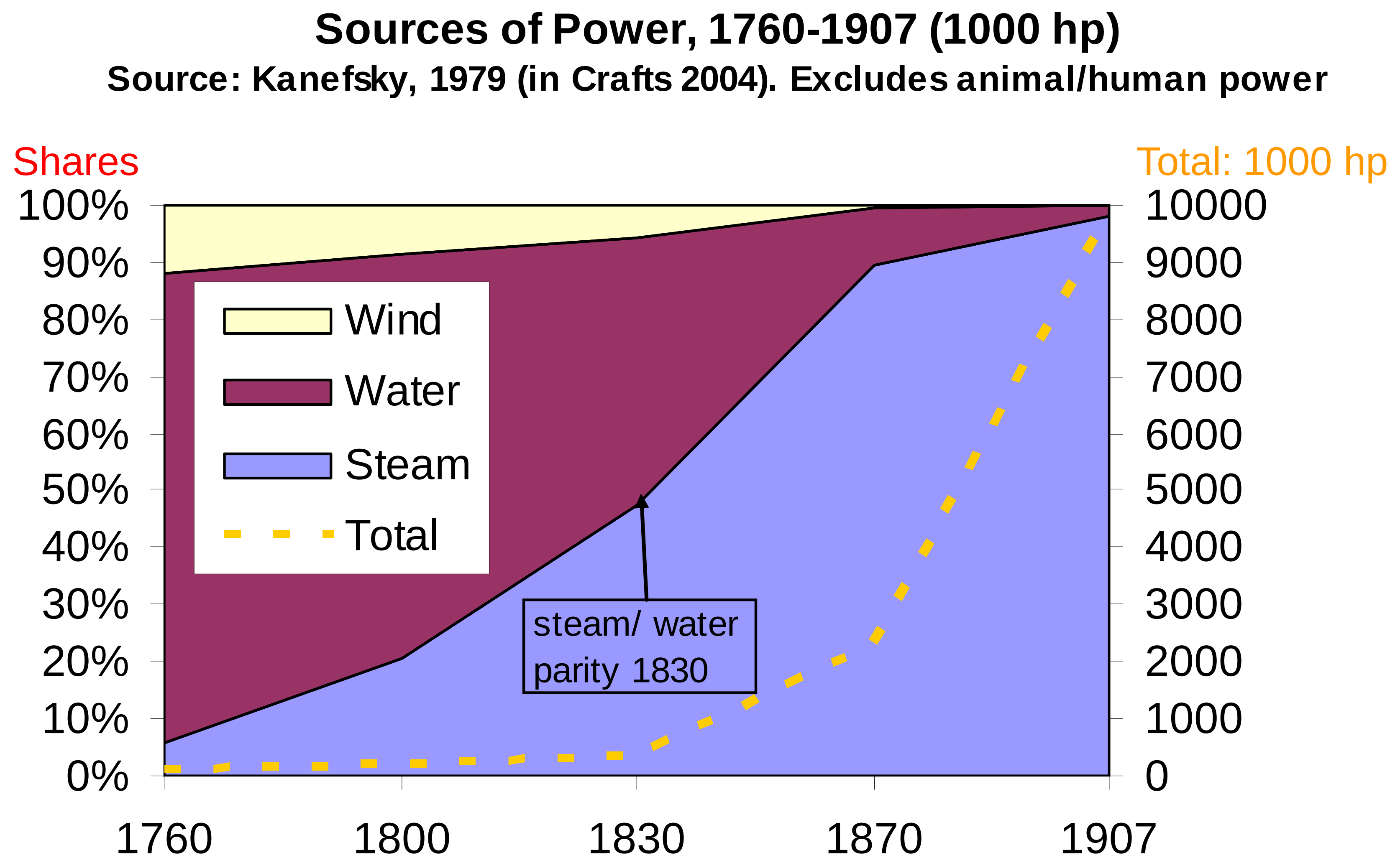


- Both in Science Museum, London

Long Run Perspective: Steam Power Development & Diffusion

- Initial high steam/water power price differential
- Gradually overcome
  - By steam's mobility advantage
  - More steam engine efficiency & control, from
    - Higher pressure & compound boilers (Cornwall; Woolf, McNaught - 1840s); and Corliss valves (1860s)
    - Parity in steam/water power shares ca. 1830 (Fig. 5)
- Steam let production move from water/wind power sites
  - Helped develop the factory system
  - Especially textiles: e.g. Manchester - 'Cottonopolis'
  - And pollution
- Railways & then ships (niches first) & trade
  - Developed transport, markets & trade

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



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

- Late C16-C18 British trade success (wool textiles) =>
  - rural industrialisation & urban growth
- E.g. London's growth (1500-1800: 15,000 - 1 million people) =>
  - woodfuel shortage =>
  - eased by exploiting relatively cheaper coal (coal & ports gave Britain cheap energy)
- Responsive agriculture raised food supply & labour productivity to feed the towns =>
  - freeing labour for manufacturing
- City & manufacturing 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

Fig. 6 : Relative Price of Labour (Allen, 2009)

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Wage relative to price of capital

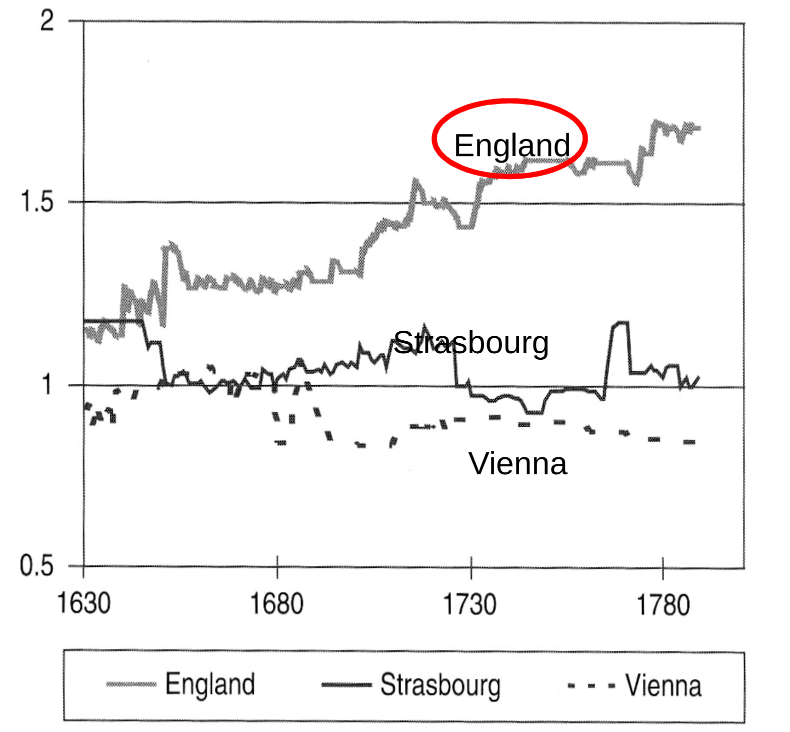

Figure 6.1 Wage relative to price of capital

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

Wage relative to price of energy

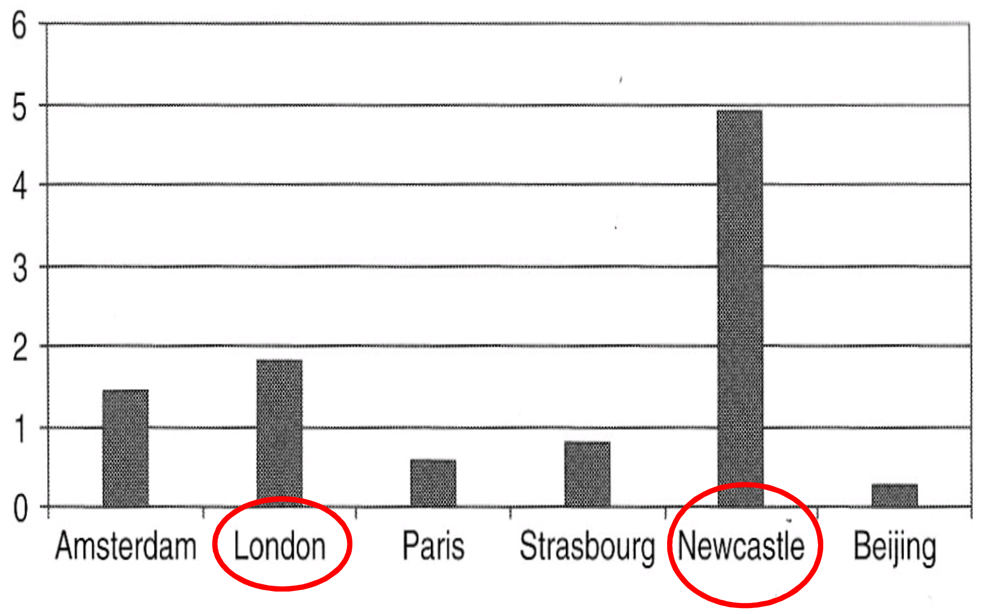

Figure 6.2 Price of labour relative to energy, early 1700s

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).

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Allen (2009), cont.

- Supply of technologies that substituted capital & energy for labour, raising output per worker =>
  - Newcomen steam engines used more capital & coal to do this
  - Cotton mills used machines to do it
  - New iron-making technologies substituted cheap coal for expensive charcoal; & mechanisation raised output/ worker
- 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 =>
  - Led to 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 they were unprofitable in countries with lower wages & costlier energy

Fig. 7: Pumping Engine Efficiency, 1727-1852: Coal Consumption

- But local learning eventually led to neutral technical progress =>
  - British engineers raised efficiency & reduced use of *all* inputs:
  - E.g. steam pump coal consumption fell from 45 pounds/ HP-hour in 1727 to 2 pounds in 1852
- By mid-C19 the technologies now profitable to use in countries like France (with expensive energy) & India (with cheap labour)

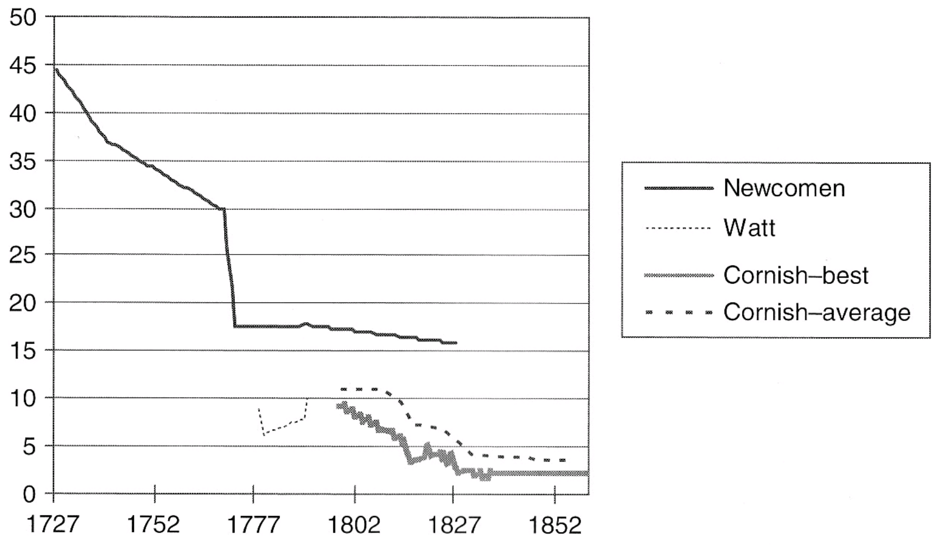


Figure 7.1 Coal consumption in pumping engines: pounds of coal per horsepower-hour

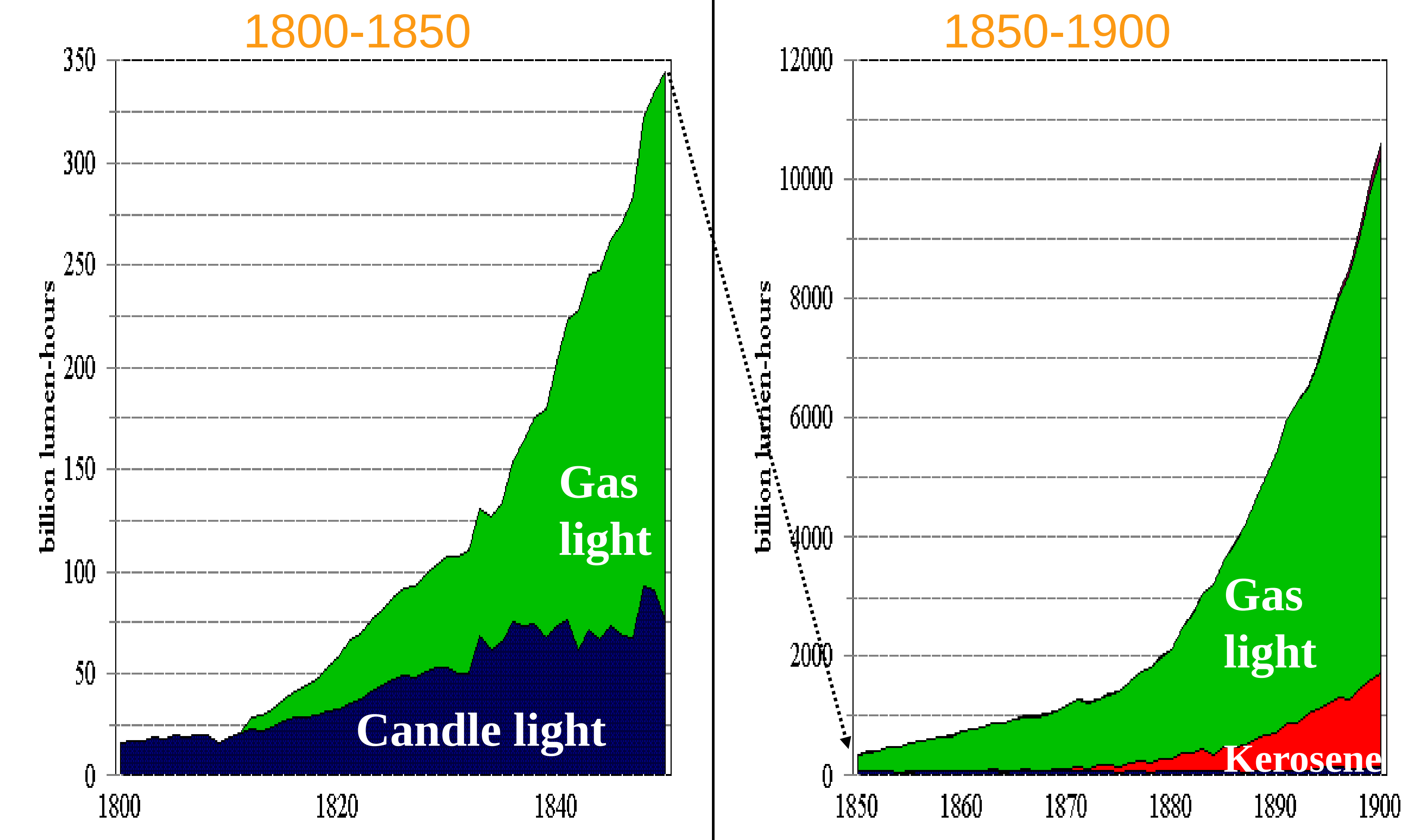
Sources: Hills (1989, pp. 37, 44, 88, 59, 111, 131), von Tunzelmann (1978, pp. 67–70), Lean (1839).

Source: Allen (2009, 165)

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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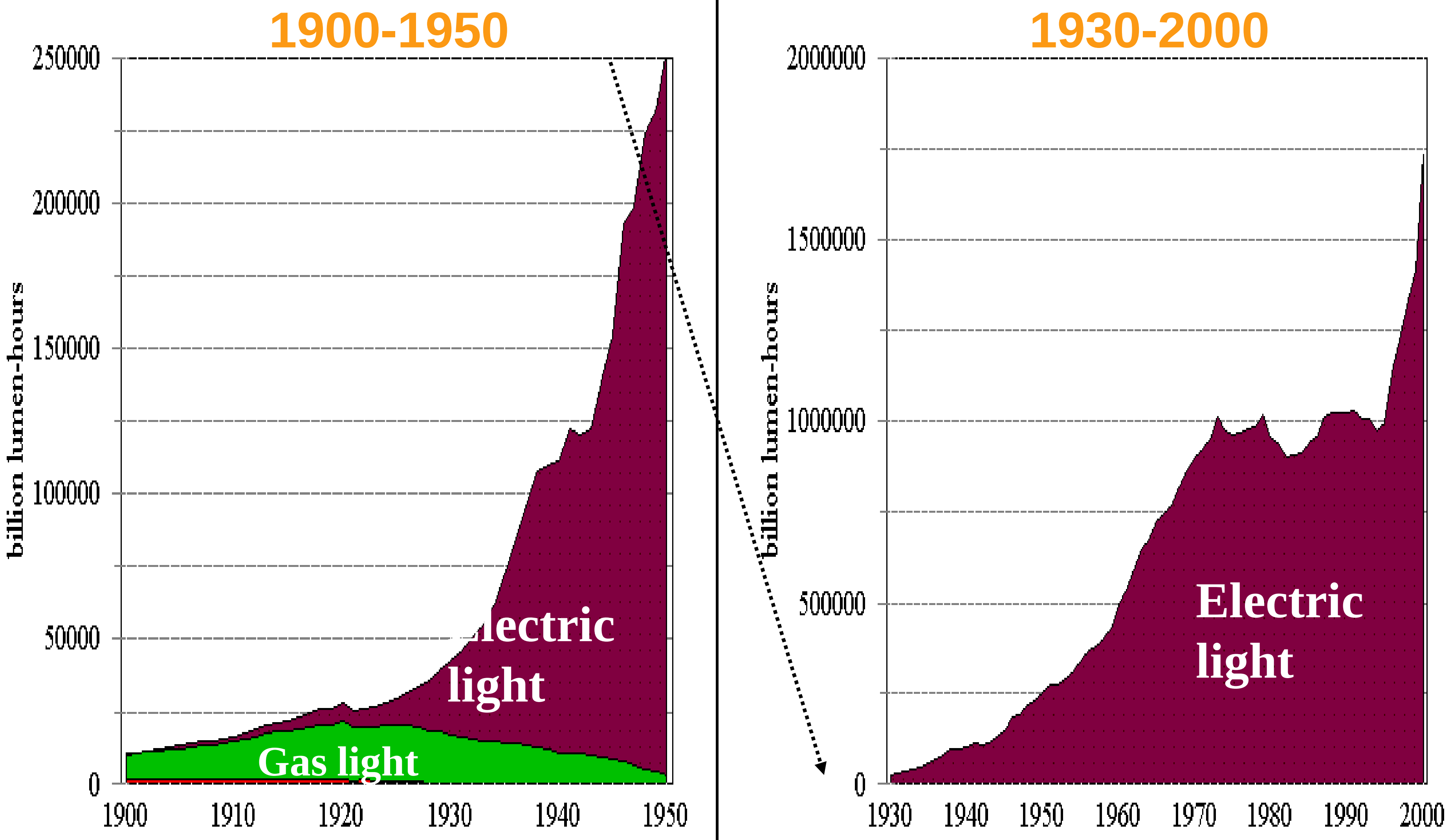
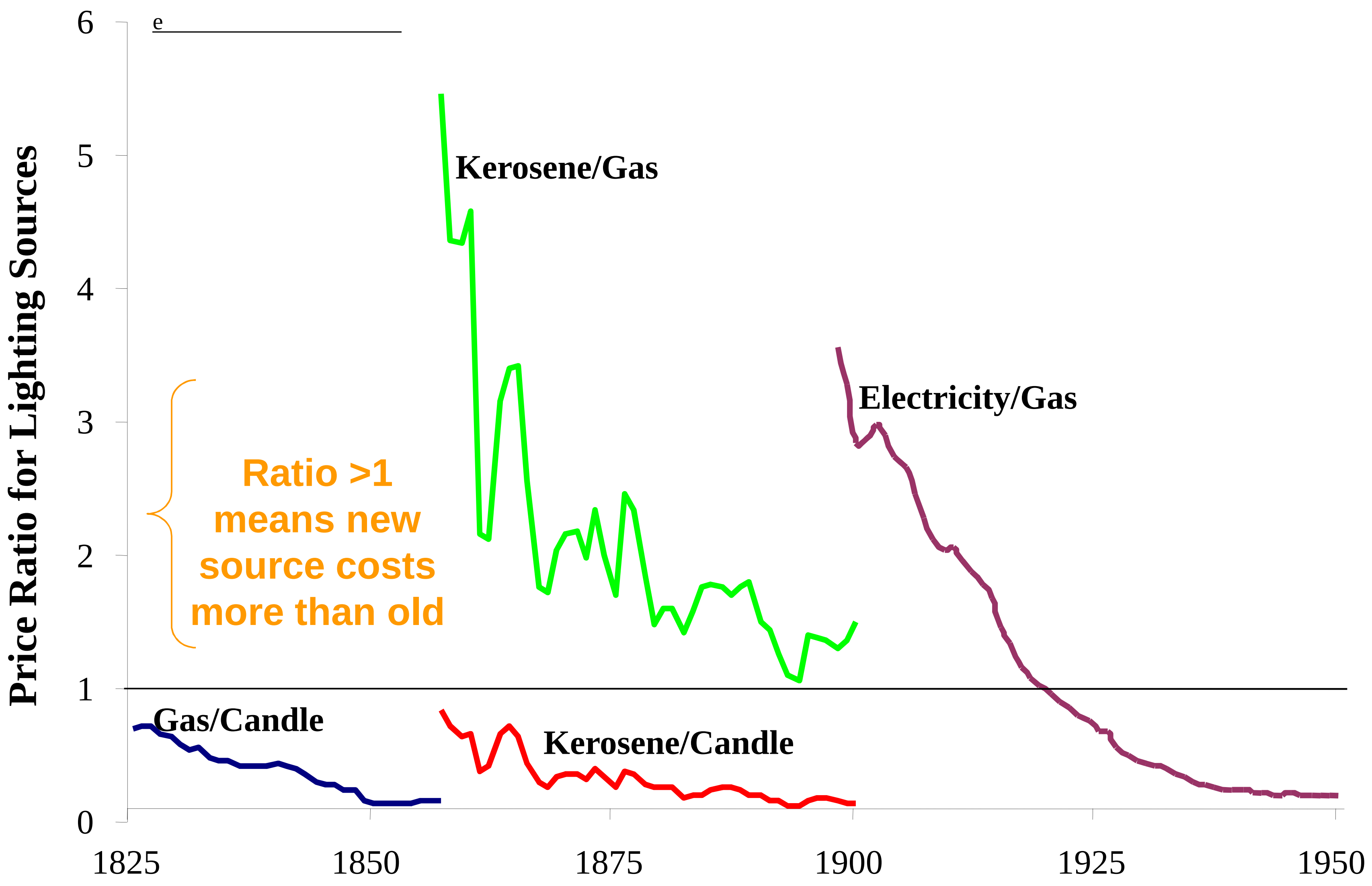


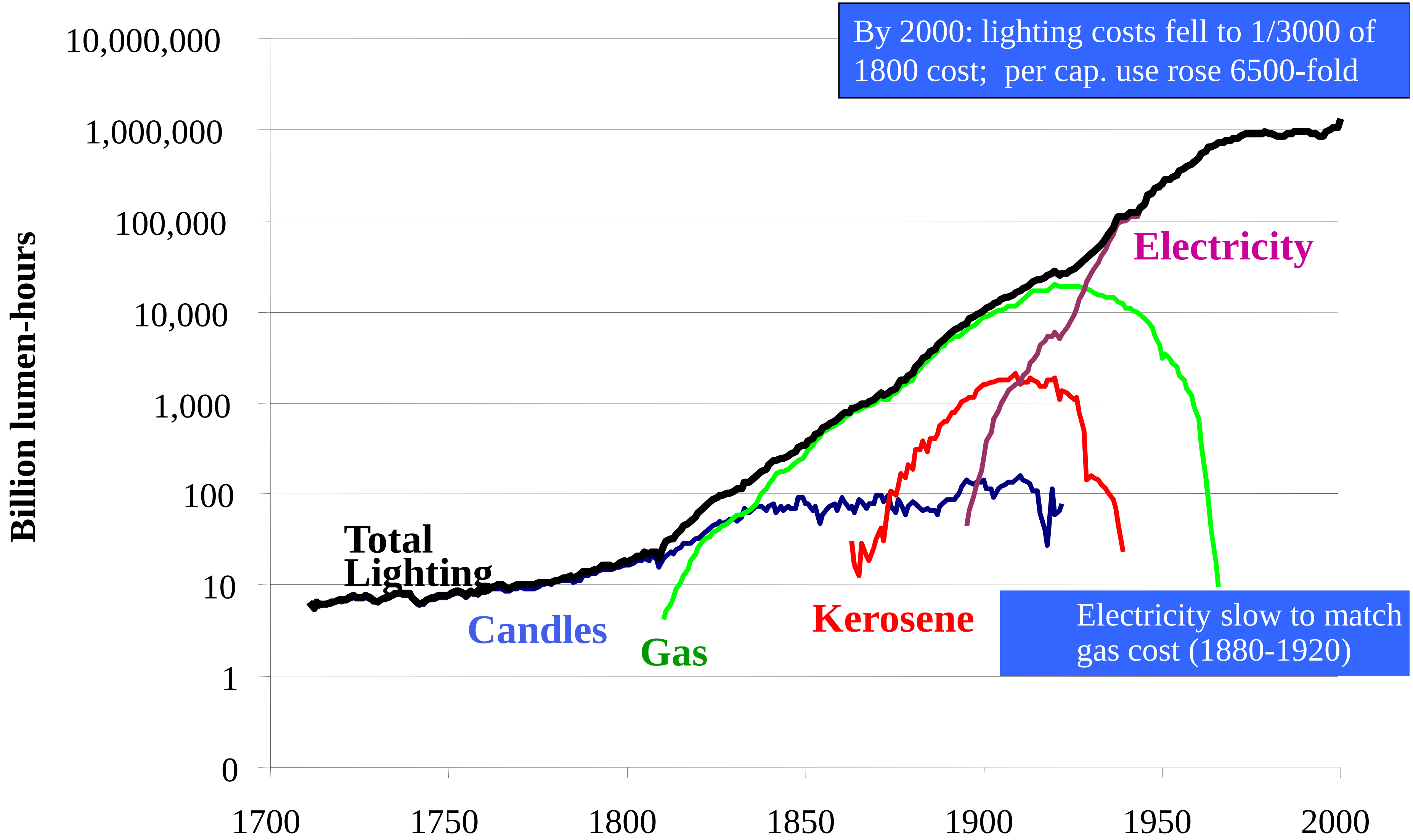
Fouquet & Pearson (2006) *Energy Journal*, Vol. 27(1)

Fig. 10. UK Price Ratio of Lighting from Competing Energy Sources, 1820-1950



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

Fig. 11. UK Energy Service Transitions: Lighting – use of Candles, Gas, Kerosene & Electricity (1700-2000)

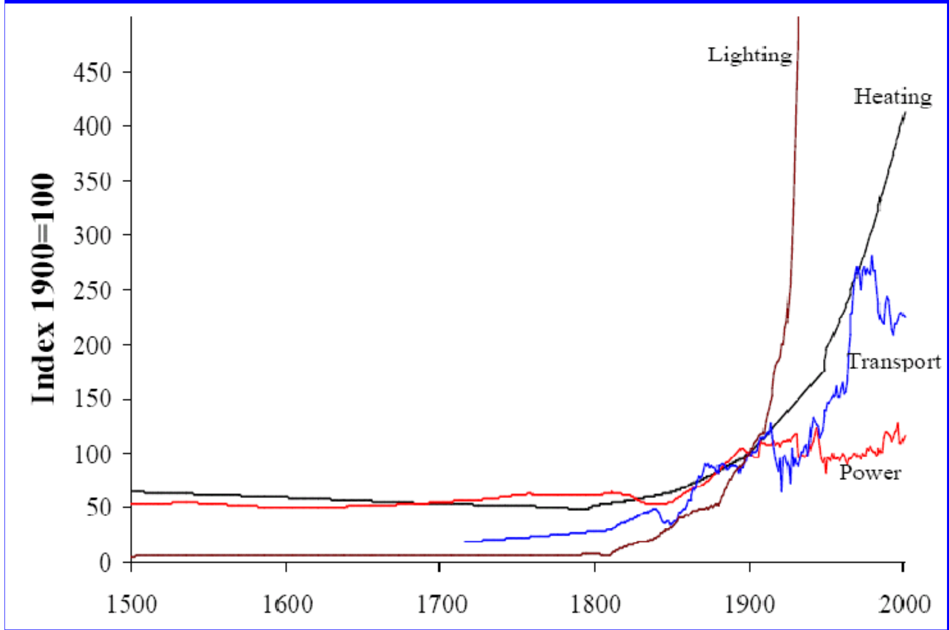


Source: authors ' own estimates – see Sections II.2 and II.3 Billion: 10 [9] (i.e. one thousand million)

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

Energy Service Indices

Fig. 12a. Efficiency of UK energy technologies, 1500-2000 (index: 1900=100)



Fouquet & Pearson (2007), IAEE conference, Wellington

Fig. 12b. Cost of consumer energy services, 1500-2000

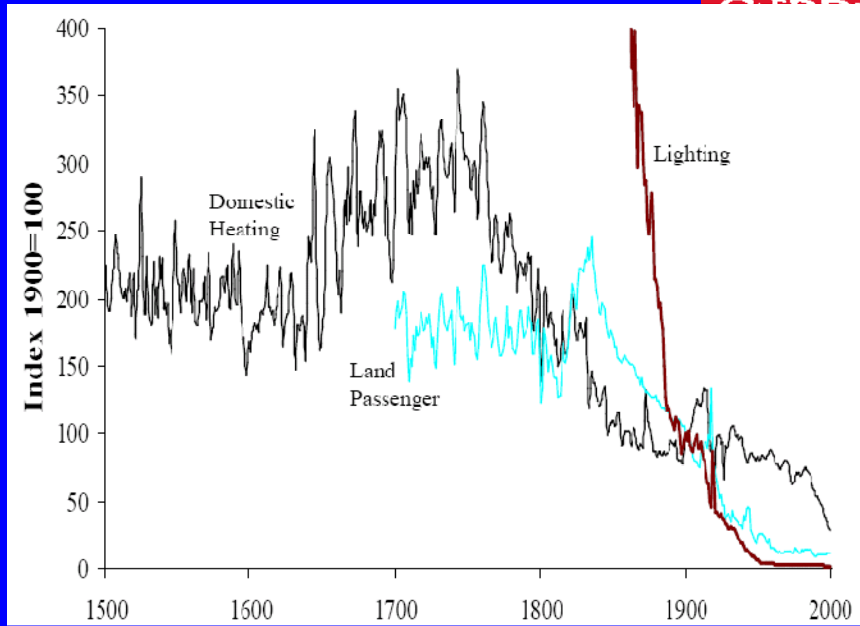
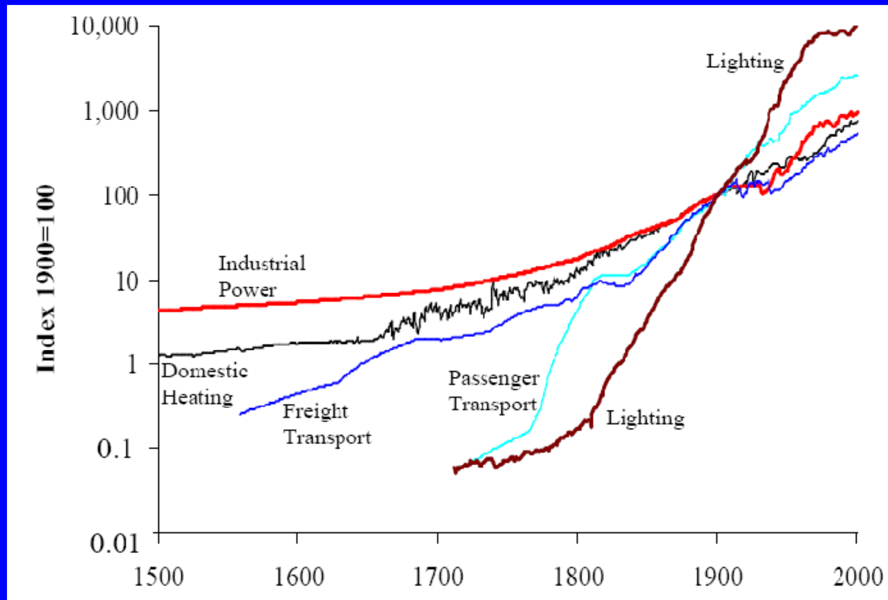


Fig. 12c. Energy services consumed, 1500-2000



'Industrial' includes all sectors except for the domestic sector

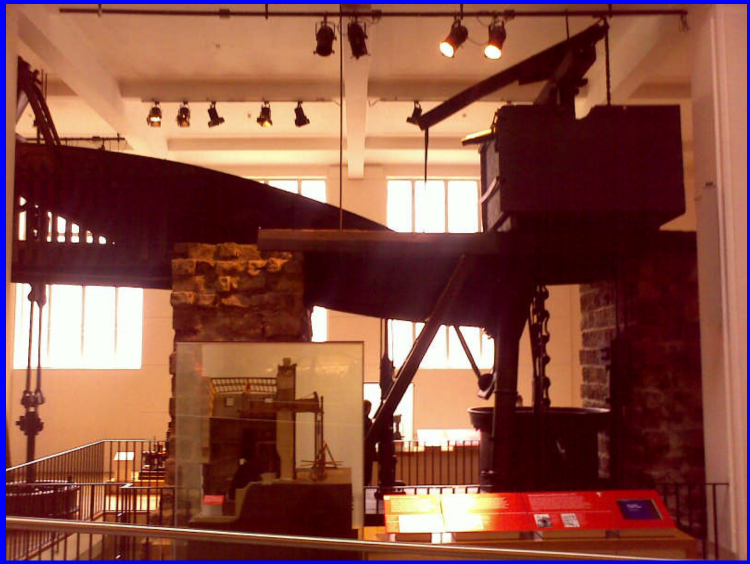
See also: Fouquet (2008), *Heat, Power and Light*, E. Elgar

A Long-Run Perspective on UK Transitions

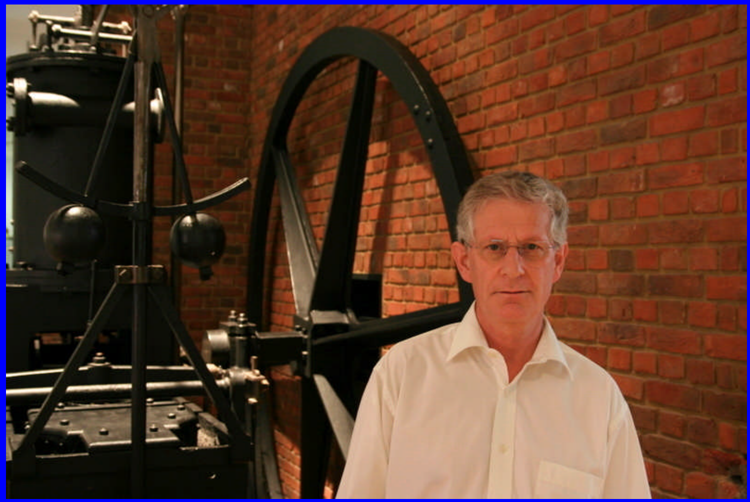
- Transitions to new fuels, technologies, infrastructures & uses can have profound effects on economy, welfare & environment
  - extraordinary potential of efficiency improvements
- But new technology diffusion **took time**
  - Major productivity fx. of steam engines, locomotives & ships only observable 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 (1880-1920)
- Energy system inertia
  - First mover advantage & path dependence?
  - Mining & textile industries were first with steam
  - But slow to adopt electricity in 2^{nd} C19 Industrial Revolution
  - Relative to chemicals & engineering, shipbuilding & vehicles

Fig.13: 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 in workshops (1810-1930)



Some Lessons from UK Energy Transitions

- But Allen identified key conditions underlying the 1st industrial revolution
  - the combination of relative prices plus cheap energy resources (coal), with physical, human & financial inputs & socioeconomic change
- It took many 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

Some Examples of Managed Transitions

- UK
  - UK gas & electricity industries sought to shape & encourage energy uses & habits in C19 & C20
  - Expensive subsidised 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
  - Netherlands

Insights from Managed Past Transitions: Four Scoping Studies 2010

February 2010*Transition Pathways* workshop: scoping studies that explored four previous UK transitions & the insights they might offer for low carbon transitions

- The scaling up & rolling out of electric power plant by CEGB & partners, 1960s
- The transition/conversion from town gas to natural gas, 1960s
- How the UK gas & electricity industries sought to shape & encourage energy uses & habits in C19 & C20
- 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

• http://www.lowcarbonpathways.org.uk/lowcarbon/news/news_0017.html

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. Successful 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

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

The Future for Low Carbon Energy Systems?

- 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 & 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)

General Purpose Technologies

- Three key attributes of a GPT:
  - *Pervasiveness:* wide range of general applications
  - *Technological Dynamism:* continued innovation, so costs fall/ quality rises
  - *Innovational Complementarities:* GPT users improve own technologies & find new uses for the GPT
- Steam engines, ICE, electrification & ICT cited as examples
  - Raised productivity growth - but took decades
  - Since a GPT's penetration involves a long acclimatization phase
  - While other technologies, institutions & consumption patterns adapt to it
- But the GPT model is contested theoretically & empirically
  - Doesn't allow for interdependence between technologies, etc.

The hypothesis of the *Sailing Ship Effect*

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- 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' (SSE)/ 'Last Gasp Effect' (LGE) makes the incumbent technology more efficient & competitive
- Before being 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)

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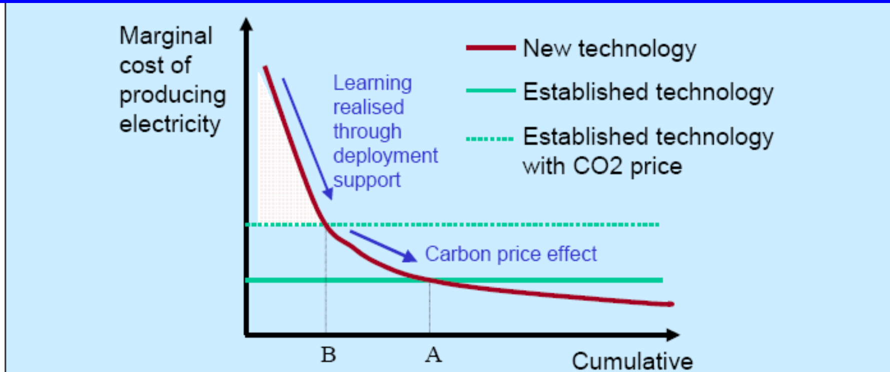
Figure 14: Experience Curves & Financing Learning

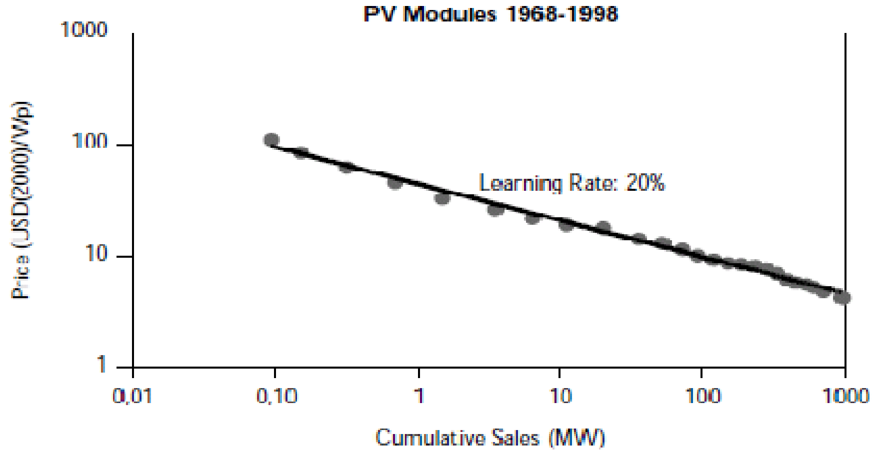
Stern Climate Change Review (2006)



Source: Stern Review, Figure 16.6

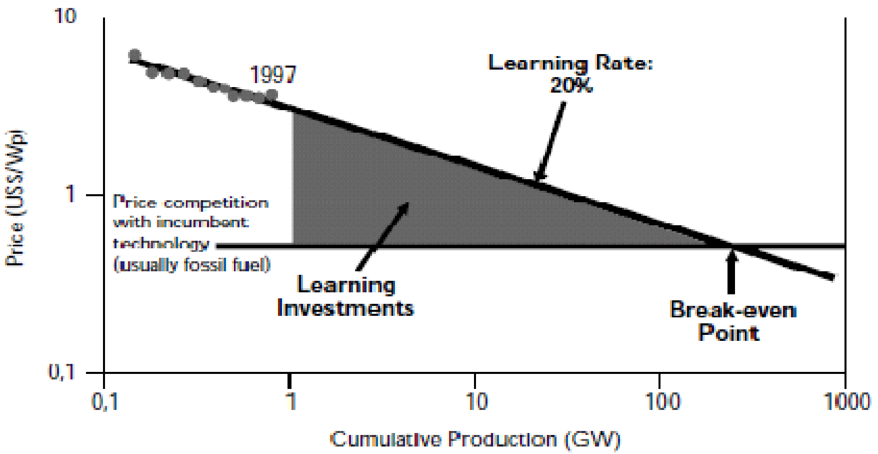
PV Modules

Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

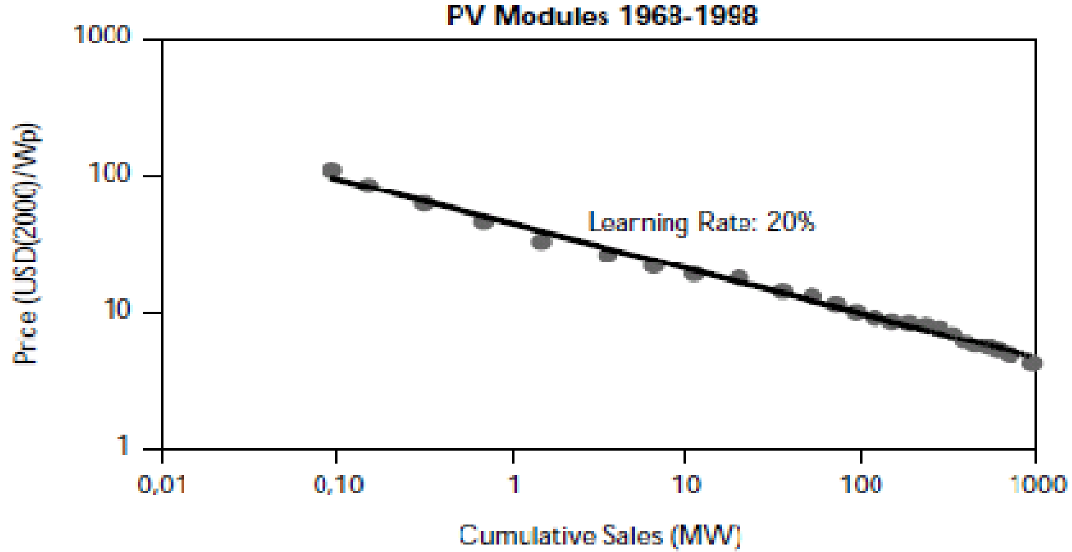
Figure 3.4. Making Photovoltaics Break Even



Source: OECD/IEA(2000).

Fig.15 SSE/ Last Gasp Effects?

Figure 3.3. Thirty Years of Technology Learning



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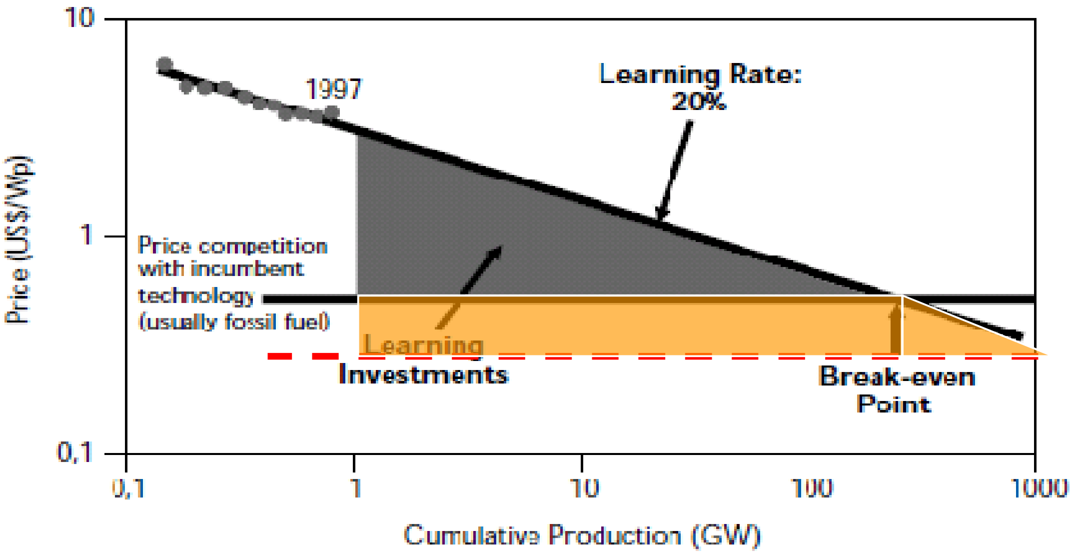

Source: OECD/IEA(2000).

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

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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 & we seek radical innovation
- And suggests giving proper attention to dynamic interactions between new & incumbent technologies

A Third, Low-Carbon 'Industrial Revolution'?

- Getting there from here means more than substituting some low carbon technologies into *existing* uses & institutions. Low carbon technologies need the 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 & Sailing Ship/Last Gasp Effects
    - So we need to address interactions between new & incumbent technologies
    - Policy beds both to stimulate penetration of more efficient & low carbon technologies & the decline of less efficient & higher carbon incumbents

A Third, Low-Carbon 'Industrial Revolution'?

- Relative prices and physical and human resources
  - Price signals are only one element in the conditions needed to stimulate low carbon transitions; other stimuli are required, as the Stern Review suggests
  - If Allen's (2009) messages about the 1st industrial revolution hold for this revolution, where are the relative prices & physical, human & financial resources & institutions needed for risky innovation and behavioural change?
  - Role of carbon/energy prices here
  - And of other wider policy measures
- The third industrial revolution doesn't have to start in the UK – but it does need to happen here

Thank you!

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