Endogenous Technological Change and Uncertainty in Energy System Modeling: Implications for Climate Policy

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Policy background

• Energy technology costs often drive policy assessments
  – Technological change (TC) drives optimal level, timing, and cost of abatement over long run

• Recent trend in targeted technology policies aimed at innovation market failures
  – To keep pace with policymakers, many IAMs endogenize TC
  – Host of uncertainties and methodological issues

• Does the current practice of certain ETC understate the cost of climate policy?
Approaches to modeling technology change

• Exogenous: technology cost fixed outside of the model
  – Common practice for both aggregate and detailed models

• Major criticism – not responsive to technology-specific policy initiatives

• Endogenous technological change: technology cost is a function of model variables, determined by the model itself
  – Learning-by-doing brings about incremental improvements to production and allows firms to lower costs (Arrow 1962)
  – Correlates cumulative experience to performance

\[ C_t = C_0 \left( \frac{q_t}{q_0} \right)^{-b} \]

\[ PR = 2^{-b} \]
Figure 1.5. Electric Technologies in EU, 1980-1995

- Photovoltaics (~65%)
- Wind power - average (82%)
- Wind power - best performance (82%)
- Electricity from biomass (~85%)
- Supercritical coal (97%)
- NGCC (96%)

Source: IEA, 2000
Methodological notes

• Data availability and consistency, especially new entrant technology
• Critiques: R&D, spillover effects (mis)attributed to learning, costless, hindsight bias
• Advanced formulations address many limitations, e.g., component-learning model, multi-factor experience curve, technology clustering, segmented learning
• Additional concerns specific to optimization, e.g., non-convex, implied causality
Learning and R&D can impact optimal abatement profile and policy costs

• Endogenous TC lowers policy costs; impact on optimal abatement pathway depends on innovation mechanism

• This work re-examines findings under the lens of uncertainty
• If we account for uncertain tech change, what is the implication for the level, timing, and cost of CO$_2$ abatement?
Stylized electric system model examines uncertain technology change

• Objective minimizes total cost of meeting electricity demand
  – Available generation is dispatched to meet annual demand, new capacity added as necessary to meet growing load with least cost
• Supply-side: detailed set of generation technologies
  – Capacity addition vs. dispatch
  – Capital costs undergo ETC via learning curves vs. fixed costs
• Two key features address dimensions of uncertainty
  – Temporal foresight: perfect vs. limited
  – Stochastic learning: certain & constant vs. uncertain & stochastic process
• Demand-side: single aggregate annual demand (no operational constraints)
• Scope: aggregate US electric system, partial-equilibrium
• Near-term timescale: 2012 – 2040, 5% discount rate
• Policy cases explore a range of CO₂ prices, escalating from 2015
• NLP implemented in GAMS
Set of 9 electric generation technologies

- Technologies characterized by capital and O&M costs, heat rate, CO$_2$ emissions rate, installed capacity per AEO2013
- Technology learning applies to incumbents & new-entrants

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<th>Technology</th>
<th>Capital Cost $/kW</th>
<th>Heat Rate BTU/kWh</th>
<th>VOM cost $/MWh</th>
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Results outline

• Carbon policy outcome for $20/ton tax
  – Perfect foresight, certain learning
  – Limited foresight, certain learning
  – Limited foresight, uncertain learning

• How the electric system evolves
  – Certain vs uncertain learning under a range of carbon policies

• Impact on the marginal abatement cost (MAC) curve
Under $20/\text{tCO}_2$ with perfect foresight, certain learning decreases total emissions.
Cumulative CO$_2$ emissions are higher under limited foresight.

With limited foresight, total emissions increase for the same $20 tax.

Learning consistently decreases CO$_2$, but total emissions still higher.
Certain learning overstates emission cuts under a $20/tCO_2$ policy

When we account for uncertain TC, total emissions increase 12GtCO_2 – at $20/ton, an additional $240B
Electric system in “no policy world” relies on fossil generation
Electric system mix at $10/ton

CCS only comes in under learning, when planner’s expectation of carbon price hits $65/ton
Electric system mix at $20/ton

Nuclear relied on to decarbonize when CCS isn’t an economic option.
Electric system mix at $50/ton

Without learning, CCS isn’t deployed until planner expects CO₂ prices above $200
2025 MAC curve illustrates effect of uncertain learning on climate policy.
Does endogenous tech change provide meaningful policy insight?

• Evidence of endogenous change & tractability of experience curve is attractive

• Important to analyze technology-specific policies
  – Focus here on CO$_2$ price but RPS, CES remain for future work

• Yet, if not done carefully, can misinform policy
  – These results caution against assuming certain TC – robustly shown to overstate climate goals and understate policy costs
  – Not all models can accommodate the added dimensionality of a limited foresight, stochastic setting
  – If so constrained, well-informed exogenous technology costs may be more instructive
Questions and discussion