

# Induced Innovation, Inventors, and the Energy Transition

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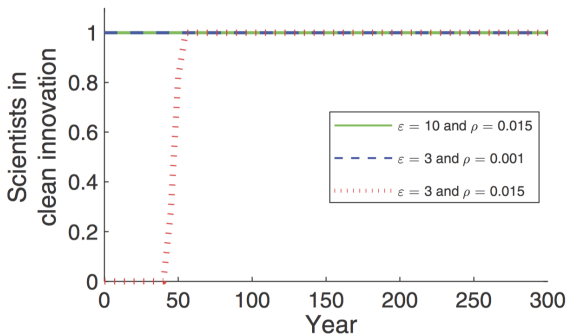
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# Motivation

- 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.

- 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 \$/tCO<sub>2</sub>

# 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)

Data

Stylised Facts about Energy Inventors

Empirical Strategy

Results

Conclusions

# Data

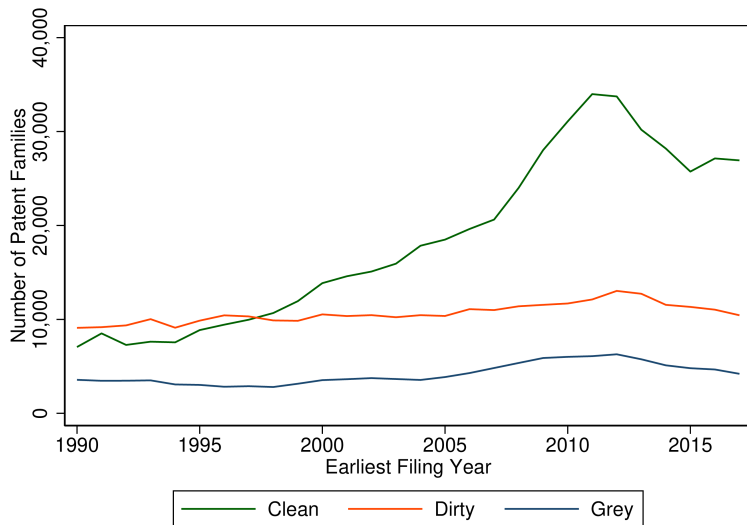
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- Patent data from PATSTAT (Autumn 2021 Edition)
- Extract energy-related patents using CPC/IPC codes from prior work [Details](#)  
Dechezleprêtre et al. (2014), Johnstone et al. (2010), Lanzi et al. (2011), and Popp et al. (2020)
- Extract all patents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



# 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

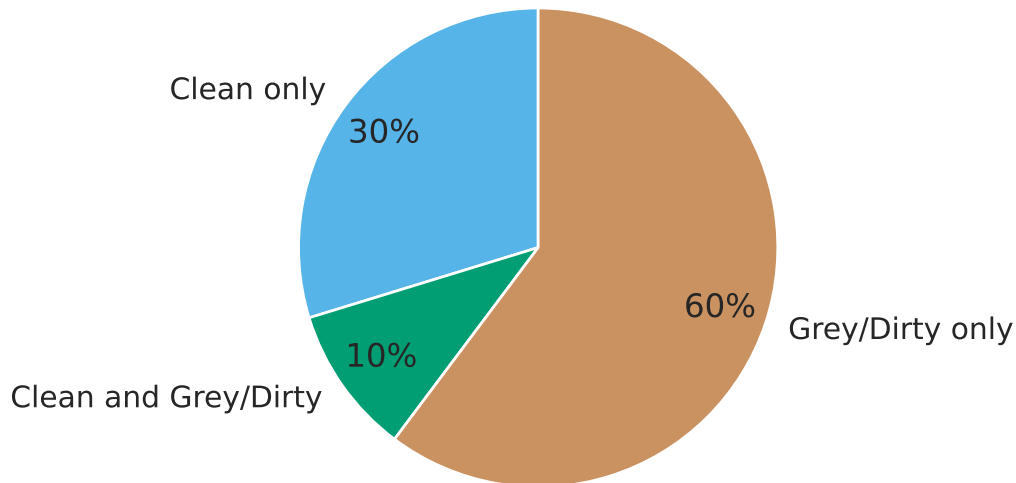
- PATSTAT standardized name ID (PSN ID)
  - Harmonized according to the Univ. Leuven procedure
  - Incomplete: about 70% of energy inventors not harmonized
- Improving over PSN ID
  - Removing special characters
  - Changing all middle names to middle initials
  - Keeping only first middle initial for 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**

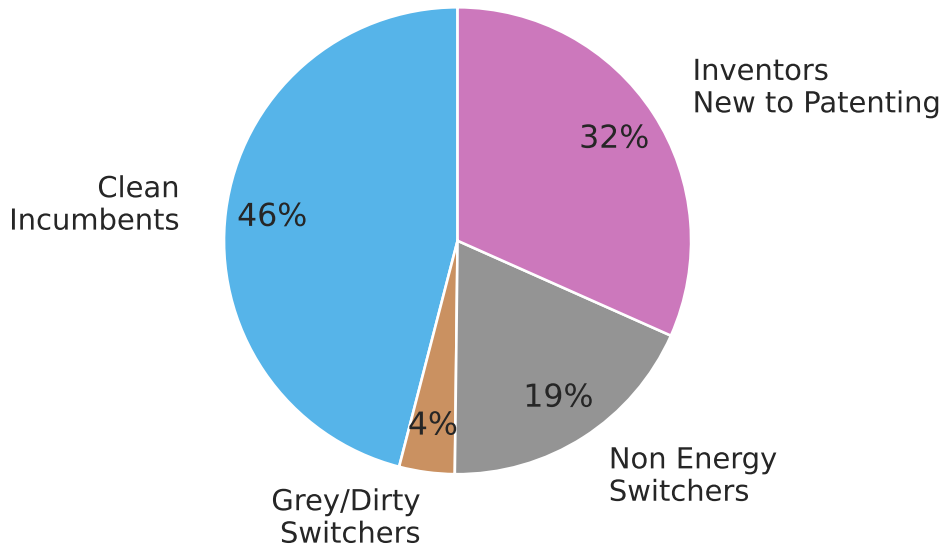
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## Fact 1: Energy Inventors Specialize in Clean or in Dirty

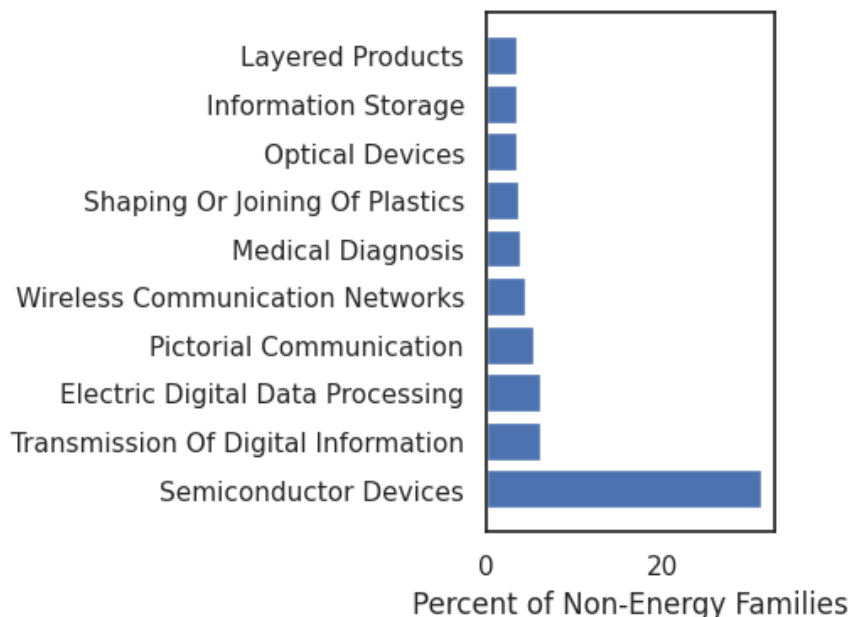
⇒ Clean Patents Come Primarily from Inventors Who Specialize in Clean



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



## Non-Energy Patents of Clean Entrants: ICT and Semiconductors

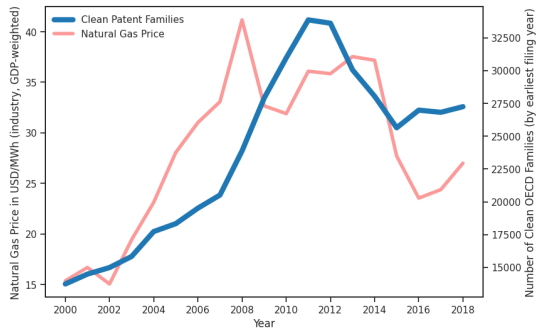


# Empirical Strategy

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# Do Changes in Energy Prices Induce More/Entry into Clean Patenting?

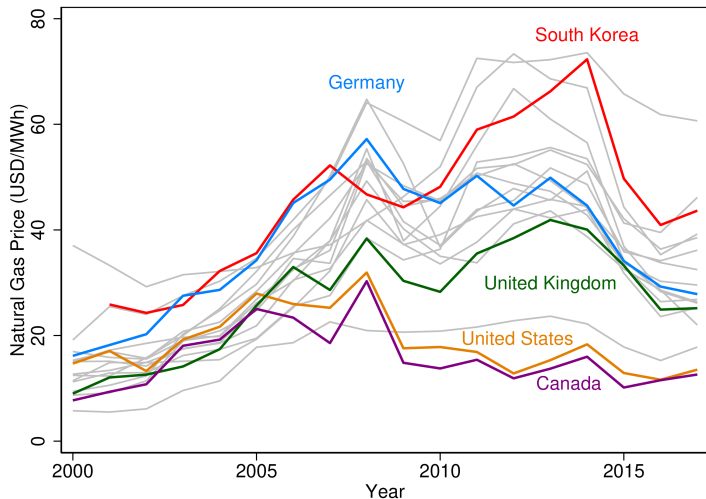
- When natural gas is more expensive, clean tech becomes more competitive
- Inspiration from Acemoglu et al. (2019): shale gas boom and clean innovation
- Prices yesterday as a proxy for expected demand today
- Should trickle down as higher incentives to innovate in clean
- Both for firms and inventors





# Identification Strategy

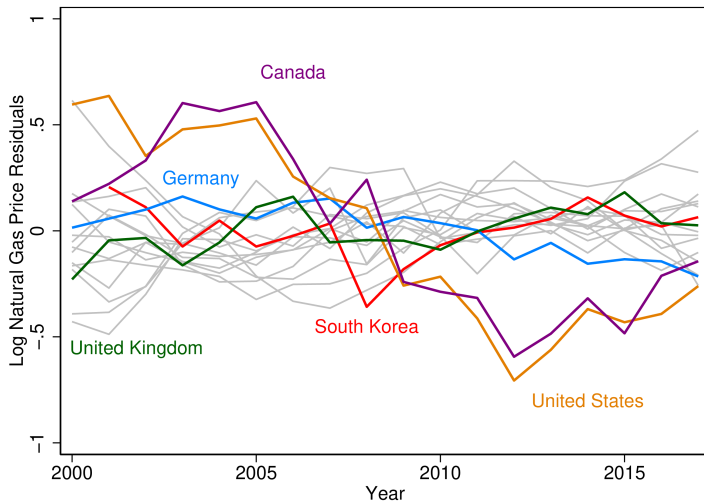
Exploit geographic variation in energy prices over time (after accounting for common shocks)



- Natural gas prices from IEA
- End-Use Energy Prices and Taxes for OECD countries
- Use industrial prices due to electricity sector data limitations

# 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)

## 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  $\gamma_t^k$  and  $\eta_j^k$

## Results

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# 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)	0.282*** (0.044)	0.279*** (0.044)	0.304*** (0.061)	0.327*** (0.061)	0.297*** (0.054)	0.278*** (0.054)
Prices (log, t-2)	0.180*** (0.045)	0.107** (0.045)	0.215*** (0.064)	0.132** (0.064)	0.296*** (0.053)	0.221*** (0.053)
Prices (log, t-3)	0.180*** (0.047)	0.160*** (0.046)	0.134** (0.053)	0.107** (0.054)	0.029 (0.056)	0.011 (0.055)
Cumulative Effect	0.642*** (0.050)	0.546*** (0.052)	0.652*** (0.069)	0.565*** (0.070)	0.622*** (0.057)	0.511*** (0.061)
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)	85,905	85,905	85,905	85,905	85,905	85,905
Observations	590,767	590,767	590,767	590,767	590,767	590,767
Pseudo-R2	0.289	0.290	0.366	0.367	0.264	0.265

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

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

- 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](#)



## Response at the Extensive Margin: Entry Elasticity of Incumbents

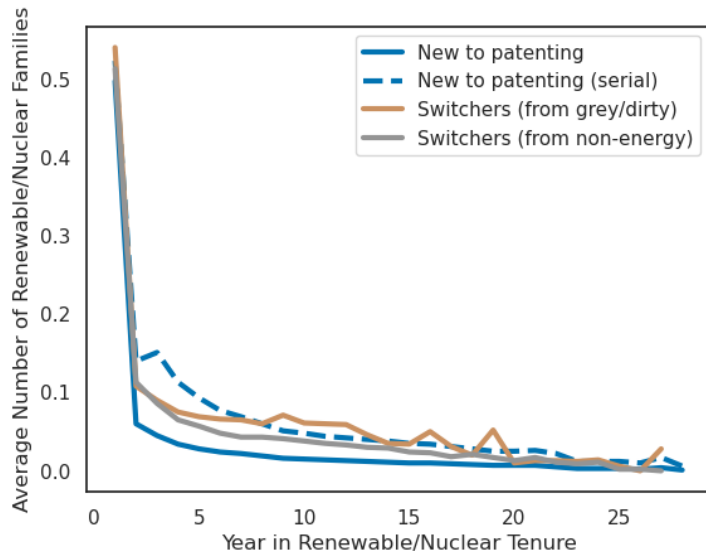
	(1) New to Patenting	(2) From Grey/Dirty	(3) From Non-Energy
Prices (log, t-1)	-0.046 (0.144)	0.017 (0.131)	-0.119 (0.146)
Prices (log, t-2)	0.128 (0.171)	-0.240* (0.137)	-0.257* (0.148)
Prices (log, t-3)	0.536*** (0.195)	0.679*** (0.134)	0.314** (0.151)
Cumulative Effect	0.618*** (0.166)	0.456*** (0.124)	-0.062 (0.181)
Year FEs	X	X	X
Firm FEs	X	X	X
Country-Year Covariates	X	X	X
Firm Clusters (SEs)	3,779	4,703	4,642
Observations	43,733	53,109	52,559
Pseudo-R2	0.699	0.605	0.647

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.

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



# Decomposing the Induced Innovation Effect by Inventor Type

\$51/tCO<sub>2</sub> (54% of the GDP-weighted global average price of natural gas in 2014)

Over the course of 10 years

Source	Patents	Share (%)
<i>Intensive margin response</i>		
Incumbent inventors	48,234 (5,758)	71.2 (5.7)
<i>Extensive margin response</i>		
Entry from grey/dirty	4,410 (1,199)	6.5 (1.8)
Entry from non-energy	-760 (2,218)	-1.1 (3.3)
Entry to patenting	15,839 (4,255)	23.4 (5.3)
<b>Total</b>	67,724 (7,590)	100.0 .

## Conclusions

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- 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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