Path Dependence in Energy Systems

Lecture 5
What determines which energy technologies are in use?

- Technically best choices from technologies available?
Some different rich-country energy choices

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Energy flow diagram for countries in 2007 removed due to copyright restrictions.
What determines which energy technologies are in use?

- Technically best choices from technologies available?
  - Probably not: different rich countries make different choices – French nuclear, EU v. US rail & transit systems…
  - Surely incomplete: What determines rate/direction of innovation and thus the set of available technologies at any time?

- **People** make choices – individual & collective – not always “optimal”; the market just coordinates

- History: culture shapes individual & collective choices
  - Chinese failure to exploit massive advantages in many areas
  - Dutch/Danish decision to retain reliance on bicycles

- Main focus today: three ways past energy decisions shape future ones -- versions of path dependence
1. Cost of **durable** capital is important in many energy technologies/systems

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Sunk costs don’t matter, but…

• Suppose your plant produces Q units of output/year.
  ● Variable cost is \( v \) per unit.
  ● Plant cost \( F \) to build, will last \( T \) years, interest rate is \( r \)
  ● New plant: variable cost \( v^* \), costs \( F^* \) to build, will last \( T \) years
  ● When do you scrap the old plant & replace with the new one?

• Use continuous compounding: \$1 in \( t \) years = \( e^{-rt} \)
  ● Compound \( n \) times/year: \( 1/[(1 + r/n)^n]^t = 1/[(1+1/z)^z]^t, z=n/r \)
  ● \( \lim z\to\infty = \lim n\to\infty = e^{-rt} \)

• Compute unit capital cost \( c^* \):
  \[ F^* = \int_0^T c^* Q e^{-rt} \, dt = \frac{c^* Q}{r} [1 - e^{-rT}] \]
  • \( c^* \) falls with \( T \), rises with \( F^* \); for \( T \) large, \( c^* \to rF^*/Q \)
  • \( F \) sunk, but only scrap if \( [v^* + c^*] < v \); tougher the more important are capital costs in old (\( v \) low), new (\( c^* \) high)

• \( T \) is very large for institutions, know-how, policies…
Old generating plants live on...

- Coal plants have large $T$, large $c/v$, large up-front cost
  - If replacement cost = $R$; economic cost of replacing $x$ years early = $R[1 - e^{-rx}]$

- Clean Air Act $\Rightarrow$ EPA sets standards for new plants; raises their cost v. old (dirty) ones; slows replacement

2. Big changes in policy regimes often very disruptive – hence rare

- Rational policy inertia (decades) → inertia in technologies used
  - Architecture of clean air act unchanged since 1970s; not up for debate absent serious problems
  - Ag price supports, tax subsidies for oil drilling seem immortal
  - London pre-WWI electricity system

- Gawande on health care reform: different universal health care systems because of inertia, different prior regimes:
  - UK: government ran health care during WWII (US ran many industries, but not health), easy to continue post-war
  - France: chaos post-WWII; built system on pre-war funds
  - Swiss: only had private insurance; universal system simply required purchase, subsidized low-income
  - US: got employer subsidies to get around WWII wage controls; tax-exemption an economic mistake, but immortal
  - MA: built on employer-based system, no change for most
3. Early choices can fix later path because of +interactions on the path

- Classic definition (Mahoney): initial choice, not inevitable (“contingent”), fixes later path – for a while

- Classic example: QWERTY keyboard chosen to minimize jamming on old mechanical typewriters
  - Some say endured beyond technology even though inferior to Dvorak because of mass training, value of standard; hard to change
  - Evidence of inferiority weak, and could buy Dvorak keyboards for a while – arbitrary choice can persist if performs OK, change hard

- Second example: Swiss watch-making, started early on because Swiss farmers had time in the winter
  - Over time built up design expertise, pool of skilled workers, training centers, distribution channels – tough to dislodge
  - Initial location somewhat arbitrary (why not Danish farmers?), but once set, advantages build, tough to dislodge
Energy Examples of +Interactions: Institutions & Physical Systems

• Caveat: Unruh has good framework but over-states – DC not superior to AC early; electric cars weak…

• Gasoline autos:
  - R&D, training
  - Jobs → clout
  - Road network
  - Culture adapts
  - Policy supports
  - Driving → taxes
  - Firm-level rigidities – companies tend to focus on getting better at what they are good at, not leaps (Palm, BlackBerry, GM)
  - “Historically derived subjective modeling of the issues” – autos as central to “the American lifestyle,” shapes debates
More examples of +interactions in energy systems – not all pro-carbon

- Electricity:
  - Appliances
  - Training
  - Jobs
  - Habits
  - …

- Air travel (planes, airports, training, legislation, jobs…)
- Natural gas for heating (wells, pipelines, laws, regs)
- Broadly, US on an energy-intensive path v. other countries with equivalent education, health, etc.
- But bicycles in Amsterdam? Subway in London?
So energy systems can’t be changed?

• Has been done, can be done, despite clear “lock-in” effects
  
  • Sometimes just takes R&D – sail to steam, gas to electric lights, coal to diesel locomotives
  
  • Sometimes takes changes in policy – interstate highway system, limited liability for nukes, environmental policy hitting coal generation
  
  • Often new systems face chicken-egg problems: lights for electricity, roads for cars, stations for natural gas cars


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