Environmental Economics and Innovation

LSE EEE Presentation

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Environment and Innovation - Why Should People Care?

Innovation $\approx$ Reducing the costs of pollution mitigation options and the costs of substitutes to depleted natural resources

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This is important because:

- Improves cost-effectiveness of environmental policies
- Reduces political economy constraints of environmental policies
- Eases trade-offs between environment and development

$\Rightarrow$ Faster and deeper progress on environmental goals

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- The result of costly **investment** made based on expected returns.
- NB: For firms, whether it pays itself off largely depends on env. policies.

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Clean Innovation $\Leftrightarrow$ Environmental Policy

Environment and Innovation - Why Should Economists Care?

What can economics bring to the table?

- Are we underinvesting in it? To what extent? Size of the market failures.
- How do clean innovation policies interact with other environmental policies (e.g., carbon tax)?
- Elucidating mechanisms to foster clean innovation (micro questions on the who, where, and how)

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Competition for resources:

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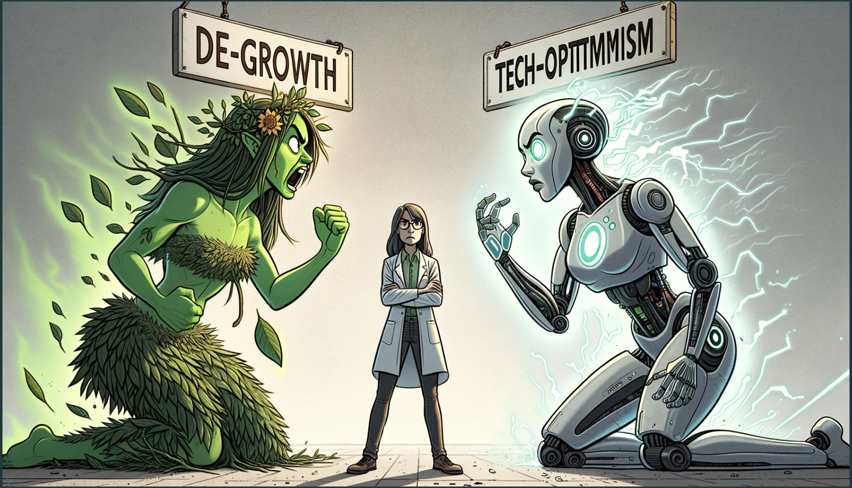
Case for public investments in energy R&D need empirical/quantitative evidence
Competition for resources:

- Funding for **other types of R&D** (defence, health, space...)
- Funding for **clean tech adoption** ("we have the technologies")

Bringing science and evidence-based arguments to the debate...



Prior Work - What Have We Learned?

Useful literature reviews:

Dechezleprêtre and Hémous (2022), Popp (2019), Popp et al. (2010)

MACRO

"Directed Tech Change"

Combining carbon pricing and R&D subsidies is optimal. Importance of path dependency.

Acemoglu et al. (2012, 2016, 2019), Aghion et al. (2016), Fried (2018), and Lemoine (2023)

MICRO

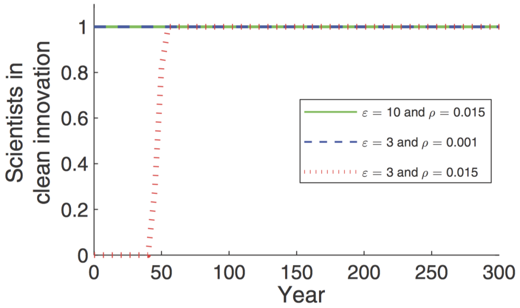
"Induced Innovation"

Clean innovation can be induced by higher energy prices, environmental policies (regulations, pigouvian fees and demand subsidies)

Calel and Dechezleprêtre (2016), Gerarden (2023), Noailly and Smeets (2015), and Popp (2002)

MACRO

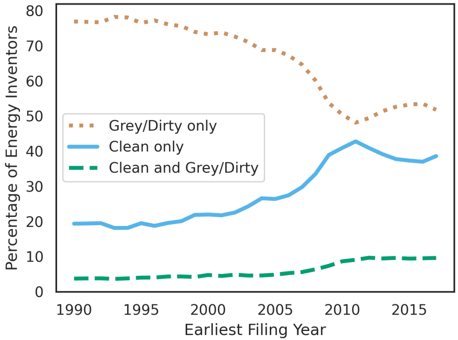
What scientists should do



Acemoglu et al. (2012)

MICRO

What inventors have done



Dugoua and Gerarden (2023)

Going Forward - Two (Important) Avenues (in my biased opinion)

Human Capital

Which inventors are the more elastic? How to design policies (e.g., R&D subsidies) to maximize output?

Ongoing projects:

- Induced Innovation, Inventors, and the Energy Transition
- How DOEs Government Funding Fuel Scientists?

Global Cooperation

How to design international agreements that increases incentives for innovation? How to foster clean innovation in global industries?

Ongoing projects:

- Induced Innovation and International Environmental Agreements: Evidence from the Ozone Regime

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Induced Innovation and International Environmental Agreements: Evidence from the Ozone Regime*

EUGENIE DUGOUA†

Motivations

- Global collective action problems
  - Some of the most pressing issues facing humanity
  - Progress has been limited (e.g., climate change, biodiversity...)
- There is one shining exception: the fight against ozone depletion
  - Ozone depletion caused by industrial gases: CFCs
  - Montreal Protocol negotiated in 1987
  - Stratospheric ozone on the recovery
- What role did science and innovation play in the ozone crisis?
  - Did the agreement induce innovation?
  - No quantitative analysis available until now

This Paper

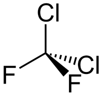
- Question: Did Montreal foster science and innovation on CFC substitutes?
- Data: Full text of scientific articles and patents
- Methodology
  - Track documents mentioning CFC substitutes
  - Construct panel datasets: # documents mentioning molecule i in year t
- Identification of the causal effect
  - Difference-in-differences (DiD) and Synthetic Control Method (SCM)

    ⇒ control units: Hazardous Air Pollutants (HAPs)
  - Topic modeling of the documents' text:

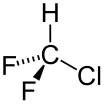
    ⇒ molecule-level topic proportions to account for possible confounder
- Interpret the results in light of the theory on International Environmental Agreements
  - Modify workhorse model of IEAs by adding induced innovation

Developping CFC Substitutes

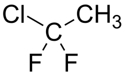
- Examples of CFCs and CFC substitutes:



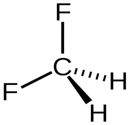
CFC-12



HCFC-22



HCFC-142b

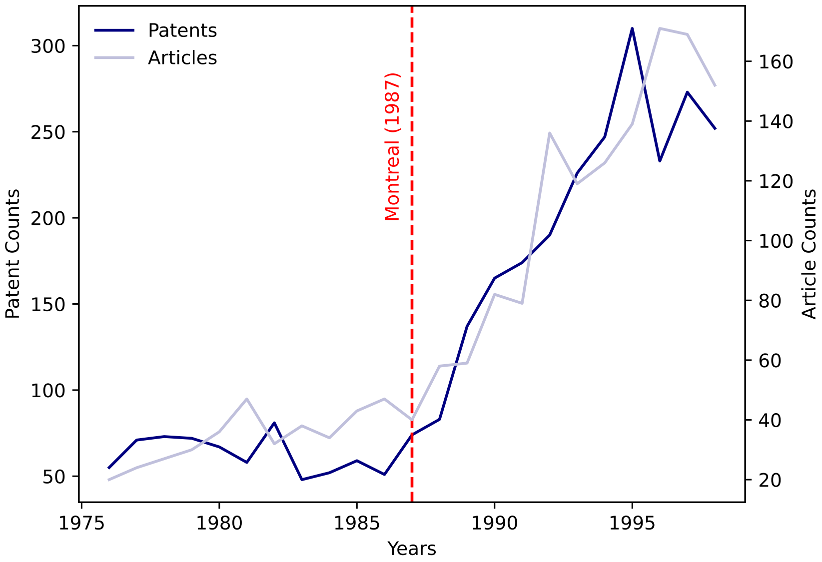


HFC-32

$\Rightarrow$ Molecular structures of potential substitutes were known

- Instead, the key technological challenges were about:
    - Making large scale production cost-efficient
    - Redesigning processes and equipment already installed
    - Learning about environmental acceptability and human toxicity
- I compile a list of 14 molecules identified as potential substitutes in a 1988 report on the atmospheric dynamics of potential substitutes

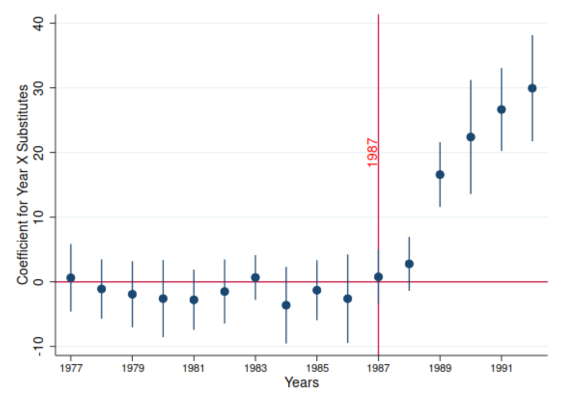
Results: Patent and Article Counts Increase after 1987



DiD Controlling for Topic Proportions

Patents

≈ 400% increase



Table

Articles

≈ 580% increase

Table

In Short

- The Montreal protocol triggered an increase in research and innovation on CFC substitutes
- Inconsistent with the narrative of “CFC substitutes being available”
- How does this fit with the theory of International Environmental Agreements?
  - Barrett (1994): Cooperation happens only when it’s not needed...
  - Similar reasoning in other models (Harstad et al. 2019)
  - Interpretation of Montreal in this context: $\approx$ unilateral action
- These models of IEA ignores the role of induced innovation

New Interpretation, New Lesson

Modest Agreement $\Rightarrow$ Induced innovation $\Rightarrow$ Deeper Agreements

- Targets agreed in Montreal can be thought as not very ambitious
    - Maybe encoded unilateral actions (low costs, high benefits)
    - Consistent with IEA theory
- But targets were binding (trade measures)
    - Guaranteed a worlwide market for future substitutes
    - Required experimentation and R&D work
    - Induced innovation and lowered expected abatement costs
- Enabled more ambitious targets in 1990 and 1992

Lessons for other environmental problems?

- Cooperation problems with high MAC need not be doomed
  - Ozone cooperation was successful because the beginning of the MAC curve was expected to be low and a binding treaty could be negotiated
  - That ascertained a worldwide market for subtitutes (even if small) which incentivized firms to invest in R&D which lowered abatement costs
- Small but binding commitments can induce innovation and lower costs
  - Unlikely that ambitious but non-binding pledges can do the same
  - Leveraged trade to create an enforcement mechanism (potential for a climate clubs à la Nordhaus (2015)?)
  - Focused very much so on one sector (the chemical industry)

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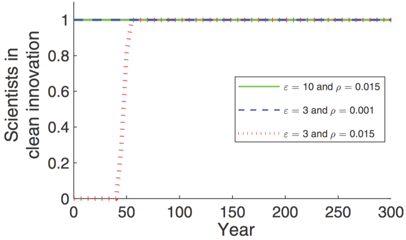
Induced Innovation, Inventors, and the Energy Transition*

Eugenie Dugoua[†]
London School of Economics

Todd Gerarden[‡]
Cornell University

In Acemoglu et al. (2012), the pool of scientists switches from dirty to clean.



- It takes years to train in a particular field, to develop particular skills. And so scientists may face adjustment costs. This raises a series of questions:
- To what extent can inventors be induced to work on different things?
- What is the role of new entrants vs incumbents?
- These questions matter for the speed at which directed technological change will materialize in the short and medium term.

Induced Innovation, Inventors, and the Energy Transition

- We document the types of inventors behind clean innovation and the extent to which they respond to economic incentives
- Measure innovation using global data on patent applications (PATSTAT)
  - Electricity generation-related patents (classified based on patent technological codes)
  - Inventors with at least one OECD patent post 1990
- Document stylized facts about energy inventors
- Estimate how individual inventors respond to changes in natural gas prices

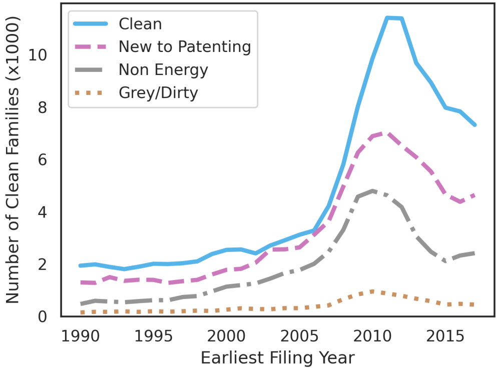
  Both intensive and extensive margin responses

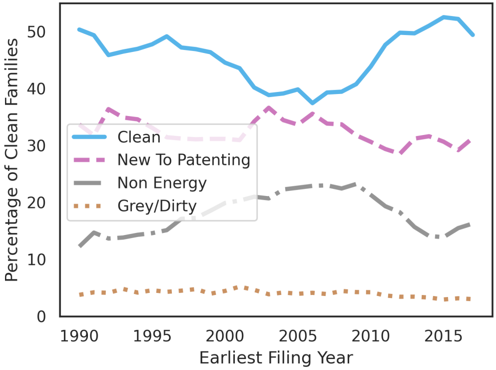
  Natural gas prices $\uparrow$ $\Rightarrow$ expected demand for substitutes in the future $\uparrow$

  Simulate how inventors would respond to carbon pricing

    Using a SCC of 51 $/tCO2

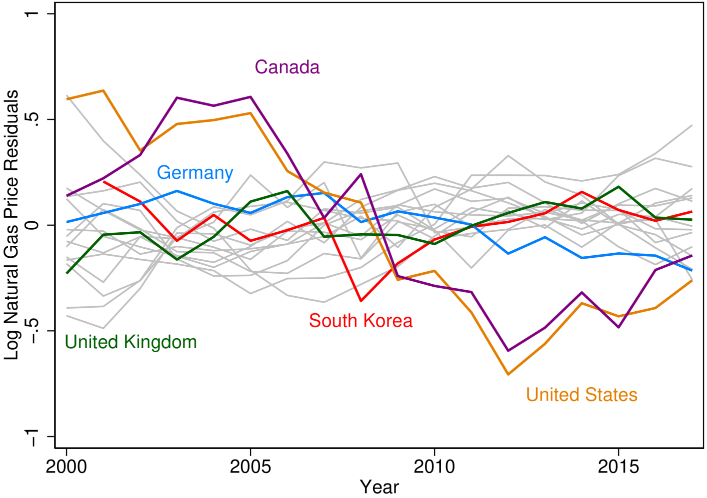
About Half of Clean Patents Come from “New Entrants”





Identifying Variation: Quasi-Random Changes in Natural Gas Prices

- Due to transportation constraints
- After accounting for country and time fixed effects



Response at the Intensive Margin: Output Elasticity of Incumbents

$$PAT_{it}^{C} = exp(\beta_P \ln P_{it-1} + \beta_X X_{it-1}) + u_{it}$$

- PAT_{it}^{C} is the count of clean patent families by inventor i in year t
  - Estimation via Poisson pseudo maximum likelihood
- P_{it} is the price of natural gas that inventor i is exposed to at time t
  - Garage inventors: price of home country
  - Corporate inventors: price that the firm they are associated with are exposed to
  - If associated to several firms: average weighted by the share of inventor i's energy patents that are associated with firm j
- X_{it} includes inventor and year fixed effects, GDP per capita, and RD&D budgets
  - Inventor and Year f.e.
  - "Tenure" f.e. (i.e., number of years since first patent)
  - Energy and low-carbon RD&D budget (data from IEA)
  - GDP and GDP per capita (from the World Bank)

NB: Adaptation of Aghion et al. (2016) and Noailly and Smeets (2015) to Inventor Level

Constructing Firm-Level Prices

- We construct firm-level prices as weighted average of country-level prices:

$$\ln P_{jt} = \sum_c \frac{s_{jc} GDP_c}{\sum_c s_{jc} GDP_c} \ln P_{ct}$$

  - P_{ct} is the average tax-inclusive natural gas price in country c in year t
  - GDP_c weighting adjusts for differences in market size across countries
  - s_{jc} captures exposure of firm j to country c
- We calculate s_{jc} as firm j's share of energy patents in country c
  - Robustness checks with pre-period 1990-1999
  - Firms with no pre-period: equally exposed to all countries (weighted by their GDP)
- We connect patents to Orbis firms (via Orbis IP)

Response at the Extensive Margin: Entry Elasticity of Inventors

- We estimate a firm-level model analogous to the inventor-level model:

$$E_{jt}^{k} = \exp(\beta_P^k \ln P_{jt-1} + \beta_X^k X_{jt-1} + \gamma_t^k + \eta_j^k) + u_{jt}^k,$$

  - E_{jt}^{k} is the number of new entrant inventors of type k filing a clean family with firm j in year t.
  - We estimate these models separately by type k
  - We classify entrants into three types:
    - those who previously patented in grey/dirty but not in clean
    - those who previously patented in non-energy
    - those who were not previously observed in the patent data.
  - P_{jt-1} is the price of natural gas that firm j is exposed to in year $t-1$.
  - We include in X_{jt-1} the GDP per capita as well as energy and low-carbon RD&D spending by governments that firm j is exposed to in year $t-1$.
  - Year and firm fixed effects are denoted γ_t^k and η_j^k

Decomposing the Induced Innovation Effect by Inventor Type

Source	Induced Innovation Effect	Total Number of Clean Families
Intensive margin response		
Incumbent inventors	**71%**	46%
Extensive margin response		
Entry to patenting	**23.4%**	32%
Entry from grey/dirty	**6.5%**	4%
Entry from non-energy	**-1%**	19%

- Entrants are less responsive on the margin compared to their contribution to overall patenting.
- Over-reliance on incumbents. Sub-optimal if time is of the essence.
- Motivate future work to study the formation of human capital in clean energy.

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How DOEs Government Funding Fuel Scientists?

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LSE G&E

Todd Gerarden
Cornell Dyson

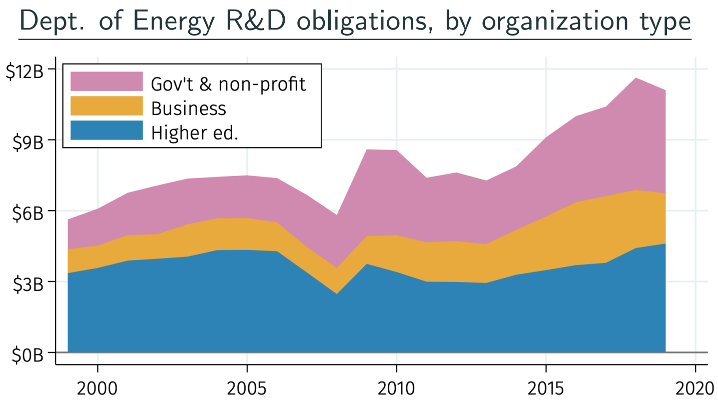
Kyle Myers
HBS

Jacquelyn Pless
MIT Sloan

Motivation

- Competitive markets (might) under-provide innovation (imperfect appropriability)
- Many innovation policies subsidize firms (R&D tax credits, grants, etc.), but innovation begins with people
  - Implicit assumption: will increase demand for inventors and thus scientist entry
- Frictions in education preventing individuals from investing to become inventor?
  - If supply of inventors is inelastic, demand-side policies might just increase wages of high-skilled workers (Goolsbee 1998)
  - Human capital policies may be most direct mechanism (Akcigit et al. 2018; Bloom et al. 2019; Van Reenen 2021)

40-60% of Dept. of Energy Research Funding Goes to Higher Education



- Yet we know little about its impact on scientist entry and innovation
- If no one is constrained, education subsidies should have no effect

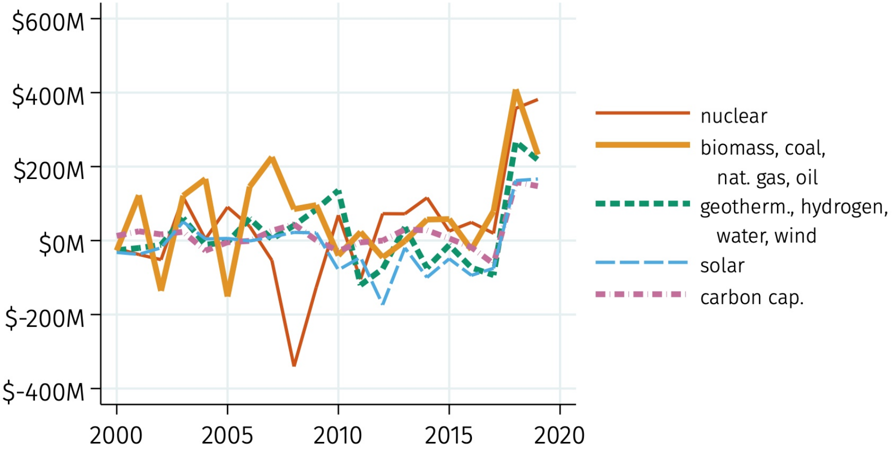
This Paper: Can Government “Produce” (Energy) Scientists?

- **Research question**: how does DOE funding for R&D affect the quantity of new scientists and direction of science?
- **Data: some big lifts**
  - Outcomes: Proquest PhD dissertations (new!), patents
  - Technology-specific DOE budget requests and Congressional appropriations (new!)
- **Method(s): exploit funding “windfalls”**
  - Considering a few different approaches that leverage noise in the “budget game”
  - Windfalls = appropriations - requests
  - Empirical approach for now: production function estimation
- **Preliminary results:**
  - Are dissertations predictive of patenting ? Yes (correlation).
  - **Government funding** $\rightarrow$ **more dissertations?** Yes (but learning more than that)
  - Preliminary **counterfactuals**: no DOE funding $\rightarrow$ substantially fewer PhDs

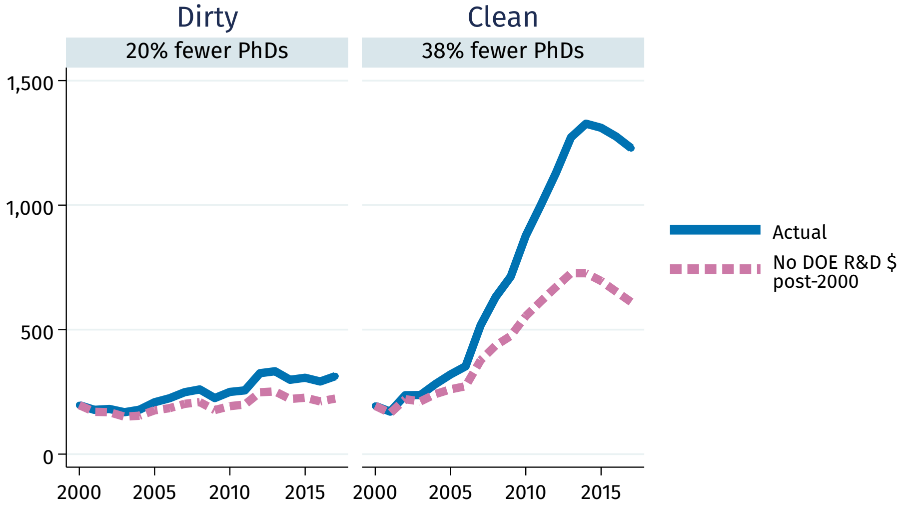
DOE Technology-Specific Appropriations $\neq$ Requests

	FY 1990 Approp.	FY 1990 REQUEST
Solar Energy R&D	$89,659	$71,156
Geothermal	18,077	15,409
Electric Energy	17,828	17,313
Energy Storage	12,047	8,589

Technology-Specific “Windfall” (= Appropriations - Requests)



Thought Experiment: What if DOE Never Funded Research Post-2000?



Thank you!

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- Global Coordination Challenges in the Transition to Clean Technology: Lessons from Automotive Innovation

Global Coordination Challenges in the Transition to Clean Technology: Lessons from Automotive Innovation

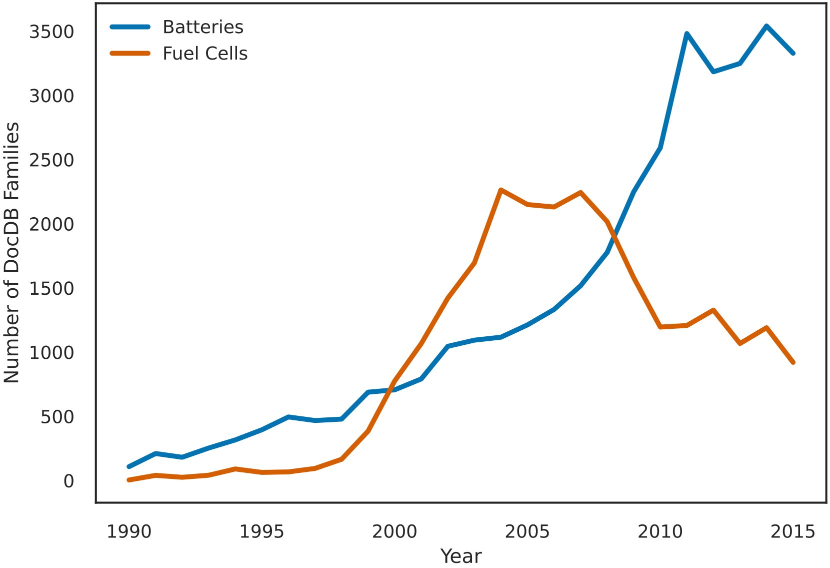
Eugenie Dugoua
LSE G&E

Marion Dumas
LSE Grantham

Motivation

- Empirical puzzle
  - Automotive industry globally aligned on a switch to Battery Electric Vehicles (BEV)
  - But BEVs were not the only option. Fuel Cell (FC) cars considered for many years
  - No single option significantly superior. All required cross-sectoral coordination
  - How did the industry converge on the BEV?
- Relevance for green innovation policy
  - Protracted periods of uncertainty pose problems for the transition
  - Coordination externalities is one of the justifications given for industrial policy (Rodrik 1996; Stern and Stiglitz 2021), but there is little evidence of how they affect tech change

Fuel Cells Experienced a Reversal Fortune and BEV Took Over



From high technological uncertainty to focus on BEVs - How?

- The short answer: cost of batteries significantly decreased, while the upstream supply chain for hydrogen remained less developed compared to electricity.
- This paper is about the longer answer:
  - We argue that the transition to clean cars is best understood as a global coordination problem.
  - How did battery costs come down? and what happened to FCs?
  - Could *national* policy interventions shape this *global* industry's choice?
- First quantitative study of the innovation dynamics between FC and BEV
- An empirical descriptive exercise; interpretation guided by theoretical arguments
- This case study highlights some key questions/issues for innovation policy:
  - Types of coordination: geographic, up/downstream, spillovers with other sectors
  - Could industrial policy for decarbonisation be organized at the scale of global markets?
  - If picking a technology: mind the cross-sectoral complementarities/spillovers

This Paper In Short

- Data on firms' innovation and national policies:
  - OEMs (name, sales) from Marklines; Subsidiary information from Orbis
  - Suppliers from Factset Revere
  - Patents from PATSTAT Global 2022
  - RD&D funding data from the IEA
  - Manual collection of countries' national strategic plans for clean vehicles
- Transition to clean cars: best understood as a global coordination problem
  - A problem of technological uncertainty in a globalized production network
  - With strong technological complementarities upstream/downstream
- The car industry initially "picked" fuel cell hydrogen cars (late 1990s)
  - No policy coordination around the world and no cross-sectoral coordination
- But eventually switches its focus to BEVs
  - By then, costs are down more than 10 times (thanks to other sectors)
  - Large cross-sectoral spillovers (evidence from patent citation and supplier links)
  - Global BEV alignment 2008-2010, akin to a tipping point

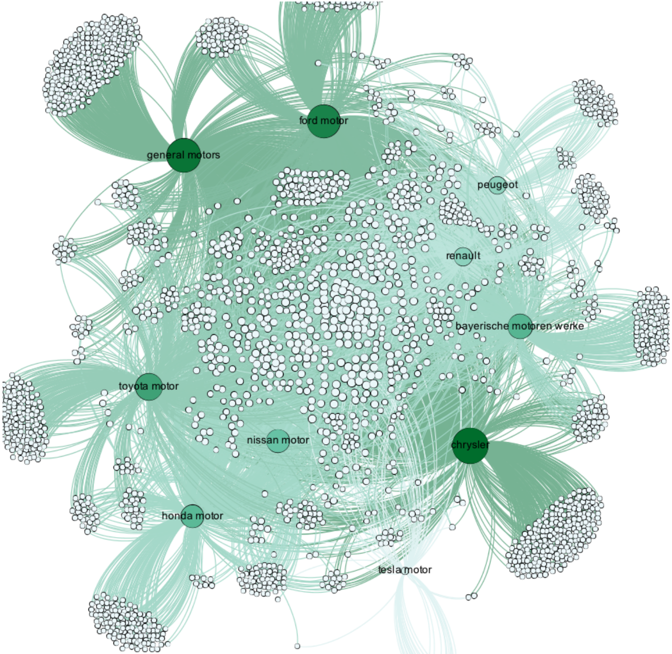
Technological Complementarities: Hydrogen vs Battery Electric Cars

	BEV	FCEV
Storage technology	Battery	Fuel cell stack + Hydrogen tank
Supply chain of storage technology	Electrode, electrolytes, separator, stack assembly	Electrode, electrolytes, separator, catalyst
Fuel production	Existing electricity grid	New hydrogen production supply-chain
Fuel distribution	Charging stations	Fueling stations

No modularity

Strong complementarities upstream and downstream (Baldwin and Clark 2000)

The Car Industry is a Strongly Integrated Global Production Network



- Global integration of production starting in the 1970s (Feenstra 1998), accelerating in the 1990s (Timmer et al. 2014)
- Half of all OEM pairs share a supplier
- Low modularity (0.3)
- Very low clustering

Supplier relationship statistics

Significant innovation on batteries happened outside the industry