Induced Innovation, Inventors, and the Energy Transition

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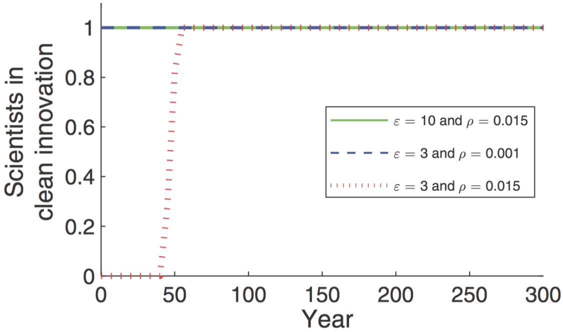
Motivation

- Clean energy innovation is critical to reducing the costs of climate mitigation
- Innovation is not exogenous! Robust empirical evidence for an induced innovation effect.
- The literature on directed tech change has also shown that the optimal climate policy is a combination of carbon pricing and R&D subsidies.
- Here is an illustration from Acemoglu et al. (2012): the pool of scientists rapidly switches from dirty to clean



We Zoom in on These Scientists and Consider the Role of Human Capital

- 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.

This Paper

- 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

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- Document stylized facts about energy inventors

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- 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

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        Using a SCC of 51 \$/tCO2
- Induced innovation relies primarily on the intensive margin

    $\Rightarrow$ Path dependency, a key feature shaping the dynamics of directed technical change

    Results strengthen the rationale for early government intervention

Prior Literature

- Models of directed technical change
  - Acemoglu et al. (2012, 2016), Fried (2018), and Lemoine (2020)
  - Nowzohour (2021): adjustment costs in switching to clean
- Empirical work on induced innovation: at the firm level
  - Aghion et al. (2016), Johnstone et al. (2010), Newell et al. (1999), Noailly and Smeets (2015), Popp (2002), and Popp and Newell (2012)
  - But firms' responses inherently dependent on available human capital
  - Going to the inventor-level is necessary to better understand potential frictions
- Research on individual inventors
  - Response to financial incentives (e.g., Akcigit et al. 2022)
  - Influence of childhood on inventors' career (e.g., Bell et al. 2019a,b)
  - Implications for innovation policy (e.g., Romer 2000)

Outline

Data

Stylised Facts about Energy Inventors

Empirical Strategy

Results

Conclusions

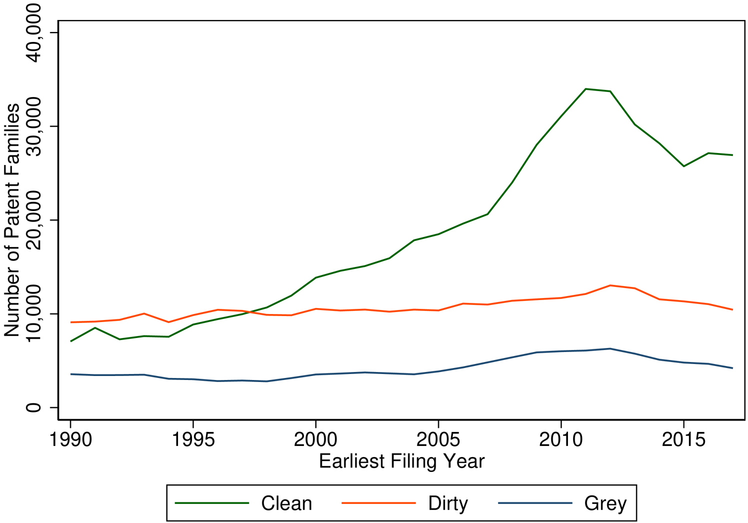
Data

Patent Data Overview

- Patent data from PATSTAT (Autumn 2021 Edition)
  - Analysis done at the level of docdb families
  - Restrict to families in OECD countries post 1990 (and post 2000 for regressions)
- Extract energy-related patents using CPC/IPC codes from prior work Details
  - Dechezleprêtre et al. (2014), Johnstone et al. (2010), Lanzi et al. (2011), and Popp et al. (2020)
- Extract all patents of inventors that have an energy-related patents

Patent Codes for Clean, Dirty, Grey

- Clean technologies:
  - Solar, wind, marine, geothermal, hydro
  - Nuclear
  - Energy storage, smart grids, hydrogen ("enabling")
- Dirty technologies: Combustion of traditional fossil fuels
  - Liquid carbonaceous, gaseous and solid fuels
  - Gas-turbine plants, combustion apparatus/processes
- Grey technologies:
  - Efficiency
  - Biomass and waste



Sample: Energy families with at least one patent in an OECD country.

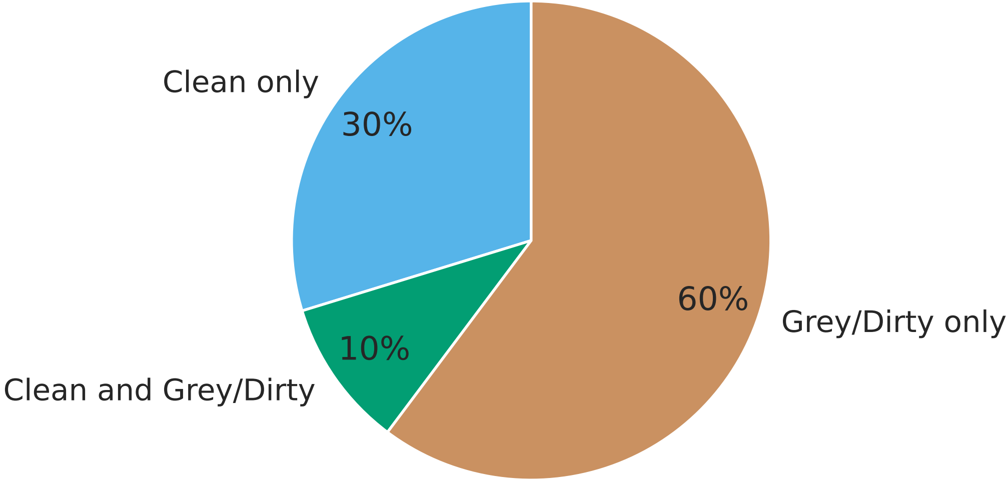
NB: For regression purposes, CCS excluded from *clean* and Fracking from *dirty*.

Inventor Disambiguation in PATSTAT

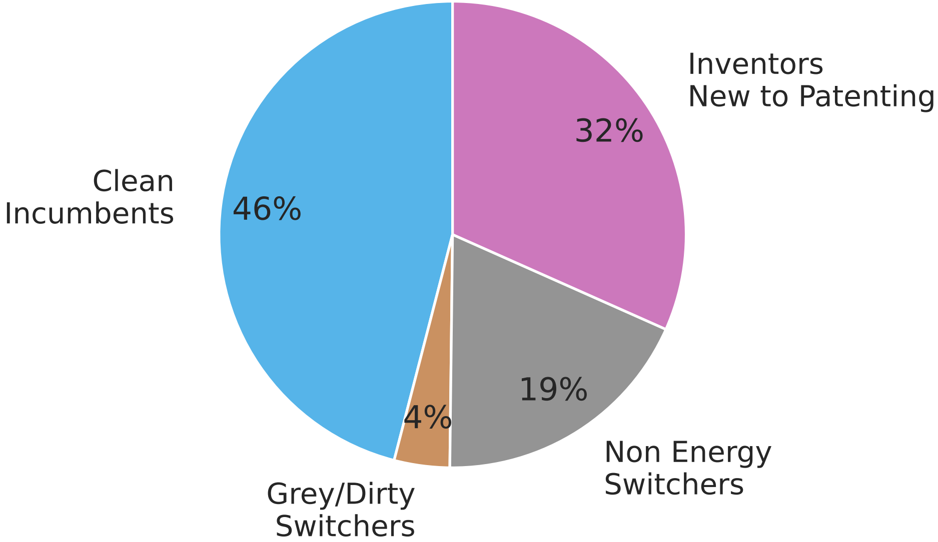
- PATSTAT standardized name ID (PSN ID)
  - Harmonized according to the Univ. Leuven procedure
  - Incomplete: about 70% of energy inventors not harmonized
- Improving over PSN ID
  - Removing special characters
  - Changing all middle names to middle initials
  - Keeping only first middle initial for people with multiple middle names
- Performance comparable to disambiguation effort by Li et al. (2014)
  - Sample: USPTO grants 1975-2010
  - Correct matches: 92.1% (Nbr unique inventors: 30,264)
- Potential for false positive ("John Smith" problem)
  - We examine number of countries and number of PSN ids associated with inventors
  - If too high (>99th percentile), revert back to using PSN ids
  - If gap in patenting $>$ 15 years, ignore observations before the gap
  - Drop inventors that patent for more than 60 years.

Stylised Facts about Energy Inventors

Fact 1: Energy Inventors Specialize in Clean or in Dirty
$\Rightarrow$ Clean Patents Come Primarily from Inventors Who Specialize in Clean



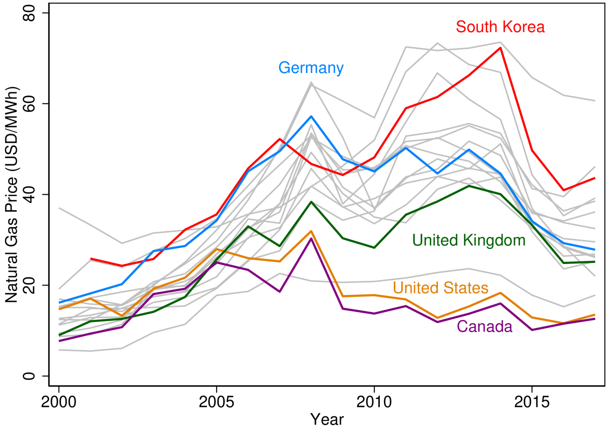
Fact 2: About Half of Clean Patents Come from “New Entrants”



Empirical Strategy

Identification Strategy

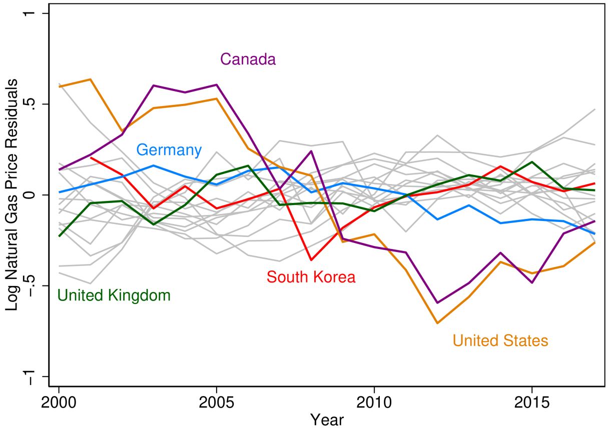
Exploit geographic variation in natural gas prices over time



- Natural gas prices from IEA, End-Use Energy Prices and Taxes for OECD countries, Use industrial prices due to electricity sector data limitations
- Inspiration from Acemoglu et al. (2019): shale gas boom and clean innovation
- When natural gas is more expensive, clean tech becomes more competitive
- Should trickle down as higher incentives to innovate in clean, both for firms and inventors
- Prices yesterday as a proxy for expected demand today

Identifying Variation: Quasi-Random Changes in Natural Gas Prices

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



- Instrumental Variable approach using the **shale gas boom** in the U.S. and Canada starting in 2009
- Techniques to extract shale gas led to an increase in natural gas supply
- This generated a **persistent** reduction in the price of natural gas
- The price reduction was geographically isolated due to LNG transport constraints
- Shale gas boom explains 51% of the (residual) price variation

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)

- Akin to a "shift-share" design: we rely on exogeneity of the natural gas price shocks rather than exogeneity of the shares
  - Alternative standard errors following Borusyak et al. (2022)

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

Results

Response at the Intensive Margin: Output Elasticity of Incumbents

	(1) Simple Count	(2) Simple Count	(3) Citation-Weighted	(4) Citation-Weighted	(5) Coinventor-Weighted	(6) Coinventor-Weighted
Prices (log, t-1)	0.203***	0.187***	0.353***	0.347***	0.225***	0.201***
	(0.047)	(0.047)	(0.059)	(0.058)	(0.055)	(0.054)
Prices (log, t-2)	0.158***	0.087*	0.123**	0.021	0.289***	0.214***
	(0.046)	(0.046)	(0.058)	(0.058)	(0.055)	(0.054)
Prices (log, t-3)	0.131***	0.106**	0.015	-0.021	0.017	-0.008
	(0.045)	(0.045)	(0.051)	(0.052)	(0.054)	(0.053)
Cumulative Effect	0.491***	0.381***	0.492***	0.347***	0.531***	0.406***
	(0.051)	(0.053)	(0.065)	(0.067)	(0.059)	(0.063)
Year FEs	X	X	X	X	X	X
Inventor FEs	X	X	X	X	X	X
Tenure FEs		X		X		X
Country-Year Covariates	X	X	X	X	X	X
Inventor Clusters (SEs)	86,041	86,041	86,041	86,041	86,041	86,041
Observations	591,269	591,269	591,269	591,269	591,269	591,269
Pseudo-R2	0.289	0.290	0.366	0.367	0.264	0.264

Dependent variable: Number of Renewable/Nuclear docdb patent families.

Poisson pseudo-maximum likelihood. Standard errors clustered by inventor in parentheses.

Response at the Extensive Margin: Entry Elasticity of Incumbents

	(1) New to Patenting	(2) From Grey/Dirty	(3) From Non-Energy
Prices (log, t-1)	0.066	0.576***	0.384**
	(0.166)	(0.145)	(0.164)
Prices (log, t-2)	0.053	-0.285**	-0.215
	(0.156)	(0.133)	(0.147)
Prices (log, t-3)	0.283	0.415***	0.115
	(0.211)	(0.136)	(0.153)
Cumulative Effect	0.402**	0.705***	0.284
	(0.165)	(0.122)	(0.180)
Year FEs	X	X	X
Firm FEs	X	X	X
Country-Year Covariates	X	X	X
Firm Clusters (SEs)	3,833	4,812	4,728
Observations	45,048	56,034	55,326
Pseudo-R2	0.702	0.611	0.652

Dependent variables: number of renewable/nuclear inventors per group.

Sample: balanced panel from 2000 to 2014.

Poisson pseudo-maximum likelihood. Standard errors clustered by firm in parentheses.

Decomposing the Induced Innovation Effect by Inventor Type

$51/tCO2 (54% of the GDP-weighted global average price of natural gas in 2014)

Over the course of 10 years

Source	Patents	Share (%)
Intensive margin response		
Incumbent inventors	38,323	65.0
	(5,947)	(6.5)
Extensive margin response		
Entry from grey/dirty	6,818	11.6
	(1,180)	(2.3)
Entry from non-energy	3,479	5.9
	(2,205)	(3.6)
Entry to patenting	10,303	17.5
	(4,229)	(6.2)
Total	58,923	100.0
	(7,714)	.

Conclusions

Final Thoughts

- 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.
- (How) can entry be stimulated? Stay tuned for the next paper!

HOW DOES GOVERNMENT FUNDING FUEL SCIENTISTS?

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Thank you!

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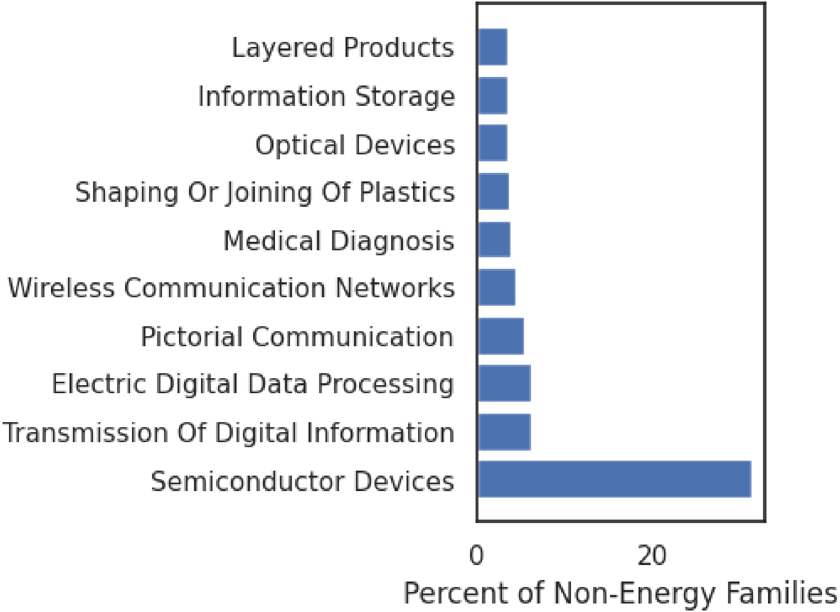
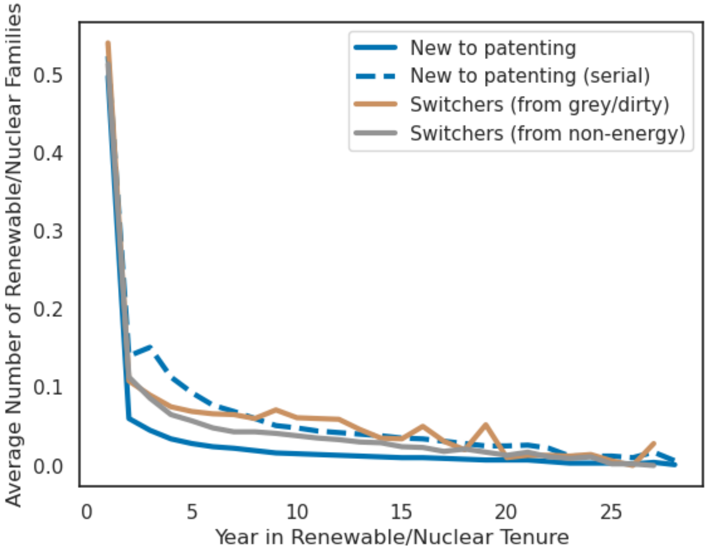
Non-Energy Patents of Clean Entrants: ICT and Semiconductors



Lifecycle: Inventors' Patenting Over Tenure (Co-inventor Weighted)



Additional Checks

- Instrumental Variable approach using the shale gas boom in the U.S. and Canada
  - Utilization of techniques to extract shale gas led to an increase in natural gas supply
  - This generated a persistent reduction in the price of natural gas
  - The price reduction was geographically isolated due to LNG transport constraints
  - Shale gas boom explains 51% of the (residual) price variation

- Alternative price measures Here