Energy Transitions, General Purpose Technologies & the Challenge of Low-Carbon Technologies

Peter Pearson
Centre for Energy Policy & Technology (ICEPT)
p.j.pearson@imperial.ac.uk

Complexity Economics for Sustainability

Seminar 3: Are economic growth & sustainability compatible?

Madingley Hall, Cambridge

4 Dec. 2009

Outline

- The challenge of low-carbon innovation
- Can we learn from past energy transitions & policies?
  - The British Industrial Revolution(s)

  "A lantern on the stern can help with navigation ahead" (Horrell)
- The potential role of General Purpose Technologies

A Third, Low-Carbon ‘Industrial Revolution’?

- How to get 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
- A role for General Purpose Technologies (GPTs)?
  - Such as smart grids (electricity & ICT)
  - But GPTs take time to develop
  - May be slowed by path dependence, lock-in and Sailing Ship/Last Gasp Effects
  - Are contested – empirically & theoretically
- Relative prices and resources
  - If Allen’s (2009) message about 1st Industrial Revolution holds for this Revolution, where are the relative prices & physical &human resources needed for risky innovation?

Perspective on Energy System Transitions

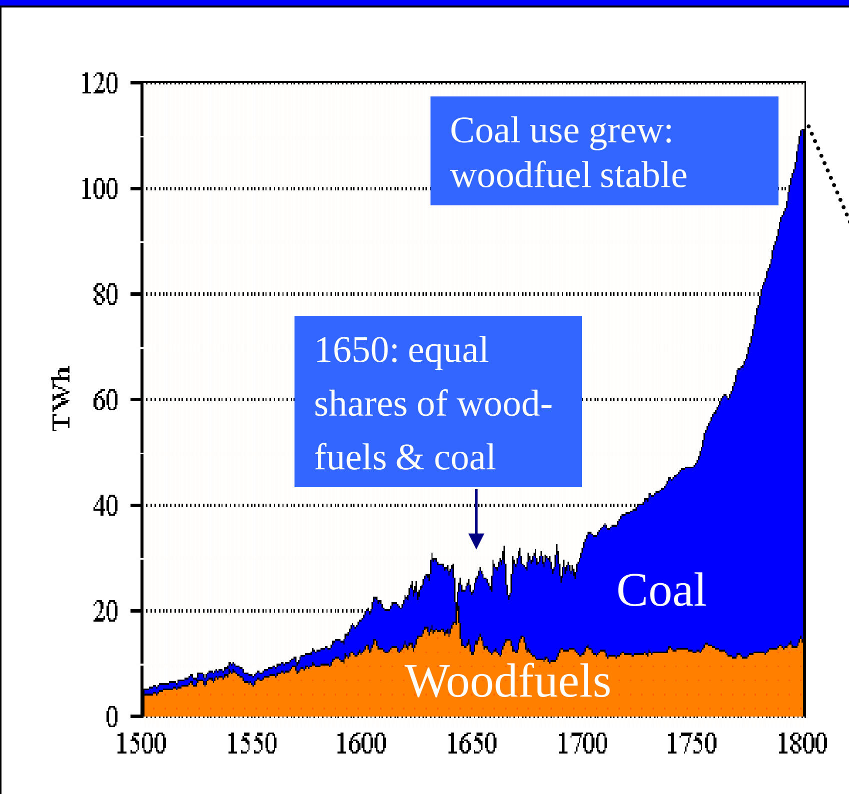
- Energy systems are complex evolutionary entities
- Transitions mean interactions between
  - Fuels & energy converting technologies
  - Infrastructures (transport networks, pipes & wires…)
  - Institutions (markets, companies, finance…)
  - Policy regimes (institutions, bureaux, regulations…)
  - Economic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

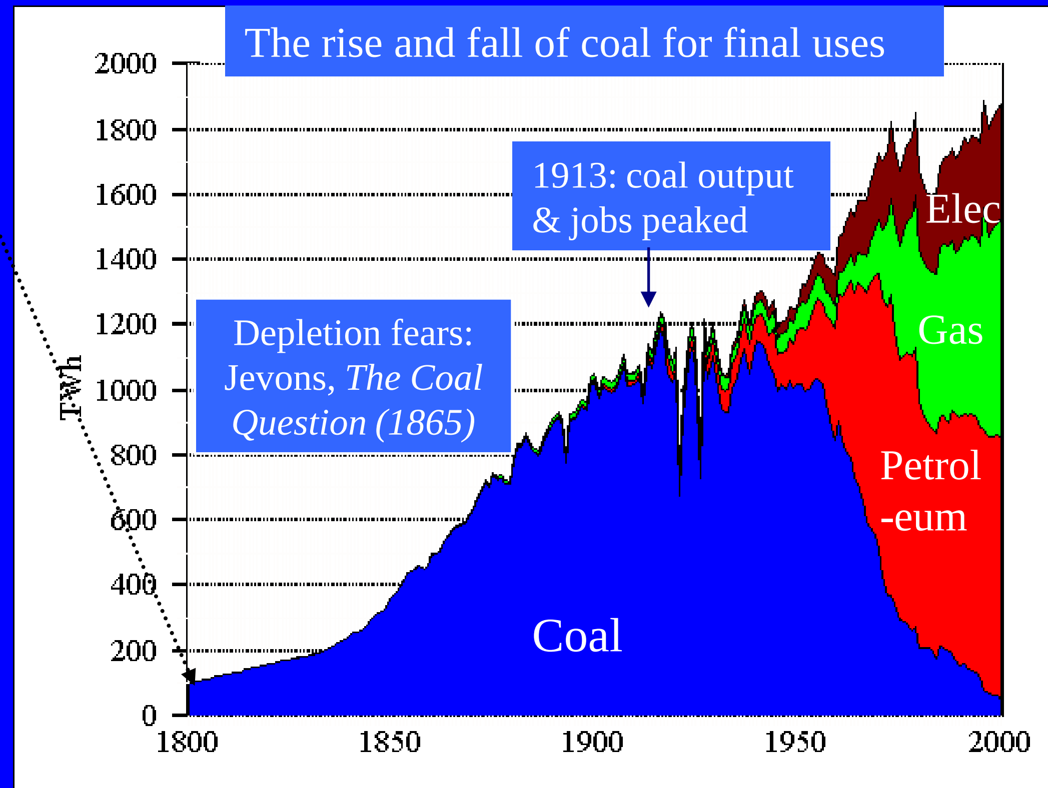
Energy & Britain's 1st 'Industrial Revolution': C16th-19th Energy Transitions

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

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

Fig. 2: UK Final Energy Consumption, 1800-2000 (TWh)





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

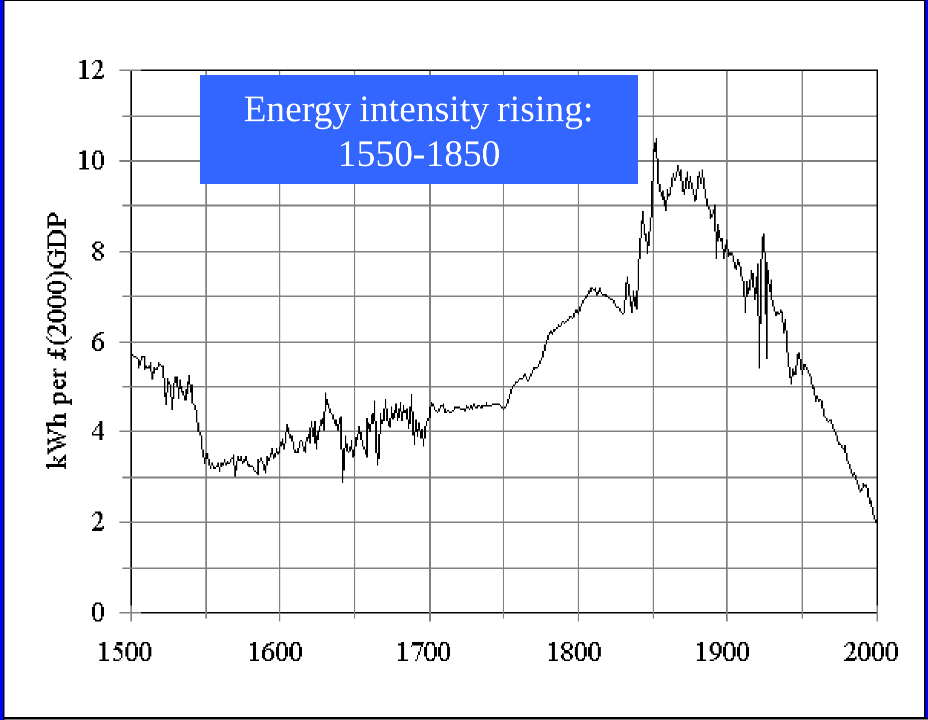
- Allen, 2009: British Industrial Revolution - wages high, energy & capital cheap, relative to other countries in Europe & Asia
- Innovations in steam engines & cotton mills & substitution of coal/coke for wood in metal manufacturing uniquely profitable in Britain

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

Fig. 3: Energy intensity & prices

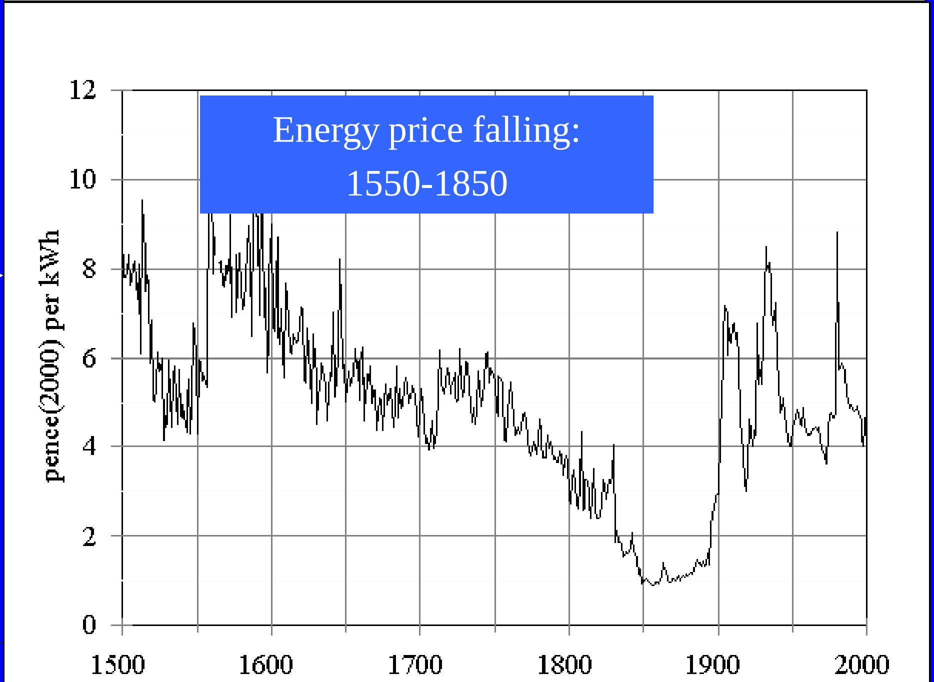
Inverse relationship between:

UK energy intensity (E/GDP) →



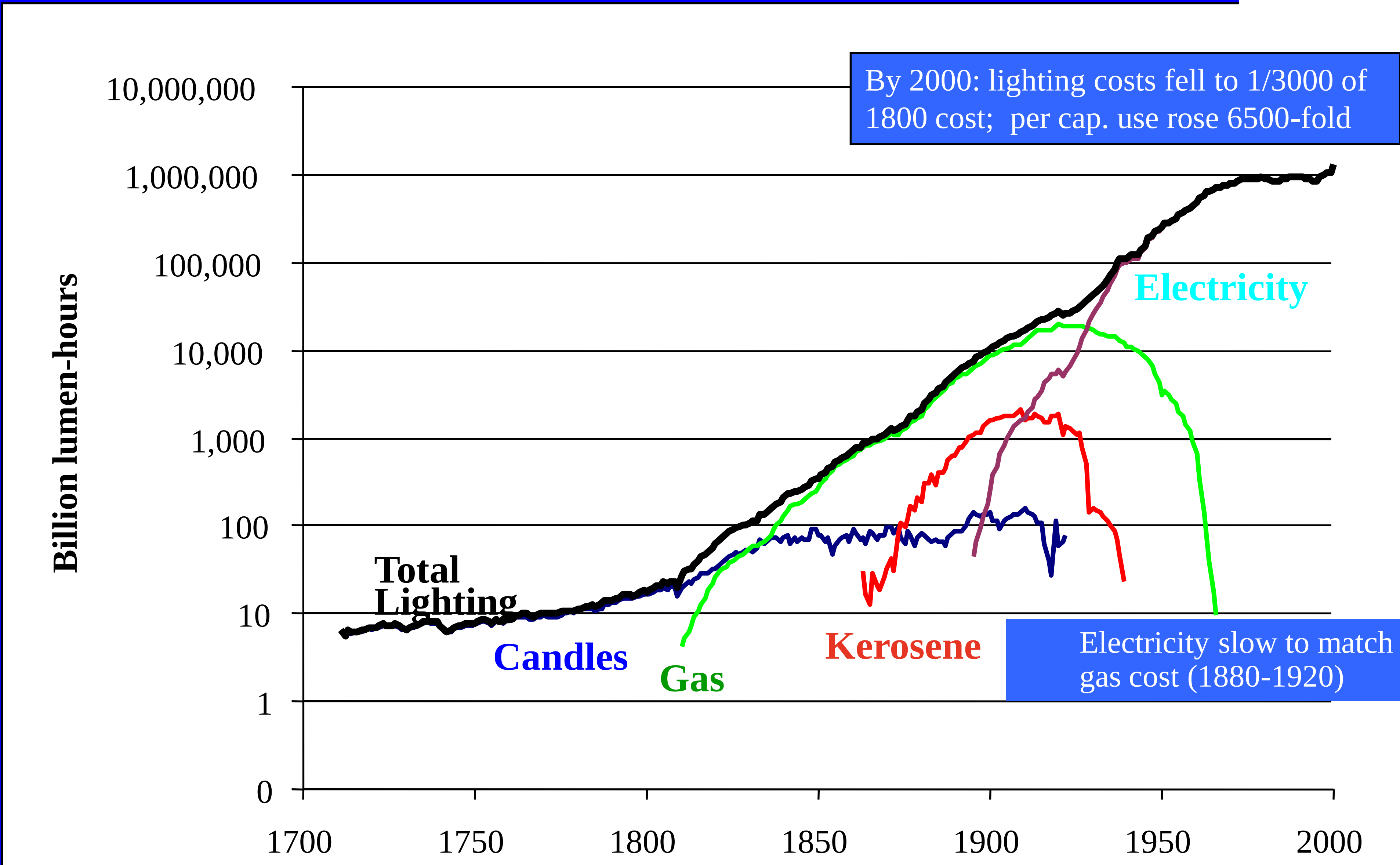
and

Real energy prices (p/kWh) →



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

Fig. 4. 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)

Other Energy Services

Fig. 6. Cost of consumer energy services, 1500-2000

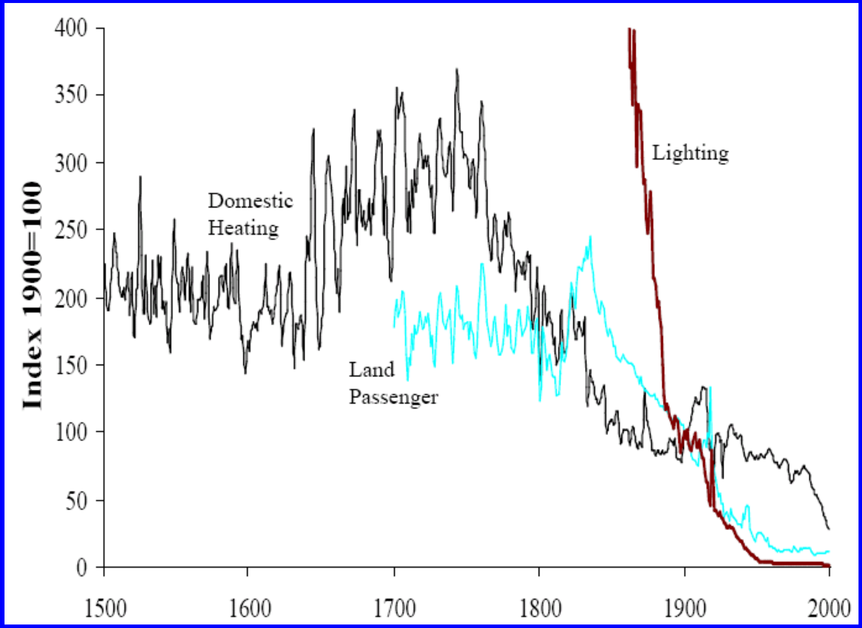
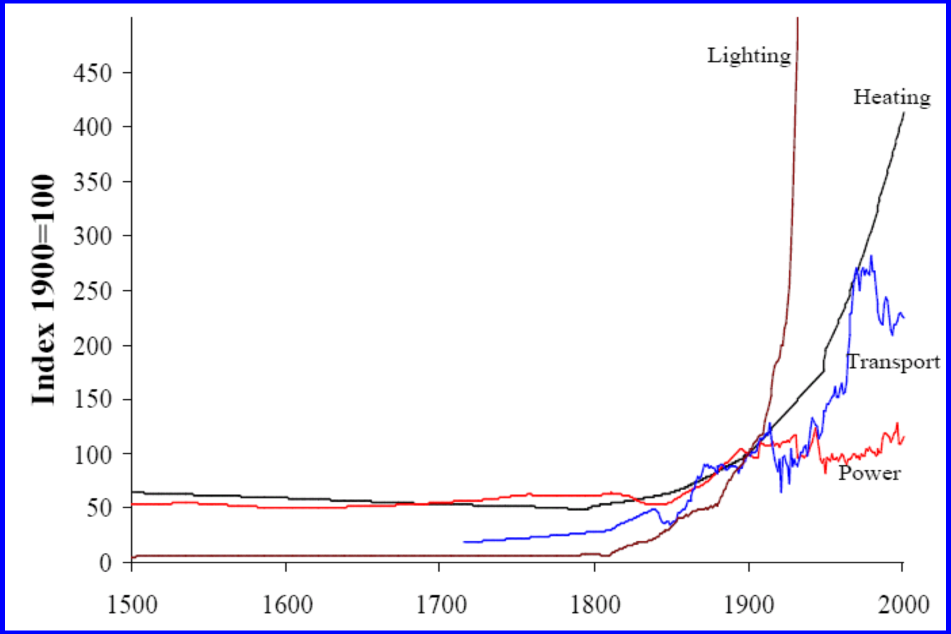
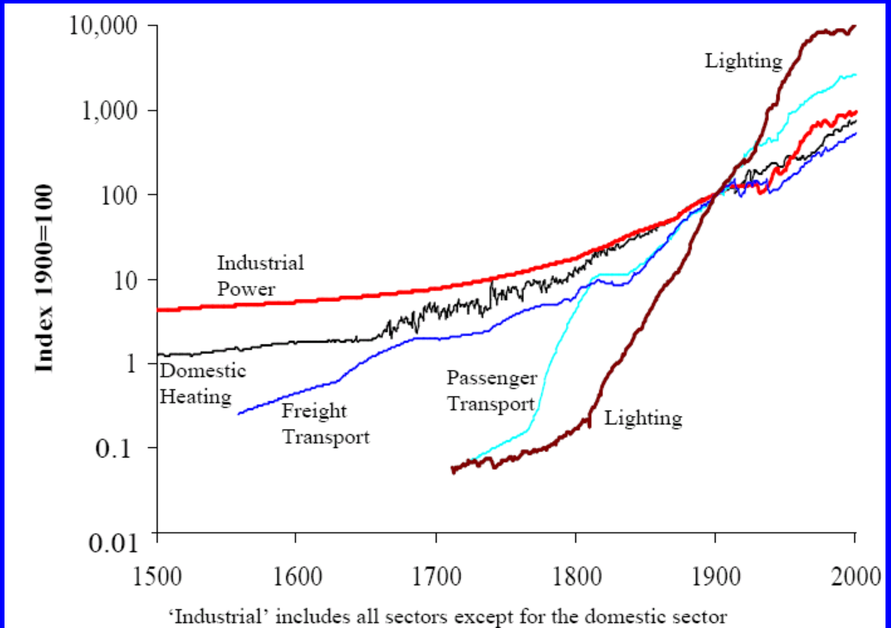


Fig. 5. Efficiency of UK energy technologies, 1500-2000 (index: 1900=100)



Fouquet & Pearson (2007), IAEE conference, Wellington

Fig. 7. Energy services consumed, 1500-2000



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

C18: coal & new steam technologies

- Newcomen 'atmospheric' beam engines pumped water from coal & copper mines (>100 by 1733)
- Boulton & Watt's 'separate condenser' patent (1769-1800)
  - raised efficiency & profits
- Watt (1782) & others developed rotary steam power
  - could now drive machines
- But slow penetration
  - by 1800, only 2200 engines in mining & manufacturing

Steam Power: Development & Diffusion

- High steam/water power price differential slowly overcome
  - By steam's mobility advantage
  - More engine efficiency, from
    - Higher pressure compound boilers (1840s); Corliss valves (1860s)
- Steam let production move from water & wind power sites
  - Helped develop the factory system
  - Especially textiles: Manchester - 'Cottonopolis'
- Railways & then ships & trade
  - Developed national & international transport & markets

A Long-Run Perspective

- New technology diffusion **took time**
  - Major productivity fx. of steam engines, locomotives & ships servable 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

Some Lessons from UK Energy Transitions

- Transitions have profound effects on economy, welfare & environment
  - But took multiple decades for measurable growth effects 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

Fig.8: Turning over the Capital Stock takes Time…

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

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

- Both in Science Museum, London

The Future for Low Carbon Energy Systems?

- Two previous UK Industrial Revolutions were about manufacturing
  - C18 revolution driven by textiles, iron & steam
  - end C19 2^{nd} revolution: electricity, chemicals, petroleum & mass production
- Improved technology (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 3rd 'Industrial Revolution'?

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 given as examples
  - raised productivity growth - but took decades

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 and competitive
- Before being ultimately superseded by the successor technology
- Cited SSE/LGE examples include:
  - Improvements in sailing ships after the introduction of the steam ship in late C19
  - The response of gas lighting, via the Welsbach incandescent mantle, to the 1880s arrival of the incandescent lamp
  - The response of carburettors to the introduction of electronic fuel ignition in the 1980s (Snow)

icept

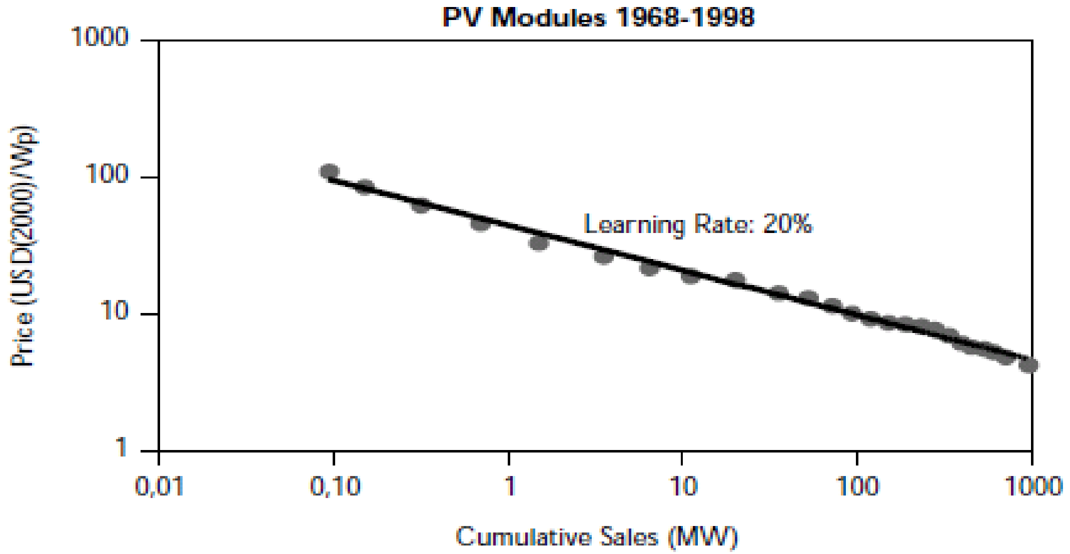
Castaldi & Nuvolari (2003)

- 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 three 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”).
  - Technical change takes place in an environment of high uncertainty which is not in line with neoclassical models of economic analysis (on which the GPT model is based), that assume perfectly informed rational agents and equilibrium.

Edquist and Henrekson (2006)

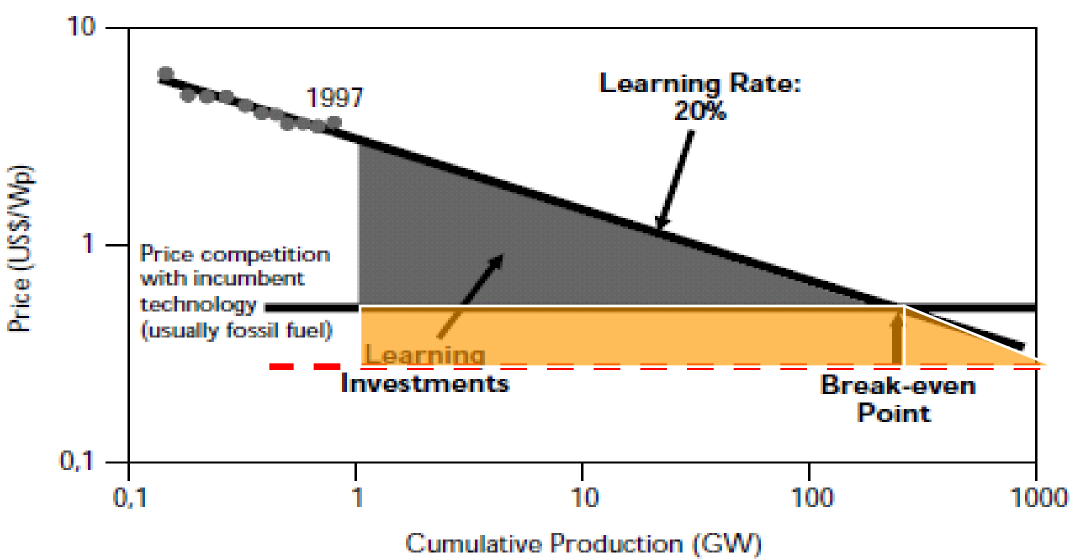
- Explore the impact of the steam engine, electrification & ICT – on productivity growth
- Finds that major technological breakthroughs affect aggregate productivity growth
  - but slowly: 140 years for the steam engine, 40-50 years for electrification & ICT
- Each technological breakthrough offers a 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.

Figure 3.3. Thirty Years of Technology Learning



Source: Adapted from Harmon (2001).

Figure 3.4. Making Photovoltaics Break Even



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 Sailing Ship Effect Hypothesis for Lower Carbon Transitions & Policy

- Significantly increased (price/quality) competitiveness of incumbents, through 'sailing ship' effects & 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 'sailing ship' effects could overestimate penetration
- So, appreciating sailing ship effects/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'?

- How to get 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
- A role for General Purpose Technologies (GPTs)?
  - Such as smart grids (electricity & ICT)
  - But GPTs take time to develop
  - May be slowed by path dependence, lock-in and Sailing Ship/Last Gasp Effects
  - Are contested – empirically & theoretically
- Relative prices and resources
  - If Allen's (2009) message about 1st Industrial Revolution holds for the Low Carbon Revolution,
  - where are the relative prices and physical and human resources needed to drive risky innovation?

Sources

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

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

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)

Foxon, T J, Hammond, G P, Pearson, P J, Burgess, J and Hargreaves, T (2009), 'Transition pathways for a UK low carbon energy system: exploring different governance patterns', paper for 1st European Conference on Sustainability Transitions: "Dynamics and Governance of Transitions to Sustainability", Amsterdam, Netherlands, 4-5 June 2009 http://www.lowcarbonpathways.org.uk/lowcarbon/publications/

Pearson, P J G and Fouquet, R (2003), ‘Long Run Carbon Dioxide Emissions and Environmental Kuznets Curves: different pathways to development?’, Ch. 10 in Hunt, L C (ed.) *Energy in a Competitive Market*, Edward Elgar, Cheltenham.

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 JG(2007) **‘**Revolutions in Energy Services, 1300-2000’, 30th Conference of International Association for Energy Economics (IAEE), Wellington, New Zealand, 18-21 February

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.