Industrial revolutions, technological paradigm shifts and the low carbon transition

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1. A long-run perspective on energy & the Industrial Revolution

Britain's Industrial Revolution & Energy Transition: C16th-C19th

In a long drawn-out transition, Britain went:

- **From** a traditional agricultural economy: renewable energy flows limited by productivity of land & technology
- **To** a new regime: growth, welfare & pollution transformed by depleting fossil stock for larger energy flows (Wrigley)
- With innovations including
  - Cotton mills & new spinning & weaving technologies
  - Steam engine
  - Substituting coal/coke for wood in metal manufacture
  - Social, political, institutional & technological changes
  - New manufactured consumer goods at attractive prices
- That helped drive mechanisation, urbanisation & Britain's first 'Industrial Revolution'

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

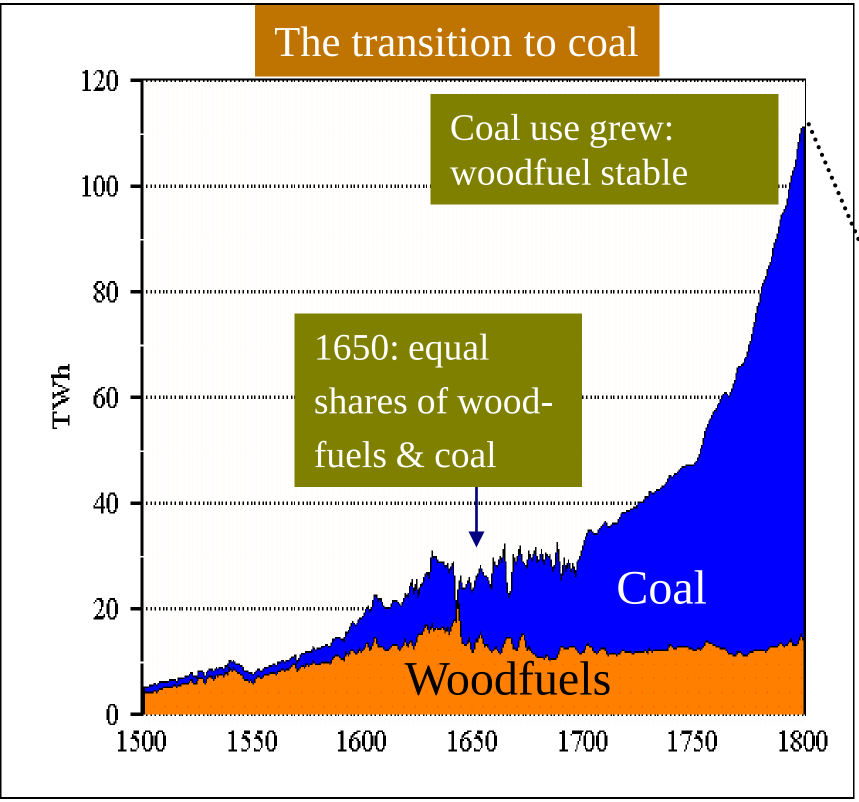
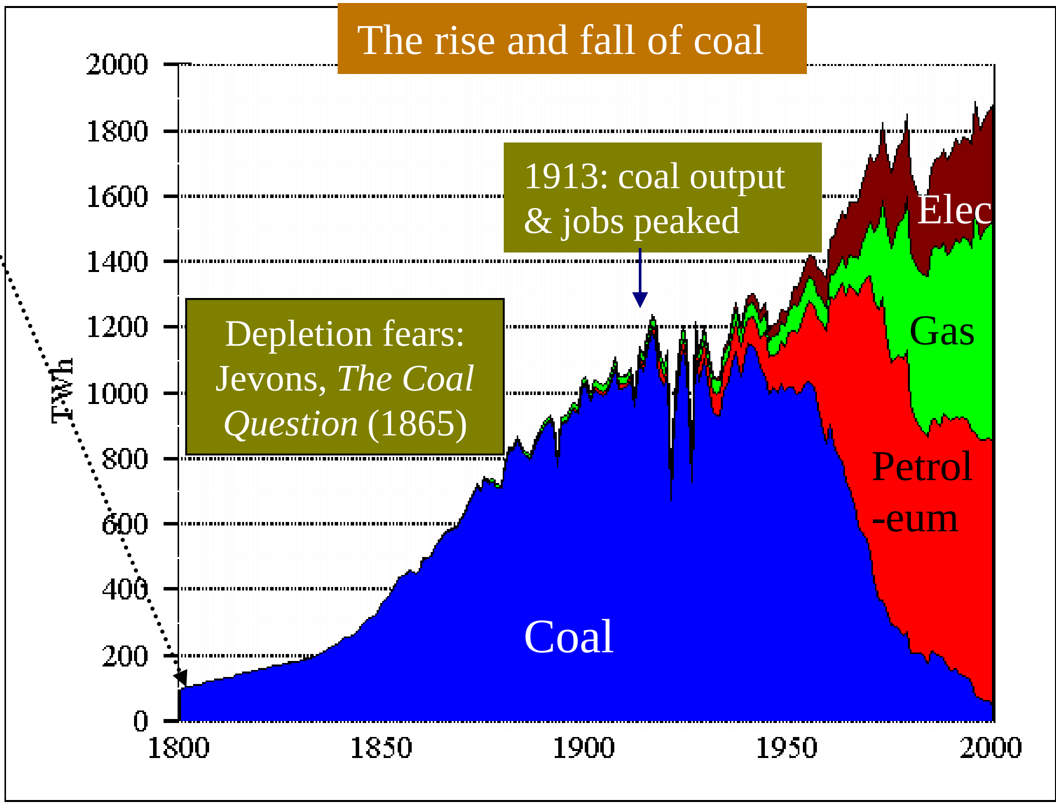


Fig. 1b: UK Final Energy Consumption, 1800-2000 (TWh)



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

Fig. 2a : UK *energy intensity* (energy use/GDP)

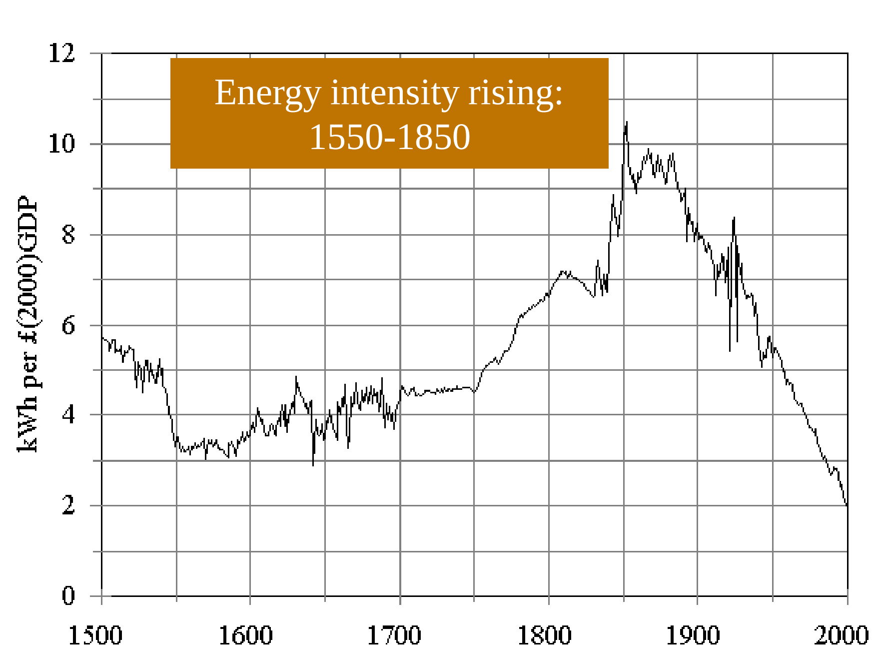
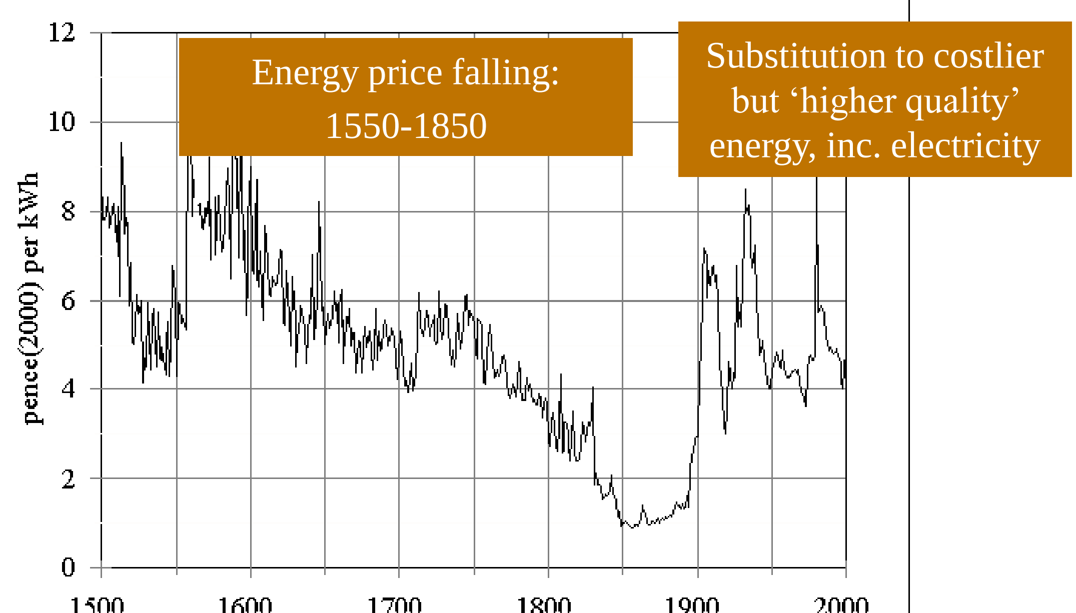


Fig 2b: 'Real' (inflation-adjusted) average energy prices: p/kWh



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

Fig.3: Early Steam Engine Developments

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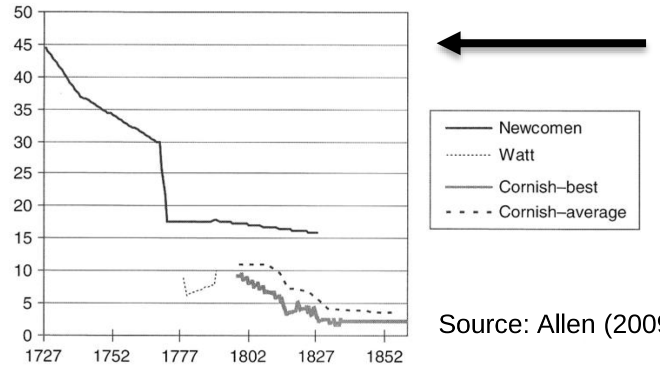
- 1698-1733 Savery's patent.
- 1710-12 Newcomen's 'atmospheric engine'
- 1769-1800: Watt's separate condenser patent
- Then higher pressure steam, compound boilers & Corliss valves
- Big efficiency/cost gains



Pumping Engine Coal Use: from 45 lbs/hp-hour in 1727 to 2 lbs in 1852

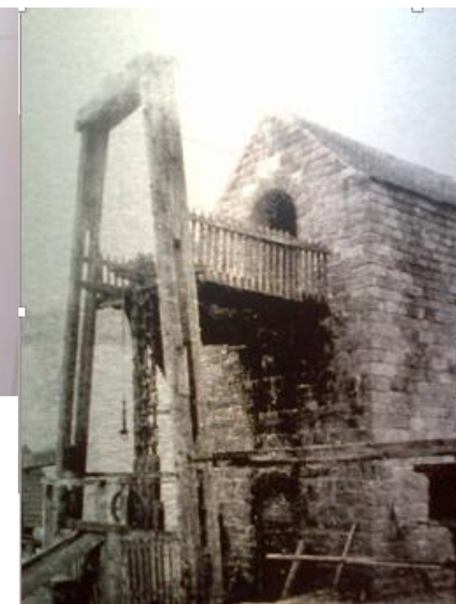
Source: Allen (2009, 165)

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).

Thompson's Atmospheric Beam Engine (ran 127 years:1791-1918)

- Already 'old' technology
- Size of a house
- Pumped water from Derbyshire mines



Bell Crank Engine - rotary power (ran 120 years: 1810-1930)

- 'New' technology
- Size of small bathroom
- 1799 Murdoch patent;
- 1799-1819: Boulton & Watt built 75

Both in Science Museum, London

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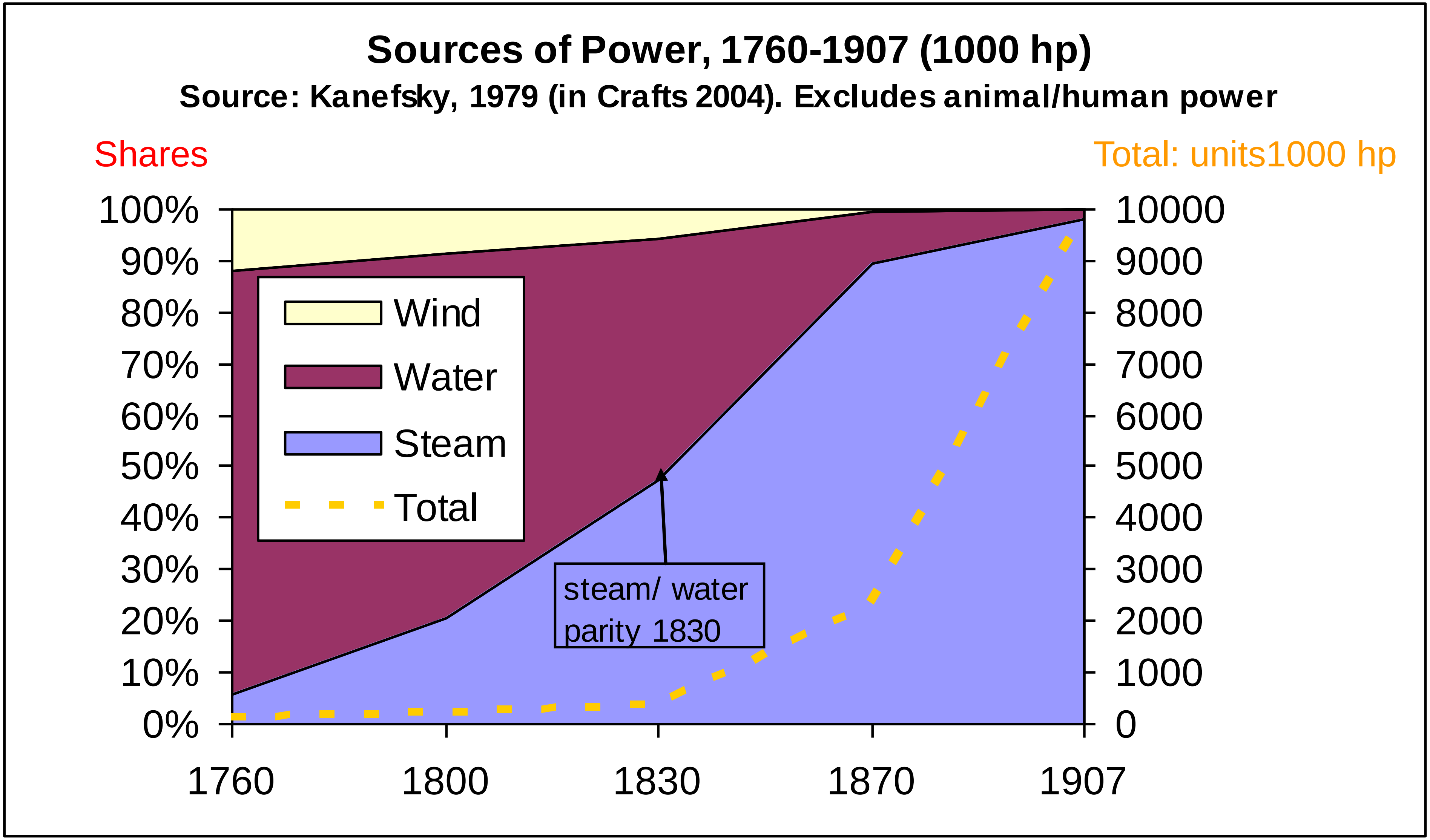
Fig. 4: Sources of Power, 1760-1907 (shares; total)

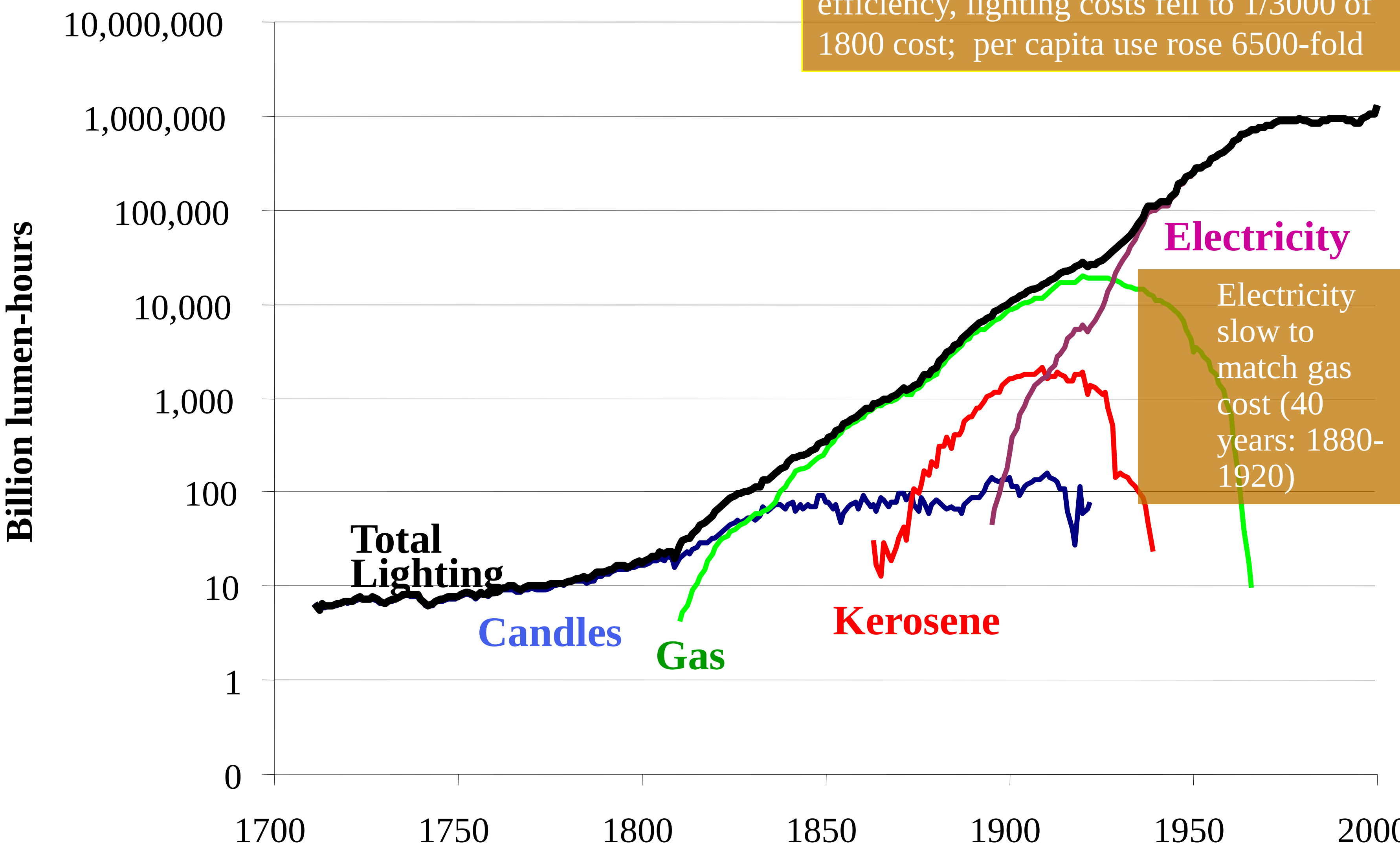


Energy Services: UK lighting experience

- The energy is for energy *services* that people value
  - *illumination*, transportation, cooked meals, refrigeration, comfortable temperatures…
- Evidence: extraordinary potential of innovation to cut costs, enhance quality & raise welfare
- Example: UK lighting services (1300-2000)
  - Innovation in fuels, technologies, infrastructures & production, mostly post-1800, cut costs, enhanced quality & access
  - With rising incomes, led to 'revolutions' in light use
- Other energy services also saw major efficiency improvements (Fouquet 2008)

Fig. 5: UK Energy Service Transitions: Lighting – Candles, Gas, Kerosene & Electricity (1700-2000)

By 2000, mostly through greater conversion efficiency, lighting costs fell to 1/3000 of 1800 cost; per capita use rose 6500-fold



Electricity slow to match gas cost (40 years: 1880-1920)

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)

2. A Low Carbon Industrial Revolution?

A Low Carbon Industrial Revolution?* (I)

- It has been argued that a UK low carbon transition could/should amount to *a low carbon industrial revolution*.
- Two propositions underlie this claim
  - Productivity gains & economic benefits would resemble those of past revolutions
  - The necessary scale of changes in technologies, institutions & practices compares with those of past industrial revolutions or 'waves' of technological transformation
- The attraction of a New Industrial Revolution is clear:
  - Earlier revolutions saw new technologies displace incumbent, less efficient energy sources (wood, charcoal, water, animal & human power), technologies & institutions;
  - And led to a growing & *sustained* stream of productivity improvements, innovations & economic gains

* Pearson & Foxon (2012)

So, what led to Britain's Industrial Revolution?

- Two views: "Allen (2009) stresses that the new technologies were invented in Britain because they were profitable there but not elsewhere, while Mokyr (2009) sees the Enlightenment as highly significant & underestimated by previous scholars," Crafts (2010)
- **Allen:** high wages & cheap energy (coal) led to demand for technologies to substitute energy & capital for relatively costly labour – e.g. for the steam engine, Britain needed to pump water from coal mines & had the cheap fuel (coal) required
- **Mokyr**: ideology of the Enlightenment improved technological capabilities & institutional quality, enabling Britain to exploit its human & physical resource endowment – a supply-side argument
- Crafts: Allen & Mokyr's approaches are complementary
- These & other analyses show how socio-economic, institutional & technological factors catalysed & sustained the long drawn-out Industrial Revolution

Technological change, economic growth & the GPT

- *General Purpose Technologies* (GPTs): 3 properties - "A single generic technology […] that initially has much scope for improvement & eventually comes to be widely used, to have many uses, & to have many spillover effects" (Lipsey et al. 2005).
  - E.g. steam engines, electrification, ICE & ICT
- The GPT helps explain why the 1st Revolution's technical progress went on, instead of petering out, as before.
- GPTs raised productivity growth - but took many decades
  - Since a GPT's penetration involves a long 'acclimatisation' phase
  - While other technologies, forms of organisation, institutions & consumption patterns adapt to & gain from the GPT
  - E.g. steam: hard to find productivity effects until after 1850, with growth of railways, steamships &other uses (Crafts, 2004)
- The set of available low carbon technologies don't yet seem to show all 3 properties of GPTs

Technological Revolutions & Techno-Economic Paradigms

- In a related approach, evolutionary economists (Freeman & Perez 1988, Perez 2009) identified 5 *technological revolutions*:
  - Clustered interrelated technology systems that eventually transformed the whole economy
  - But full benefits realised slowly: wider institutions & practices adapted in a turbulent process of diffusion & assimilation
- The *techno-economic paradigm* is the vehicle of transformation – a 'best practice' model that:
  - Gradually becomes a shared common sense or 'logic'
  - Shaping the trajectories of technologies, institutions, expectations & behaviour
  - Eventually becoming a powerful inertial force hindering the next revolution
- Much recent research has investigated the role played by incumbents (firms, technologies, institutions…)

Displacing & embracing high carbon incumbents

- Low carbon technologies must compete with & displace incumbent fossil fuels, technologies & institutions
- Low carbon technologies have the *socially* desirable but not fully priced characteristic of low CO_2 emissions
- But as yet, except in niches, they tend to lack attributes with superior *private* market value to entrenched fossil fuels
- Several analyses emphasise the *path dependent, locked in* states of incumbent high carbon technologies & institutions
- While other analyses have also pointed to possibilities of *path creation & creative accumulation* by incumbents
- So low carbon policy should be mindful of incumbents' strategies & capabilities, both to resist & to embrace change

A Low Carbon Industrial Revolution? (II)

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- The low carbon transition doesn’t yet amount to another industrial revolution, in terms of
  - Its technologies & practices
  - Their desirable bundles of attributes
  - Their ability to stimulate durable long-run productivity & output gains
- A key difference: market prospects for low carbon technologies differ from those of the Industrial Revolution
  - Because the value of addressing climate change is a public good (& GHG emissions are largely unpriced ‘externalities’ – low carbon price)
  - Unaided private markets unlikely to produce appropriate innovations
- The industrial revolution wasn’t a policy-driven transformation
- And low carbon policies now influenced by dynamics of the *energy policy trilemma*: climate; energy security; affordability

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A Low Carbon Industrial Revolution? (III)

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- The benefits of industrial revolutions took many decades, while science shows the need for urgent, large-scale GHG cuts.
- For the low carbon transition to ‘work’, we need quickly to transform our energy & related systems in profound & revolutionary ways
- This will require societal & governance changes on a scale like those of previous industrial revolutions
- Which may have more in common with late 19th Century developments in clean water supply, sewerage infrastructure & health (which were about public goods), than with previous *high carbon* revolutions (mostly about private goods)
- This would then be a different kind of industrial revolution

Summary Points (I)

Time & inertia

- The transformations of Industrial Revolutions/long waves took time because not only profound technological changes but also socioeconomic & governance changes (with political repercussions) were needed.
- We have to worry as much about the socio-economic & governance aspects as the technological ones

Incumbents

- High-carbon Incumbents of all kinds are not necessarily all bad news for the low carbon transition
- It matters to harness their expertise, technical & financial resources, to encourage low carbon developments & the transformation of the old into the new

Summary Points (II)

History as blueprint?

- I'm not saying that the Industrial Revolution is a blueprint for a low carbon transition(it was, after all, a *high-carbon* transformation)
- But studying processes of socio-technical change & their historical dynamics gives clues about what issues, interactions & policies deserve policy & academic attention

The low carbon transition challenge

- Main benefits seen as communal risk reduction for the future
- Doesn't *yet* offer the benefits of the new low-cost goods & services of earlier industrial revolutions – a key societal & policy challenge

Notes and Sources

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Note: This presentation draws on research by the author & colleagues in the *Realising Transition Pathways project,* funded by EPSRC (Grant EP/K005316/1). The author is responsible for all views contained in the presentation

Allen, R (2009), *The British Industrial Revolution in Global Perspective*, Cambridge University Press, Cambridge.

Allen, R (2012) 'Backward into the future: the shift to coal and implications for the next energy transition', *Energy Policy* 50, 17–23.

Crafts, N., 2010. 'Explaining the first industrial revolution: two views.' *European Review of Economic History* 15, 153–168.

Edquist, H and Henrekson, M (2006), 'Technological Breakthroughs and Productivity Growth', *Research in Economic History*, Vol. 24.

Freeman, C., Perez, C., 1988. Structural crisis of adjustment, business cycles and investment behaviour. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), *Technical Change and Economic Theory*. Pinter, London.

Fouquet, R (2008) *Heat, Power and Light: Revolutions in Energy Services*, Edward Elgar

Fouquet, R and Pearson, PJG (1998). 'A Thousand Years of Energy Use in the United Kingdom', *The Energy Journal*, 19(4)

Fouquet, R and Pearson, P J G (2003). 'Five Centuries of Energy Prices', *World Economics*, 4(3): 93-119.

Fouquet, R and Pearson, P J G (2006): 'Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300-2000)', *The Energy Journal*, 27(1)

Fouquet, R and Pearson, P J G (2012): , 'Past and prospective energy transitions: Insights from history', *Energy Policy* 50, 1–7

Foxon, TJ, GP Hammond, PJ Pearson (2010), 'Developing transition pathways for a low carbon electricity system in the UK', *Technol. Forecast. Soc. Change*, 77, 1203–1213

Foxon, T J, Pearson, P J G(2007)'Towards improved policy processes for promoting innovation in renewable electricity technologies in the UK', *Energy Policy* (35),1539 – 1550.

Lipsey, R.G., Carlaw, K.I. and Bekar, C.T. (2005), 'Economic Transformations: General Purpose Technologies and Long-Term Economic Growth', Oxford University Press, Oxford and New York

Mokyr, J (2009), *The Enlightened Economy*, Penguin Books, London

Pearson, P.J.G. and T.J. Foxon (2012), 'A low carbon industrial revolution? Insights and challenges from past technological and economic transformations', Energy Policy 50, 117–127.

Perez, C (2009), Technological revolutions and \techno-economic paradigms, *TOC/TUT Working Paper No 20*, The Other Canon Foundation, Norway and Tallinn University of Technology, Tallinn.

Unruh, G C (2000), 'Understanding carbon lock-in'. *Energy Policy*, 28(12), 817–830

Unruh, G C & Carillo-Hermosilla (2006) Globalizing carbon lock-in, *Energy Policy* 34(10), 1185–1197.

Wrigley, E A (1988), *Continuity, Chance and Change, the Character of the \industrial revolution in England*, Cambridge University Press, Cambridge.

Wrigley, E A (2010), *Energy and the English Industrial Revolution*, Cambridge University Press, Cambridge.