An economic perspective on technological transitions related to energy and climate change

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Structure of presentation

• Technological transitions
  • What are they?
  • How do they come about?

• Technological transitions, energy and climate change
  • Why do we need one?
  • What sorts of technologies/changes will be involved?
  • What might a 2050 energy system look like (after a technological transition)?

• How might a low-carbon technological transition be brought about?
What is a technological transition?

• A technological transition is a process whereby a pervasive technological system in a society undergoes fundamental change
  • Pervasive: is important for basic societal functioning
  • System: involves more than one technology, usually with elements of infrastructure
  • Fundamental: the functioning of society is greatly altered
• Examples
  • Sailing ships to steam ships
  • Horse-drawn to horse-less carriages (i.e. Cars)
  • Advent of disruptive technologies
    – Electricity
    – Information and communication technologies
• Low-carbon energy system?
How does a technological transition come about?

Two examples of theories:

• Multi-level system change involving niches, regimes, landscapes (Geels)

• Alignment/co-evolution of social sub-systems (Freeman & Louca)
Technological regimes

• Regime stability/’lock-in’: learning by using; network externalities; economies of scale; increasing informational returns; deployment of complementary technologies (Arthur 1988, p.591)

• Change in socio-technical configuration (Geels 2002, pp.94-5)
  • Economics: price, performance, user preferences
  • Sociology: actors, interactions, institutions, context (also related to existing technology/socio-technical configuration)
  • Socio-technical: large technical systems, networks
Technological transitions - Geels

• Interactions between three levels
  • Landscapes: strong, underlying features of ideology, culture, value systems and policy (e.g. role of state market, ideas of justice/fairness; change slowly
  • Socio-technical regimes: interlocking structures of technologies, infrastructures, social practices and behaviours; stable, because of ‘lock-in’
  • Niches: small markets or protected spaces in which new technologies develop – or not; most niches remain just that, and ultimately disappear
• Under certain conditions niches can destabilise and ultimately displace a socio-technical regime
The development of niches

(Geels 2002a, Figure 3.6, p.110, 2005)

Landscape developments

Socio-technical regime

- Markets, user preferences
- Science
- Policy
- Culture
- Technology

Socio-technical regime is ‘dynamically stable’. On different dimensions there are ongoing processes.

New technology breaks through, taking advantage of ‘windows of opportunity’. Adjustments occur in socio-technical regime.

Elements are gradually linked together, and stabilise around a dominant design. Internal momentum increases.

Technological niches

Learning processes with novelties on multiple dimension. Different elements are gradually linked together.

Time
Co-evolution of social sub-systems – Freeman and Louca

• Need for co-evolutionary alignment between different interacting sub-systems (Freeman & Louca 2001)
  • Science, technology, economy, politics, culture: application to Kondratiev cycles

• The Physical Dimension, which deals with the physical issues involved in the production/storage/distribution/end use of the good or service under consideration, and has the following components:
  • Science the physically possible
  • Technology physical realisation of the physically possible
  • Infrastructure physical (including technical) support and diffusion of the physical realisation

• The Socio-Economic Dimension, which deals with the interests and drivers that push technical change along: entrepreneurs (and profits), consumers (and preferences), and public policy pressures, and has the following components:
  • Economics issues of allocation, distribution, competition
  • Institutions legal, financial, regulatory, planning frameworks
  • Political Drivers social perceptions driving political priority (security of supply, environmental issues) and the planning system, and the policy instruments through which these perceptions are implemented
  • Culture social perceptions driving social acceptability, consumer demand
Technological transitions, energy and climate change - why do we need one?

- Avoiding ‘dangerous anthropogenic climate change’
  - Pre-industrial CO₂ concentrations: 280 ppm
  - Current CO₂ concentrations: 380 ppm
  - Current GHG (CO₂e) concentrations: 430 ppm
  - Rate of GHG concentration increase: 2.5 ppm p.a.
  - Current global average temperature increase since 1900: 0.7°C
  - Target temperature increase for ‘acceptable’ climate change: 2°C
  - Probability that this will be exceeded at 450ppm: 80%
The climate implications of where we’re headed: The next 100 years compared to the last 400

Continuation of recent trends (middle of band) leads by 2100 to temperatures not reached since the Eocene (25-35 million years ago), when sea level was 20-30 m higher.

Source: Professor John Holdren, Harvard University
Emissions scenario to limit temperature change

Fossil fuel related emissions: BAU and emission abatement scenario (GtCO2)

Source: Stern Review, Part III, Chapter 9
The necessary improvements in carbon productivity

- Carbon productivity = GDP/carbon; carbon intensity = carbon/GDP
- Carbon intensity of energy = carbon/energy
- Carbon emissions = Population * GDP/capita * carbon/GDP
- To reduce carbon emissions, reduce either carbon intensity of energy or energy intensity of GDP or both
- To achieve 450ppmv atmospheric concentration of CO₂, assuming ongoing economic and population growth (3.1% p.a. real), need to increase carbon productivity by a factor of 10-15 by 2050, or approx. 6% p.a.
- Compare current increase in carbon productivity of 0% p.a. over 2000-2006, i.e. global carbon emissions rose at 3.1% p.a.; also
- Compare 10-fold improvement in labour productivity in US over 1830-1955, must achieve the same factor increase in carbon in 42 years
What sorts of technologies/changes will be involved – the Socolow ‘wedges’
Potential “wedges”: cuts of 1Gt of carbon per year in 2054

- **Efficient vehicles:** Increase fuel economy for 2 billion autos from 30 to 60 mpg.
- **Nuclear:** Tripling of capacity to 1050 Gwatts.
- **Gas for coal substitution:** 1400 Gwatts of electricity generation switched from coal to gas.
- **Carbon capture and storage:** Introduce CCS at 800 Gwatt coal stations
- **Wind power:** 50 times as much wind power as at present.
- **Solar PV:** 700 times 2004 capacity
- **Hydrogen:** Additional 4000 Gwatts of wind capacity or additional CCS capacity
- **Biomass fuel:** 100 times the current Brazilian ethanol production

*Source: Professor Robert Socolow “Stabilisation Wedges”*
What might a 2050 energy system look like (after a technological transition)?

UK CO$_2$ emissions under scenarios with different carbon constraints
What might a 2050 energy system look like (after a technological transition)?

Sectoral CO₂ emissions in years 2000, 2035, 2050 in different scenarios
What might a 2050 energy system look like (after a technological transition)?

Final energy demand under different carbon constraints
What might a 2050 energy system look like (after a technological transition)?

Electricity generation mix under different carbon constraints
What might a 2050 energy system look like (after a technological transition)?

Sectoral biomass under different carbon constraints

Energy 2050 – www.ukerc.ac.uk
How might a low-carbon technological transition be brought about?

• An unprecedented policy challenge: the Stern Review Policy Prescription
  • Carbon pricing: carbon taxes; emission trading
  • Technology policy: low-carbon energy sources; high-efficiency end-use appliances/buildings; incentivisation of a huge investment programme
  • Remove barriers to and promote behaviour change: take-up of new technologies and high-efficiency end-use options; low-energy (carbon) behaviours (i.e. less driving/flying/meat-eating/lower building temperatures in winter, higher in summer)
The (micro)economic cost: global cost curve for greenhouse gas abatement

Cost evolution and learning rates for selected technologies

Source: IEA, 2000, Stern Review, Chapter 9
Policies for carbon reduction

• Huge policy innovation over the last ten years; we know what to do
• Limited results from these policies; we don’t apply the policies hard enough
• Carbon emissions still rising in most industrial (let alone developing) countries
• Many policies need local implementation/enforcement
• (Much) More stringent application of policy instruments (especially price-based to avoid rebound effects)
• Political feasibility
• Implications for economic growth
The macro-economic costs of climate change mitigation

• Optimists:
  • ‘Costs’ are really investments, can contribute to GDP growth
  • Considerable opportunity for zero-cost mitigation
  • A number of low-carbon technologies are (nearly) available at low incremental cost over the huge investments in the energy system that need to be made anyway
  • ‘Learning curve’ experience suggests that the costs of new technologies will fall dramatically
  • Climate change policies can spur innovation, new industries, exports and growth

• Pessimists:
  • Alternative energy sources are more expensive, are bound to constrain growth
  • Cheap, concentrated energy sources are fundamental to industrial development
Scatter plot of model cost projections, 2000-2050

Each point refers to one year’s observation from a particular model for changes from reference case for CO2 and the associated change in GDP (from four sources, for periods over 2000-2050)

- IMCP with ITC dataset
- post-SRES dataset
- WRI dataset (USA only)
- EMF-21 with multigas
Policy conclusions

- Attaining the 2°C target or anything near it will require huge investments in low-carbon technologies right along the innovation chain (research, development, demonstration, diffusion).

- IEA ETP estimates of additional investment needs in energy sector: USD 45 trillion (1.1% global GDP from now until 2050)
  - Buildings and appliances: USD 7.4 trillion; Power sector: USD 3.6 trillion
  - Transport sector: USD 33 trillion; Industry: USD 2.5 trillion

- Government funding of R,D&D must increase dramatically, but demonstration and diffusion can only be driven at scale by markets

- This will require high (now) and rising carbon prices over the next half century, to choke off investment in high-carbon technologies (e.g. runways) and incentivise low-carbon investments

- These high carbon prices will also greatly change lifestyles and consumption patterns

- Provided that the world goes cooperatively in this direction, there are enormous profits to be made from these high carbon prices and changing consumption patterns

- Technological and policy uncertainty mean that the risks are also high
Overall conclusions

• The innovation potential exists for a transition to a low-carbon energy system to be technologically feasible, economically feasible

BUT

• It requires sustained, wide-ranging, radical policy interventions to bring about technological revolution and change lifestyles.
• These interventions are resisted by affected economic sectors (e.g. energy) and households who want to keep current lifestyles (e.g. transport), or attain Western lifestyles
• Politicians may not be able to bring about a low-carbon technological transition before runaway climate change