Induced Innovation, Inventors, and the Energy Transition

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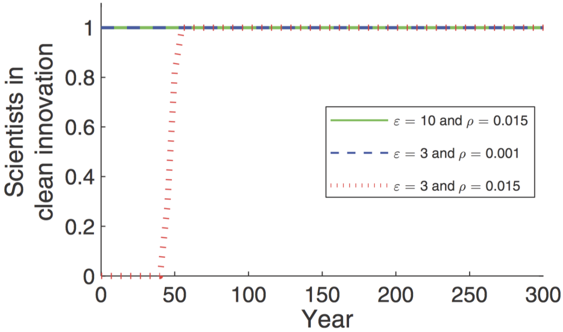
Motivation

- 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
- 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

Prior Literature

- Models of directed technical change
  - Acemoglu et al. (2012, 2016), Fried (2018), and Lemoine (Forthcoming)
  - 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

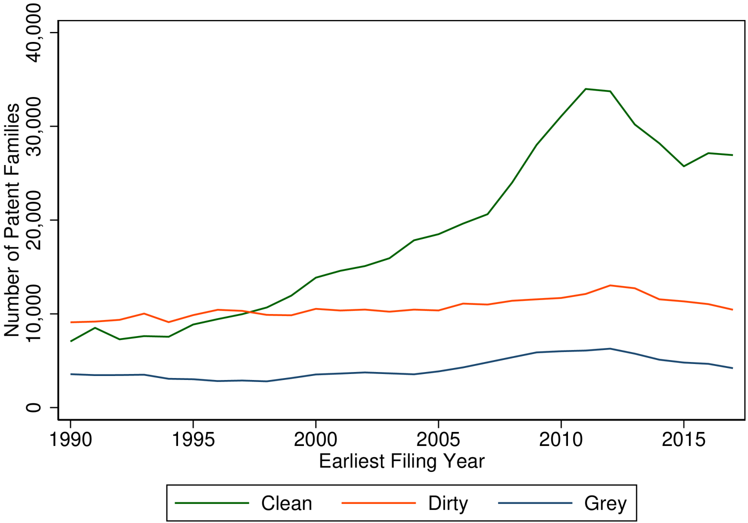
Data

Patent Data Overview

- 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.

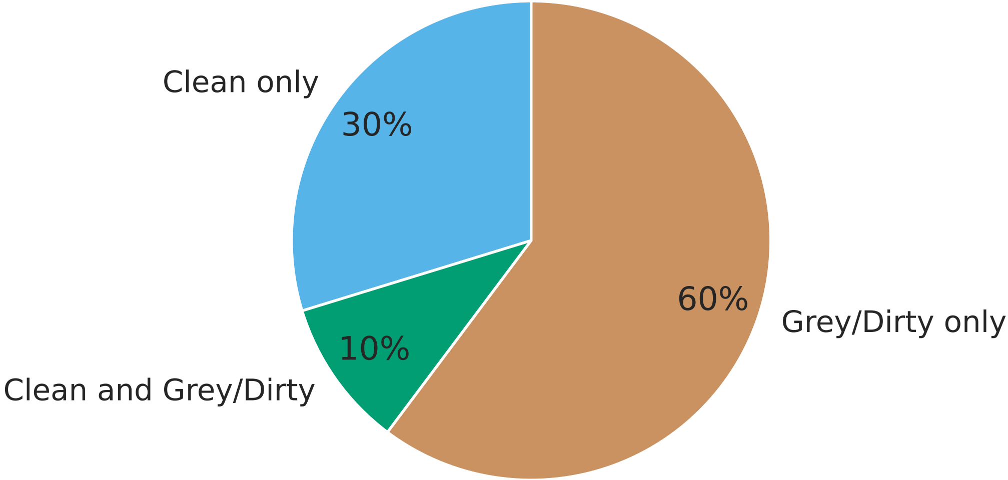
NB: For regression purposes, CCS excluded from *clean* and Fracking from *dirty*.

Inventor Disambiguation in PATSTAT

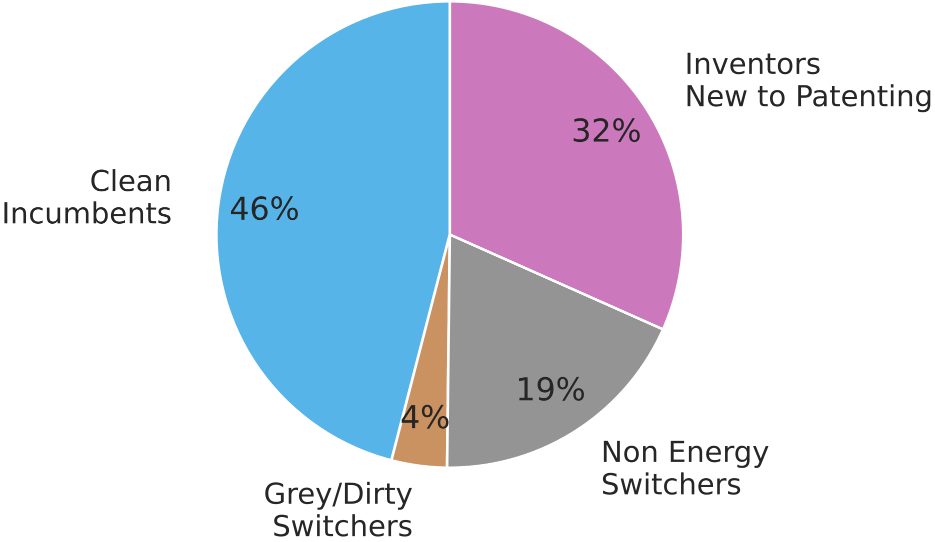
- PATSTAT standardized name ID (PSN ID)
  - Harmonized according to the Univ. Leuven procedure
  - Incomplete: about 70% of energy inventors not harmonized
- Improving over PSN ID
  - Removing special characters
  - Changing all middle names to middle initials
  - Keeping only first middle initial for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

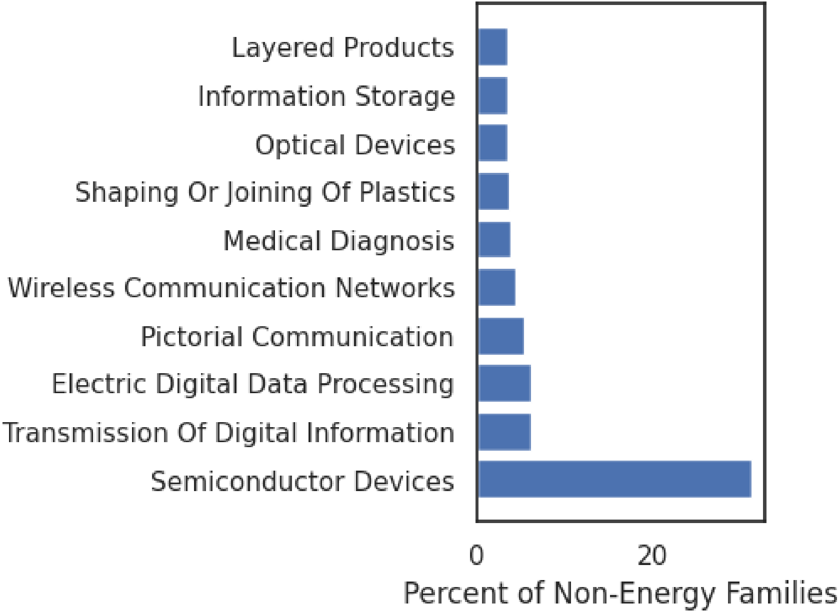
Fact 1: Energy Inventors Specialize in Clean or in Dirty
⇒ Clean Patents Come Primarily from Inventors Who Specialize in Clean



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

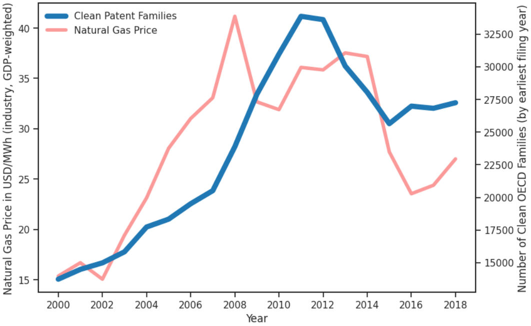


Non-Energy Patents of Clean Entrants: ICT and Semiconductors



Empirical Strategy

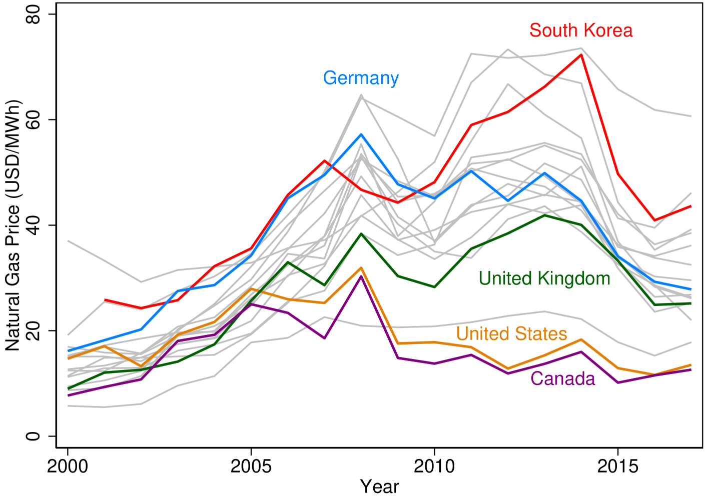
Do Changes in Energy Prices Induce More/Entry into Clean Patenting?



- 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

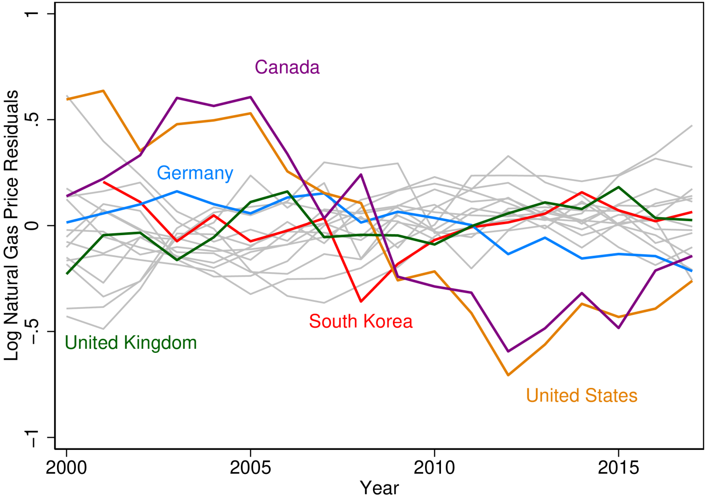
Exploit geographic variation in energy prices over time (after accounting for common shocks)



- 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)

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

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)	0.282***	0.279***	0.304***	0.327***	0.297***	0.278***
	(0.044)	(0.044)	(0.061)	(0.061)	(0.054)	(0.054)
Prices (log, t-2)	0.180***	0.107**	0.215***	0.132**	0.296***	0.221***
	(0.045)	(0.045)	(0.064)	(0.064)	(0.053)	(0.053)
Prices (log, t-3)	0.180***	0.160***	0.134**	0.107**	0.029	0.011
	(0.047)	(0.046)	(0.053)	(0.054)	(0.056)	(0.055)
Cumulative Effect	0.642***	0.546***	0.652***	0.565***	0.622***	0.511***
	(0.050)	(0.052)	(0.069)	(0.070)	(0.057)	(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.

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	0.017	-0.119
	(0.144)	(0.131)	(0.146)
Prices (log, t-2)	0.128	-0.240*	-0.257*
	(0.171)	(0.137)	(0.148)
Prices (log, t-3)	0.536***	0.679***	0.314**
	(0.195)	(0.134)	(0.151)
Cumulative Effect	0.618***	0.456***	-0.062
	(0.166)	(0.124)	(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.

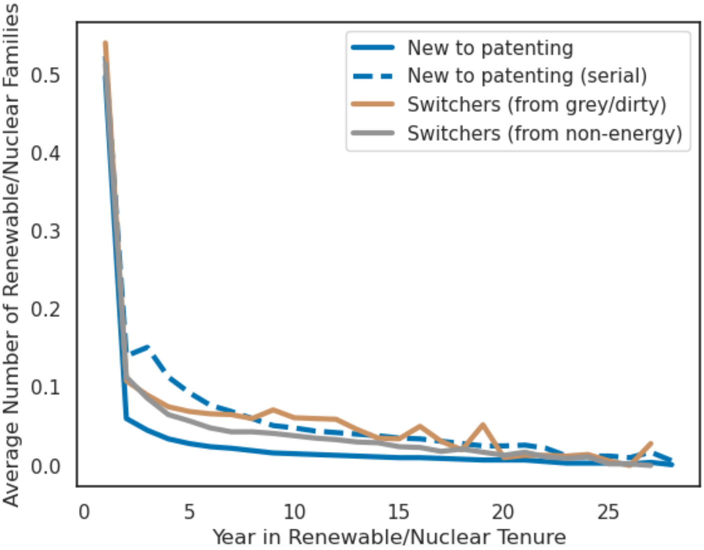
Sample: balanced panel from 2000 to 2014.

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

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

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



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

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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References i

Acemoglu, Daron et al. (Feb. 2012). "The Environment and Directed Technical Change". In: *American Economic Review* 102.1, pp. 131–166. ISSN: 0002-8282. DOI: 10.1257/aer.102.1.131. URL: https://www.aeaweb.org/articles?id=10.1257/aer.102.1.131 (visited on 10/18/2019).

Acemoglu, Daron et al. (Jan. 2016). "Transition to Clean Technology". In: *Journal of Political Economy* 124.1, pp. 52–104. ISSN: 0022-3808. DOI: 10.1086/684511. URL: https://www.journals.uchicago.edu/doi/abs/10.1086/684511 (visited on 10/18/2019).

Acemoglu, Daron et al. (2019). *Climate Change, Directed Innovation, and Energy Transition: The Long-run Consequences of the Shale Gas Revolution*. Working Paper.

Aghion, Philippe et al. (Jan. 2016). "Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry". In: *Journal of Political Economy* 124.1, pp. 1–51. ISSN: 0022-3808. DOI: 10.1086/684581. URL: https://www.journals.uchicago.edu/doi/abs/10.1086/684581 (visited on 10/18/2019).

Akcigit, Ufuk et al. (Feb. 2022). "Taxation and Innovation in the Twentieth Century". In: *The Quarterly Journal of Economics* 137.1, pp. 329–385. ISSN: 0033-5533. DOI: 10.1093/qje/qjab022. URL: https://doi.org/10.1093/qje/qjab022 (visited on 06/27/2023).

Bell, Alex et al. (June 2019a). "Joseph Schumpeter Lecture, EEA Annual Congress 2017: Do Tax Cuts Produce More Einsteins? The Impacts of Financial Incentives Versus Exposure to Innovation on the Supply of Inventors". In: *Journal of the European Economic Association* 17.3, pp. 651–677. ISSN: 1542-4766. DOI: 10.1093/jeea/jvz013. URL: https://academic.oup.com/jeea/article/17/3/651/5449343 (visited on 10/18/2019).

— (May 2019b). "Who Becomes an Inventor in America? The Importance of Exposure to Innovation". In: *The Quarterly Journal of Economics* 134.2, pp. 647–713. ISSN: 0033-5533. DOI: 10.1093/qje/qjy028. URL: https://academic.oup.com/qje/article/134/2/647/5218522 (visited on 10/18/2019).

Dechezleprêtre, Antoine, Ralf Martin, and Myra Mohnen (2014). *Knowledge Spillovers from Clean and Dirty Technologies*. CEP Discussion Paper 1300.

Fried, Stephie (Jan. 2018). "Climate Policy and Innovation: A Quantitative Macroeconomic Analysis". In: *American Economic Journal: Macroeconomics* 10.1, pp. 90–118. ISSN: 1945-7707. DOI: 10.1257/mac.20150289. URL: https://www.aeaweb.org/articles?id=10.1257/mac.20150289 (visited on 08/13/2018).

Johnstone, Nick, Ivan Haščič, and David Popp (Jan. 2010). "Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts". In: *Environmental and Resource Economics* 45.1, pp. 133–155. ISSN: 0924-6460, 1573-1502. DOI: 10.1007/s10640-009-9309-1. URL: https://link.springer.com/article/10.1007/s10640-009-9309-1 (visited on 04/19/2018).

Lanzi, Elisa, Elena Verdolini, and Ivan Haščič (Nov. 2011). "Efficiency-Improving Fossil Fuel Technologies for Electricity Generation: Data Selection and Trends". In: *Energy Policy*. Asian Energy Security 39.11, pp. 7000–7014. ISSN: 0301-4215. DOI: 10.1016/j.enpol.2011.07.052. URL: http://www.sciencedirect.com/science/article/pii/S0301421511005878 (visited on 08/28/2020).

Lemoine, Derek (Forthcoming). "Innovation-Led Transitions in Energy Supply". In: *American Economic Journal: Macroeconomics*. (Visited on 06/27/2023).

Li, Guan-Cheng et al. (July 2014). "Disambiguation and Co-Authorship Networks of the U.S. Patent Inventor Database (1975–2010)". In: *Research Policy* 43.6, pp. 941–955. ISSN: 0048-7333. DOI: 10.1016/j.respol.2014.01.012. URL: http://www.sciencedirect.com/science/article/pii/S0048733314000225 (visited on 08/14/2020).

Newell, Richard G., Adam B. Jaffe, and Robert N. Stavins (Aug. 1999). "The Induced Innovation Hypothesis and Energy-Saving Technological Change". In: *The Quarterly Journal of Economics* 114.3, pp. 941–975. ISSN: 0033-5533. DOI: 10.1162/003355399556188. URL: https://academic.oup.com/qje/article/114/3/941/1848170 (visited on 08/22/2018).

Noailly, Joëlle and Roger Smeets (July 2015). "Directing Technical Change from Fossil-Fuel to Renewable Energy Innovation: An Application Using Firm-Level Patent Data". In: *Journal of Environmental Economics and Management* 72, pp. 15–37. ISSN: 0095-0696. DOI: 10.1016/j.jeem.2015.03.004. URL: http://www.sciencedirect.com/science/article/pii/S0095069615000285 (visited on 01/31/2020).

Nowzohour, Laura Minu (2021). *Can Adjustment Costs in Research Derail the Transition to Green Growth?* Working Paper. Geneva Graduate Institute.

Popp, David (2002). "Induced Innovation and Energy Prices". In: *The American Economic Review* 92.1, pp. 160–180. ISSN: 0002-8282. DOI: 10.1257/000282802760015658. (Visited on 10/18/2019).

Popp, David and Richard Newell (July 2012). "Where Does Energy R&D Come from? Examining Crowding out from Energy R&D". In: *Energy Economics* 34.4, pp. 980–991. ISSN: 0140-9883. DOI: 10.1016/j.eneco.2011.07.001. URL: http://www.sciencedirect.com/science/article/pii/S0140988311001319 (visited on 10/18/2019).

Popp, David et al. (May 2020). *Innovation and Entrepreneurship in the Energy Sector*. Working Paper 27145. National Bureau of Economic Research. DOI: 10.3386/w27145. URL: http://www.nber.org/papers/w27145 (visited on 08/28/2020).

Romer, Paul M. (2000). "Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?" In: *Innovation Policy and the Economy* 1, pp. 221–252.