Technological change in energy/economic/policy modeling

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Why are we having this meeting?

- Assumptions about technological change are key determinants of energy/climate policy costs and effectiveness
- Technological change *is* a function of economic forces and policy actions
- Possible policy actions include not just emissions policy, but also policies directly targeted at technology
- The process of technological change is complex and inherently difficult to model
  - That's why we did not put this to rest long ago…

Overview of talk

- Defining technological change
- The microeconomics of technological change
  - Process of technological change
  - Technology supply and demand
  - Market failures and policy responses
- How is technological change currently modeled?
- A note on opportunity costs
- What we know and don't know

Defining technological change

- Technological change is the process by which the economy changes over time, in terms of the products produced and the processes used for production, so that a technological advance...
  - enables the production of greater output from the same inputs as time proceeds (or the same output with lesser inputs)

$$Y = F(K, L, E, M) \cdot A(t)$$

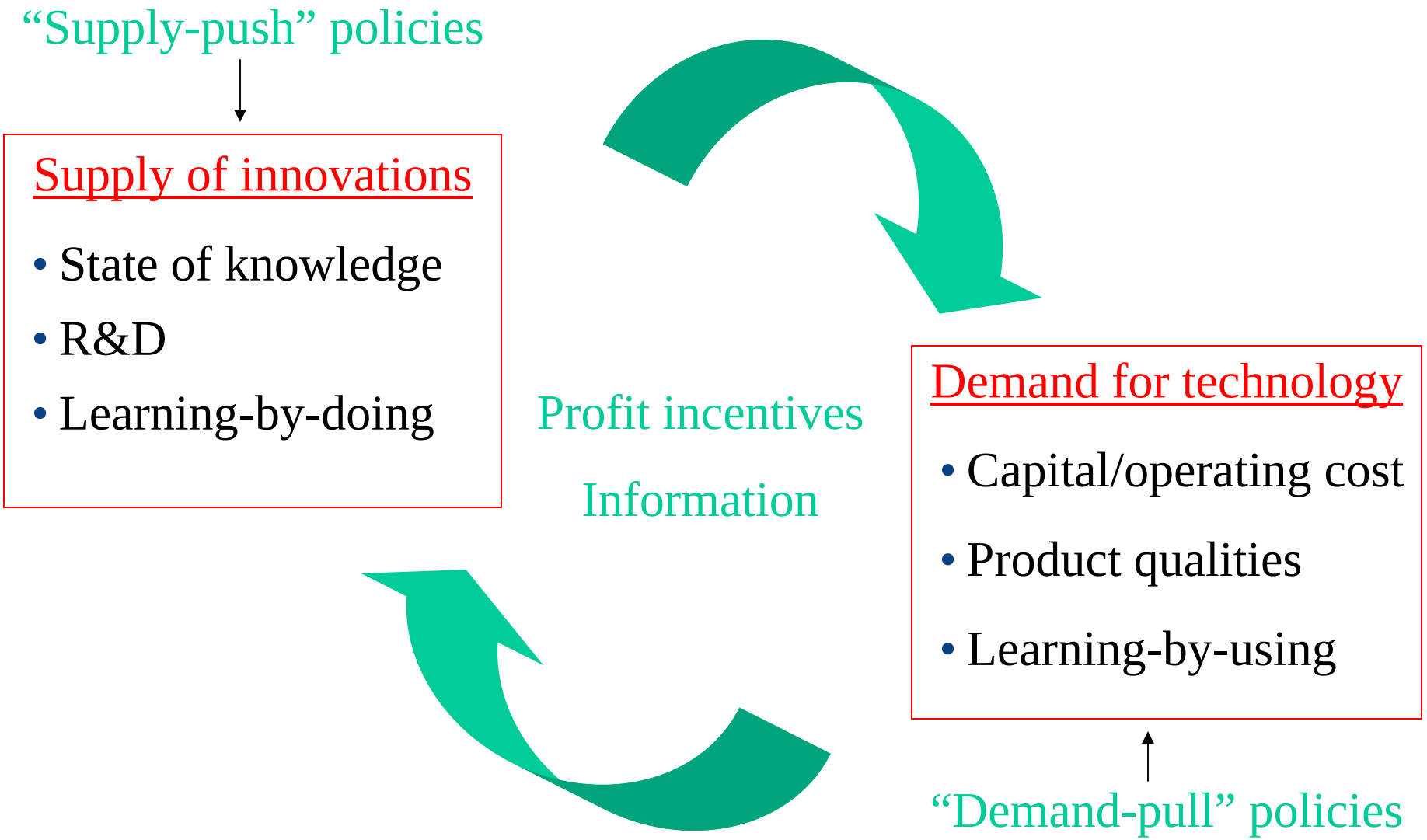
look at changes in Y over time

$$\%\Delta Y = \%\Delta K + \%\Delta L + \%\Delta E + \%\Delta M + \%\Delta A$$

The process of technological change

- Invention
  - prototype product or process (R&D)
- Innovation
  - initial commercialization
- Diffusion
  - what equipment is purchased by firms and consumers?

Technology supply and demand



Potential market failures in tech. change

- Unpriced or under-priced environmental externalities
- Positive innovation and adoption spillovers

Spillovers and appropriability

- Once created, innovation profits are difficult for firms to capture/appropriate due to spillovers
  - purchasers capture value due to competition
  - other firms/sectors/countries benefit from the new knowledge
- While other things equal this may be a good thing, it tends to lead to an underinvestment in R&D
  - reflected in a divergence between the private versus social gains from innovation; ~25% vs. 50% return
- Similar story holds for learning-by-doing-and-using, if learning spills over to other firms/users

Potential market failures in tech. change

- Unpriced or under-priced environmental externalities
- Positive innovation and adoption spillovers
- Imperfect information
  - on the availability, benefits, and costs of technologies
  - regarding the risks and rewards from investing in innovation

Potential policy responses

- Environmental policies
  - Emission price, performance standards
- Innovation policies
  - R&D funding, tax incentives, prizes, education
- Adoption policies
  - Tax credits, rebates, standards, procurement
- Information policies
  - Labeling, partnerships, audits, training

How is technological change typically modeled in climate policy assessments?

- Exogenous/autonomous
- Endogenous/induced
- Some mixture of both
- Approaches are model dependent

Exogenous technological change

- Many (most?) energy/climate policy models assume some form of exogenous technological change
  - improvements are a pre-ordained function of time, unresponsive to any policy incentives
  - e.g.: AEEI, or technologies enter after some point in time
  - dependent on model formulation (e.g, degree of disaggregation)
  - Models: DICE, DGEM, EPPA, GREEN, G-CUBED, MACRO, SGM, AMIGA

Induced technological change

- Three primary avenues to incorporating induced technological change have been taken
  - learning curves
  - R&D investments
  - direct “reduced form” relationship between energy prices and technological change (e.g., energy-efficiency improvement)
    - Models: ICAM3, NEMS

Learning curves

- Learning curves represent learning-by-doing through a direct relationship between product cost and cumulative production experience

$$C = c_0 Q^{-\beta}$$

- Production experience with a technology leads to cost reductions, which endogenizes technological change because policies increase demand for certain technologies
- Models: MARKAL, MESSAGE, NEMS

R&D investment in knowledge stock

- Explicit representation of R&D investment in a "knowledge stock", analogous to investment in physical capital
- The knowledge stock enters the production function and lowers carbon abatement costs either directly or indirectly
- Models: R&DICE, Goulder and Mathai, Goulder and Schneider, Sue Wing-EPPA, Popp
  - Goulder and Mathai use same framework to analyze learning by doing

A note on spillovers and opportunity costs

- Almost all these models neglect treating spillovers
  - Goulder and Schneider and Sue-Wing are exceptions
  - spillovers imply a divergence between private and social opportunity cost of R&D, and differences in the value of R&D in different sectors
- Many of these models neglect a proper treatment of the opportunity costs of innovation
  - learning may not be as “free” as many models assume
  - endogenizing technological change just for carbon-friendly technologies risks neglecting these opportunity costs

What we do and do not know

- What we know
  - innovative activity does respond to markets/policy
  - the technological change process involves significant market imperfections
  - conceptually how to endogenize technological change in simple models while properly accounting for costs
- What we don’t know
  - how to endogenize technological change in more disaggregated models while properly accounting for costs
  - empirical values for relevant behavioural relationships

Normative versus positive modeling

- What is the goal of the model?
- Predict the energy/emissions response to a particular policy change?
  - reduced form relationships like learning curves may be useful
- Or assess full economic costs of policies?
  - reduced form relationships will not properly account for opportunity costs
- That is, are positive or normative questions being asked of models?