NBER WORKING PAPER SERIES

THE ESG-INNOVATION DISCONNECT: EVIDENCE FROM GREEN PATENTING

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Working Paper 27990
http://www.nber.org/papers/w27990

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 2020, Revised July 2023

We are grateful for comments from Federico Bandi, Daniel Bergstresser, Christa Clapp, Spencer Dale, Shaun Davies, Carina Elfving, Falko Fecht, Jane Fuller, Leslie Gent, Alan Haywood, Geoffrey Heal, Andrew Hilton, Kateryna Holland, Harrison Hong, Mark Huson, Marcin Kacperczyk, Ulf von Kalckreuth, Oguzhan Karakas, Anil Kashyap, Simi Kedia, Jinu Koola, Phillip Krüger, Chen Lin, Pedro Matos, Roni Michaely, Randall Morck, Joelle Noailly, Lubos Pastor, Anna Pavlova, Phillip Phan, Monika Piazzesi, Alexander Popov, Nagpurnanand Prabhala, Lukasz Pomorski, John Van Reenen, Ruy Ribeiro, Daniel R Romito, Aniket Shah, Laura Starks, Luke Stein, Jerome Taillard, Luis Viceira, Alexis Wegerich, Fredrik Willumsen, Sophie Zhou. In addition, we sincerely thank seminar participants at the 2022 NBER Long Term Asset Management Conference, 2021 American Finance Association Meeting, 2021 University of Delaware Weinberg Center – ECGI Corporate Governance Symposium, 2021 ASU Sonoran Winter conference, 2021 Sustainable Finance Forum, 2021 United Nation Geneva Summit on Sustainable Finance, 2021 Stanford University ESG Conference, 2021 University of Texas at Dallas Finance Conference, 2021 Brazilian Finance Society Conference Meeting, Centre for the Study of Financial Innovation, Bundesbank Spring Conference 2023 - Climate Change and Central Banks, the University of Alabama, University of Alberta, Babson College, Baruch College, University of Bonn, Brandeis University, CamEd Business School, University of Cologne, University of Dortmund, DePaul University, Florida State University, George Washington University, Georgia State University, Harvard Business School , Hong Kong University, Johns Hopkins University, University of Missouri, National University of Singapore, University of Nebraska, Norges Bank Investment Management, Norwegian School of Economics (NHH), University of Ottawa, Rutgers University, Temple University, University of Texas at Dallas, Washington University in St. Louis, WHU School of Management, and the University of Wuppertal. We also thank the National Science Foundation (SciSIP 1535813) and the Fordham University Gabelli School of Business – PVH Corp. Global Thought Leadership Grant on Corporate Social Responsibility for funding. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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October 2020, Revised July 2023
JEL No. G11,G30,O31,O32

ABSTRACT

No firm or sector of the global economy is untouched by innovation. In equilibrium, innovators will flock to (and innovation will occur where) the returns to innovative capital are the highest. In this paper, we document a strong empirical pattern in green patent production. Specifically, we find that oil, gas, and energy-producing firms – firms with lower Environmental, Social, and Governance (ESG) scores, and who are often explicitly excluded from ESG funds' investment universe – are key innovators in the United States' green patent landscape. These energy producers produce more, and significantly higher quality, green innovation. In many green technology spaces, they appear to be influential first-movers, not easily substitutable, and to produce ongoing foundational aspects of innovation and commercialization on which other alternative energy producers build (for instance, in carbon capture).

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As of 2020, sustainable investing represents more than 33 percent of the $51.4 trillion in U.S. assets under management. Compared to 2017, sustainable and impact investing has increased by more than 42% (USSIF 2020). A large contributor to this growth has been the 2015 guidance issued by the Department of Labor which allowed fiduciaries to incorporate environmental, social, and governance (ESG) factors into their investment decision.[1] Given this push, flows to ESG increased substantially.[2]

The most straightforward motivation for ESG investing comes from a preference function that loads positively on the goals of a given ESG fund. An investor with these preferences might be willing to sacrifice an amount of risk-adjusted return in order to allow the fund to achieve those returns with an aligned ESG focus; alternatively, pay more for a fund that promises the same ex-ante risk-return dynamics while delivering an aligned ESG investment.

However, a number of other views could motivate ESG investing. For instance, a micro-founded, belief-based view of ESG investing could exist irrespective of the investor's actual preferences for ESG. If consumers value products that are ESG compliant, they might be willing to pay a premium for these, or firms might collect a monopolistic rent on production if it were a salient product differentiation attribute. Moreover, if talented workers preferred companies following ESG principles, it could also be a mechanism to attract higher quality factors of production (such as human capital) or pay less for these factors. In these ways, ESG-tilting behavior might be a source of comparative advantage that – if the market didn't fully impound – could result in favorable future return dynamics.

The clearest counterargument to these positive arguments is that the constrained portfolio maximization run by ESG-constrained fund managers is dominated by the unconstrained

[1] https://www.federalregister.gov/documents/2015/10/26/2015-27146/interpretive-bulletin-relating-to-the-fiduciary-standard-under-erisa-in-considering-economically. In 2018, the agency further clarified their ESG factor stance: https://www.dol.gov/agencies/ebsa/employers-and-advisers/guidance/field-assistance-bulletins/2018-01. Using ESG factors in investment decisions continues to undergo policy debate and refinement. For instance, in the final months of President Trump's administration, the Department of Labor published a rule on "Financial Factors in Selecting Plan Investments," which adopted amendments that essentially require plan fiduciaries to select investments and investment courses of action based solely on consideration of "pecuniary factors;" i.e., the ESG rules (85 Fed. Reg. 72846, November 13, 2020). On March 10, 2021, however, under President Biden's administration, the Department of Labor's Employee Benefits Security Administration issued a statement that says until it publishes further guidance, the Department will not enforce either final rule or otherwise pursue enforcement actions against any plan fiduciary based on a failure to comply with the aforementioned final rules concerning an investment.
(https://www.dol.gov/sites/dolgov/files/ebsa/laws-and-regulations/laws/erisa/statement-on-enforcement-of-final-rules-on-esg-investments-and-proxy-voting.pdf)

[2] According to a 2019 survey by Callen Institute, of the 89 U.S. institutional investors that were asked about their approach to environmental, social, and governance (ESG) factors when evaluating investments, 42% of them incorporated ESG factors into the investment decision-making. The corresponding figure in 2012 was 22%. The implementation of ESG is often done by either avoiding certain categories categorically (such as Tobacco (27%), Weapons (16%), Fossil Fuel (11%), Gambling (11%)) or embracing certain industries (such as Local Economic Benefit (22%), Clean Tech (14%), Environment (11%), etc.).

maximization run by other managers, resulting in likely underperformance in the risk-return space.

The academic evidence on the realized performance of ESG-focused funds is decidedly mixed (Eccles, Ioannous, and Serefaim (2014), Krüger (2015), Dimson and Karakas, and Li (2015), Khan, Serafaim, and Yoon (2016), Ferrell, Liang and Renneboog (2016), among others). Moreover, there is limited systematic evidence that firms receiving disproportional amounts of capital from ESG funds have outperformed in any measurable way. Given this, our understanding of whether ESG investment flows impact innovation that can help us solve environmental problems is incomplete.

In this paper, we aim to address this gap in the literature by being the first paper to systematically investigate *who* produces green patents, the most influential of these green patent producers, and whether the capital of investors who desire to allocate capital toward ESG objectives actually do end up investing in these producers. As a starting point, as ESG capital investment flows have been rising in the past decades, there has been a concurrent sharp increase in green innovation and patent production, as shown in Figure 1.

-- Insert Figure 1 here --

We show that the majority of this recent green patenting is not driven by highly rated ESG firms – firms that are commonly favored by ESG funds – but instead by firms that are explicitly excluded from ESG funds' investment universe. We use two large datasets that capture the complete universe of patents from 2008 through 2020 to identify the universe of green patenting activity.[3] Moreover, for much of our analysis on firm characteristics of patenting entities, we concentrate on publicly traded firms, due to there being rich, publicly available measures of firm characteristics, external activities, income, profitability, and patent holdings.

Specifically, we show that the energy sector has a large and growing percentage of its entirety of patenting activity dedicated to green research. Moreover, the incremental green patent is significantly more likely to come from energy firms than any other type of firm, including highly rated ESG firms that are producers of green patents (over twice as likely, with 17.61% of all patenting in green patenting (t = 7.69) vs. 8.60% for the average green patenting firm). In addition, the green patents of energy-producing firms are significantly higher quality, in terms of being more highly cited.

[3] While our patent data exists back to 1980, our ESG ranking data only begin in 2008, which is why we begin our main testing sample (which relies on ESG ratings) then. However, for every test not relying on ESG data, the full 40-year sample is used from 1980 to 2020.

Energy producing firms are also significantly more likely to produce "blockbuster" green patents than other firms. Yet, these energy firms are explicitly excluded from many ESG funds and the targets of many divestiture campaigns whose stated aims often include pushing forward green energy innovation.[4] On the intensive margin, energy firms even get less "credit" in terms of an incremental ESG score increase for each (higher quality) green patent they produce.

Stepping back, from a broad perspective, it may not be surprising that a firm or industry engaged in energy production, processing, storage, and distribution, would have spin-off outputs around "green innovation," simply as a function of its daily business activities. Moreover, given that a sizable portion of green innovation and green patenting is related to environmentally-focused energy issues, it might be expected that the existing energy industry would play a potentially considerable role. While this still may not fully explain why they are excluded from campaigns to forward solutions in this field, it does motivate the importance of delving deeper into understanding the energy industry's historical role in the alternative energy space, identifying areas where it may be less substitutable, and determining the comparative advantages we can glean from the competitive responses of other innovators and producers in this domain.

Given this, we thus explore in more detail the precise role that the energy industry has played in the green innovation process, including areas in which it appears to be particularly intensive and non-substitutable. We begin by examining the simple question of when energy firms tend to enter and drive innovation along the innovation pathway of green technology. One could imagine that given their size and scale advantage, energy firms might adopt a "Stackelberg" approach, wherein they observe other more innovative firms initiating a new technology tree and subsequently stepin to capitalize on the opportunities presented (e.g., Gal-Or (1987), Chamley and Gale (1992)). We find, in sharp contrast to this, that energy firms are first-mover innovators across the green patenting spectrum. Specifically, they innovate significantly earlier than other firms within the same class. For instance, they enter significantly earlier in the patenting process (over 600,000 slots earlier), translating to a roughly 80% higher chance of being the earliest "pioneer-patent" (first 10 percent) in a given green technology class.

We then explore solely these pioneer patents within each green technology category. While energy firms are early contributors to these innovations, it could be that they are posting marginally important contributions, or technology that is specific to themselves, or unapplicable to other

[4] For instance, see https://divested.betterfutureproject.org/ and https://gofossilfree.org/divestment/what-is-fossil-fuel-divestment/, both of which include many large signatories globally.

innovators or advancements in the field. In contrast to this, we find that considering solely these pioneer patents within each green technology class, energy firms' pioneer patents are significantly more highly cited, and over twice as likely (t=4.14) to be a blockbuster patent than the average pioneer green patent.

Next, we turn our focus onto a specific domain in which energy firms have assumed an especially prominent role in the early-stage innovation and throughout its innovation path, up through its commercialization phases and projects: namely the space of carbon capture technology. We chose carbon capture as it is an area highlighted by nearly all global organizations tasked with solution generation, coordination, implementation, and enforcement (as discussed in Section VII: the IPCC, the COP Meetings, the United Nations FCC, IEA, etc.) as a crucial mitigation technology for meeting global climate-related objectives. Focusing on the important area of subterranean or submarine CO2 capture/storage (Patent Class Y2C10/14), we find that: much like the universe of green patenting, traditional energy firms are early and important innovators in this domain. However, in this specific context, they assume an even more foundational role. Energy firms form the majority of pioneering patents and early ideas in this space (65% of the first patents in the space came from energy firms, with 8 of the top 10 innovators being traditional energy companies). Moreover, many of the world's largest carbon capture projects, including the first offshore carbon capture and storage plant, Sleipner in the North Sea in Norway, have been established through collaborations with traditional energy firms. These partnerships are formed due to the extensive scale of such projects and the specialized expertise in carbon flow, distribution, and storage that traditional energy companies possess. The Sleipner project, in particular, has served as a blueprint for subsequent deep-sea storage facilities, underscoring the crucial role played by energy firms in advancing carbon capture technology. Digging deeper into the actual content of the patents, we find that the text of carbon capture patents filed by energy firms differs from those filed by non-energy firms. These differences are valued by future innovators (both within and outside of green technologies), as evidenced by the higher citation rates and closer textual similarity. The cumulative evidence strongly indicates that for certain fundamental green technology spaces, traditional energy firms have served, and continue to serve unique roles: as first-movers, appearing non-replicable, with no clear substitutes, and have played a critical role not only for firms within the energy sector but also for those operating outside out it, contributing significantly to the development and large-scale implementation of these technologies.

Returning to the broad empirical patterns of patenting we observe among energy firms in green technology over time, a natural question still remains. Namely, despite the higher patenting activities and citation rates among energy companies, it is possible that the patents that energy companies create are narrowly focused, not meaningful, and/or are not consequential beyond their industry boundaries. Thus, their incremental green patenting activity may not be considered to have high real-world significance, and they operate within somewhat of an echo chamber, wherein their ideas and innovations predominantly circulate within their own industry without broader impact. To explore this, we test whether energy firms' patents are cited solely by other fossil fuel companies, or whether they are also having an impact on other outside innovators. Green patents of energy companies, it turns out, receive the majority, 74%, of their citations from *outside* the industry. By comparison, this is even slightly higher than non-energy firms' equivalent green patents – receiving 71% of their citations from *outside* the industry. Moreover, in investigating whether energy firms simply purchase or acquire these innovative patents from outside firms and innovators, we find that the vast majority (over 98%) of their green patents are initiated and developed in-house (organically). Further, traditional energy firms even appear over-represented amongst the top net green patenting firms in the economy.

Moving further, it is equally important to investigate whether outsiders have to pay a huge price to become a player in the green energy market. It is possible that energy firms create a dense web of overlapping intellectual property using green patents to prevent others from commercializing green technologies (Shapiro 2001). Under this view, excess green patenting by energy firms can be interpreted as creating entry barriers rather than fostering green solutions that can be commercialized by many players in energy markets, old and new. We investigate this possibility by investigating to what extent green patents of energy firms exhibit patent thickets using citation analysis developed to detect patent thickets in the pharmaceutical industry. We find little evidence of patent thickets in energy firms' green patents, with more evidence of thicket-like behavior among green-patenting firms outside of the traditional energy industry.

Lastly, we investigate whether green patent production – like in carbon capture – more broadly feeds itself into real, tangible products. Using two unique databases, we construct two outcome metrics: (1) energy (wattage) produced from alternative energy sources, and (2) products with low carbon emissions. We find that indeed fossil fuel companies' green-energy patents produce more kilowatts of alternative energy than those of green-energy firms, suggesting fossil fuel companies are utilizing their green patents, putting them into actual production now rather than shelving them for future use. Moreover, we find evidence that traditional energy industry companies with more green patents spend more on capital expenditures leading to products with low carbon emissions, as well.

Finally, while there is a potential endogeneity concern that ESG investing and the resulting pressures around this are forcing the behaviors we see in the data, i.e. there is a possibility that energy firms are responding to public pressure and adjusting their research and development efforts to attract ESG fund flow, two empirical patterns challenge this notion. First, the results we find are that green patents of energy firms exhibit significantly higher quality and greater impact, particularly from the perspective of firms *outside* of the energy industry. Additionally, these patents are accompanied by several other environmentally friendly markers, such as the production of energy from alternative sources. This includes their role as first movers, on average, in green technology domains, and serving as the primary and non-substitutable drivers of certain fundamental green technologies, such as in carbon capture. Second, our findings indicate that fossil fuel companies were major innovators in the green energy space well before the term "ESG" itself even came into existence (and thus before substantive capital flows related to it). The term ESG traces its origin to a 2004 United Nations Global Compact Report (United Nations (2004)). Our results on green patenting by the traditional energy industry, including the relative intensity and quality of these patents – range back to – and hold during – the 1980s, decades before the emergence of the term or movement of ESG (including any associated divestiture efforts). As an illustration of this, in 1978, a central, foundational patent in the continuation and commercialization path in the solar cell space[5] was discovered and awarded to a research team at Exxon (the patent is illustrated in Figure 2, along with another pioneering team from Exxon in Photovoltaics in 1973). As mentioned above, this is consistent with the broader evidence that energy firms are over-represented amongst pioneering green patents across all green technology sub-classes, on average, along with having the more influential of these pioneering patents to future outside follow-on innovators.

-- Insert Figure 2 here --

It bears noting once again that none of what we find we believe to be a signal of altruistic or even societal- or ESG-aligning behavior (and again, as the behavior began decades before ESG existed it almost precludes the latter). Instead, our findings are consistent with energy firms being profit-maximizing entities with the aim of being long-lived global energy providers for decades (or even

[5] The history of solar power stretches back almost 200 years, beginning with discoveries in 1839 by French scientist Edmond Becquerel, with other landmarks such as Charles Fritts installing the world's first solar panel in New York City in 1883, and Bell Labs' (Chapin, Fuller, and Pearson (1957)) US patent #2,402,662 on solar-cell construction and chaining (Kumar (2020)), along with the Exxon patent we mention above. We are grateful to the referee for pointing us to this.

centuries) to come, irrespective of what that energy source might be. Moreover, with industry- and delivery-specific experience and expertise in energy sourcing, delivery, distribution, and servicing, it may not be surprising that they possess certain positions difficult to substitute in many instances moving ahead.

Considering the entirety of the evidence, the role of traditional energy firms appears to extend beyond the volume of highly cited and blockbuster patents in the various green technology fields. Instead, they appear to emerge as influential first-movers and occupy distinctive roles not easily substitutable across many technology branches. Moreover, in certain of these branches (such as carbon capture), their scale, specialized and unique knowledge, and decades-long expertise in processing, distributing, and delivering energy products serve a foundational purpose. This capability appears to allow them to not only continue to be influential innovators, but also translates into large commercialized products that follow-on innovators continue to find valuable in their innovation and implementation decisions.

The remainder of the paper proceeds as follows. The next section provides background for our study Section III describes the data we collect on patents along with ESG metrics used in our analyses. Section IV presents our main results on green patenting including the most frequent patenting entities. Section V then explores who is rewarding in green patenting. Section VI focuses on quality markers of green innovation comparing across energy firms and other innovators, while Section VII focuses on a more in-depth analysis of the Carbon Capture innovation and commercialization landscape. Section VIII explores patent thickets, impact inside and outside of the industry, net green patenting, and real green output production. Section IX concludes.

II. Background

In addition to the above-mentioned studies, recent empirical work investigating the implications of socially responsible investing on firms includes Teoh et al. (1999), Hong and Kacperczyk (2009), and Geczy et al. (2005), among others. Teoh et al. (1999) studies the effects of the South African boycott to end apartheid and shows the boycott had no discernible effect on the valuation of firms with ties to South Africa.[6] Geczy et al. (2005) and Hong and Kacperczyk (2009) study the characteristics of stocks that are not usually favored by socially responsible investing and show that these stocks tend to have lower price-to-book ratios, less institutional ownership, and less analyst

[6] Similarly, a New York Times (2014) article notes that Stanford's divestment from coal stocks had little effect on stock prices.

coverage.

Earlier studies on the theory of impact investing argue that firms that are excluded by socially responsible investors end up facing higher costs of capital, suggesting clean projects need to clear a higher hurdle rate to be financed (Heinkel et al., 2001). Unlike Heinkel et al. (2001) who put emphasis on the negative effects of screening by socially responsible funds, Oehmke and Opp (2020) focus on the conditions under which socially responsible investors provide additional financing for clean technology relative to what profit-maximizing investors would be willing to provide. In that sense, Oehmke and Opp (2020) highlight the positive aspects of impact investing – focusing on the ability of socially responsible investors to impact firms by relaxing financial constraints for clean production. Chowdry, Davies, and Waters (2019) provide a model in which profit- and social impact- motivated investors provide financing for projects that produce both corporate profits and social good. They show that when a firm cannot commit to pursuing social goals, impact investors should hold financial claims in the firm to incentivize profit-motivated owners to pursue social goals. Moreover, Hart and, Zingales (2017) argue that companies consider maximizing shareholder welfare, including environmental concerns, and not solely financial value - explicitly calling for active fund engagement rather than divestment.[7]

The equilibrium asset pricing implications of divestment have been the subject of Davies and Van Wesep (2018), and Pastor, Stambaugh, and Taylor (2019). Davies and Van Wesep (2018) study divestment campaigns that aim to depress share prices to induce managers to change firm behavior. They make the case that divestment campaigns are likely to be ineffective and may be counterproductive, as managerial compensation contracts reward long-run profitability and stock returns, rather than short-term prices. Pastor, Stambaugh, and Taylor (2019) propose a general equilibrium pricing model incorporating ESG investment preferences. In their model, ESG-incorporating firms have negative CAPM alphas, the extent of which depends on preference heterogeneity and the strength of ESG sensitivity in preferences.

III. Data

Our analysis relies on two main streams of data: (1) The Patent Citation and Patent Assignment databases, and (2) Environmental Score data from multiple providers – the two largest and most

[7] This has also generated considerable attention in the popular press. See for instance, Andrew Edgecliffe-Johnson and Billy Nauman, "Fossil fuel divestment has 'zero' climate impact, says Bill Gates" Financial Times, 9/17/2019; William MacAskill, "Does divestment work?", New Yorker, October 20, 2015.

widespread: Sustainalytics ESG Ratings database, along with the MSCI ESG Ratings database. We collect data on all patents granted in the United States from The United States Patent Citation and Patent Assignment database for the years from 1980 through 2020.[8] We focus on publicly traded firms, for which there are rich, publicly available measures of firm characteristics, external activities, income, profitability, and patent holdings. We assign patents to Compustat firms by matching patents' assignee names with Compustat company names. In order to do this, we use a combination of natural language processing (NLP) techniques to implement exact and fuzzy matching, and then augment with hand matching (and verification).

We then further classify each patent into a technology class (essentially, the industry to which the patent applies) and whether the patent has the potential to contribute to environmental solutions, which we call "Green Patents." This "Green Patent" classification is done following the guidelines the Organization for Economic Co-operation and Development (OECD) created specifically for this purpose.[9] According to this classification, patents that are related to environmental technologies are classified into various broad environmental technology categories including environmental management, water-related adaptation technologies, biodiversity protection and ecosystem health, climate change mitigation technologies related to energy generation, and waste-water treatment or waste management.[10] Hascic and Migotto (2015) provide a detailed explanation of OECD's algorithm that identifies patents that contain environment-related technologies related to environmental pollution, water scarcity, and climate change mitigation.[11]

Additionally, we use Sustainalytics' Environmental, Social, and Governance (ESG) Ratings Database which spans 2008 to 2020 to measure a given firm's engagement in environmental issues. Sustainalytics' database aims to measure how well companies proactively manage the environmental, social, and governance issues that are the most material to their respective business. More specifically, Sustainalytics evaluates firms based on three categories: (a) Preparedness, (b) Disclosure, and (c) Performance. In the context of the Environmental (E) Component of their ESG ratings, on which we focus: Preparedness refers to company management systems and policies designed to manage material environmental risks; Disclosure refers to whether the company meets international best

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[8] https://www.uspto.gov/learning-and-resources/electronic-data-products/patent-assignment-dataset
[9] USPTO technology classes: https://www.uspto.gov/web/offices/ac/ido/oeip/taf/tecstc/classes_clstc_gd.htm.
[10] https://www.oecd.org/environment/consumption-innovation/ENV-tech%20search%20strategies,%20version%20for%20OECDstat%20(2016).pdf
[11] https://www.oecd-ilibrary.org/environment/measuring-environmental-innovation-using-patent-data_5js009kf48xw-en

practice standards and is transparent with respect to the most material environmental concerns; and finally, Performance refers to company environmental performance based on quantitative metrics such as carbon intensity and based on the analysis of controversial environmental incidents in which the company may have been involved. We use 2008 to 2020 sample as our main sample because of the sample constraint imposed by the Sustainalytics, but we report additional results using the longer time horizon, 1980 to 2020, when ESG score is not required for the analysis.

IV. Green Patenting at Industry Level

We begin our analysis by examining the top green patent-holding firms as of 2020. Table 1 shows a number of initial interesting patterns. In Panel A, we show that Energy Sector has the second most green patents among the sector-classifiable green patents. In Panel B, we observe that out of the top 50 green patent producers, for instance, 10% of them are energy firms, which are *explicitly excluded* by many ESG favored funds, and a main segment of the firms focused upon by divestiture campaigns. These firms are Exxon Mobil, Royal Dutch Shell, BP, Conoco Phillips, and Chevron. These firms collectively produced 9,343 green innovation patents over our sample period.

-- Insert Table 1 here --

In Table 2, we tabulate the number of granted patents that we use in our tests – both green and non-green – for public firms. Appendix Table A1 Panel A reports number of green patents by year by industry. Appendix Table A1 Panel B reports number of green patents by year technology sub-categories. Our final sample, containing all public firms from 1980 to 2020 that produce at least one patent is 11,397 public firms. These firms produce 3,032,611 patents, with 7.76% classified as green patents. In looking at the time series, the percentage of green patents peaks in total number in 2019, with 14,018 patents produced (representing 9.26% of all patents produced by publicly traded firms in 2019).

-- Insert Table 2 here --

We next move on to our main regression analyses in order to explore the above patterns in a more formal setting where we can control for numerous determinants of R&D and patenting. In particular, we explore the role that the energy sector is playing in the landscape of green innovation vis-à-vis other firms undertaking R&D programs and patenting in the same space. We begin by examining green patenting at the industry level.

Turning to this industry-level analysis, we first explore whether green patent production in the energy sector differs from that of green patent production in other industries. To perform the analysis, we estimate the following OLS fixed-effects model:

$$\textit{Green Patent Ratio}_{it} = b_0 + b_1 \times \textit{Energy Sector}_{it} + \textit{Year Fixed Effects} \quad (1)$$

The unit of observation in this analysis is industry-year, where we define an industry with its 2-digit SIC code. In this analysis, reported in Table 3, we only include industries if at least one firm in that industry produced a green patent in that particular year, ensuring that we compare only industries that engage actively in green patent production. In Table 3, our sample spans from 2008 to 2020, to mirror our tests that follow which explore the relationships with ESG Ratings (that only exist over that period), but we show the full 40 year sample analog for Table 3 in Appendix Table A2. *Energy Sector* is a dummy variable that equals one if the first two digits of its Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Out of 709 industry-year observations, 55 observations belong to the energy sector.

-- Insert Table 3 here --

Our main dependent variable of interest is the *Green Patent Ratio*. We compute this ratio by dividing the number of granted green patents in a given industry by the total number of granted patents in that industry in that particular year. This measure is meant to be a potential metric capturing the importance of green innovation in that industry (vs. all other innovation), through this green share. We find that the coefficient of the *Energy Sector* dummy is 9.01% (t = 7.69). This 0.0901 (t=7.69) implies that the energy sector has over twice the relative focus on green innovation in its innovation portfolio as the average industry, at 17.61% of all of its patenting dedicated toward green patenting (vs. 8.60% for all other firms also active in green patenting).

Moreover, at the sector-wide level, in an absolute sense, the energy sector appears to have a sizable percentage of its innovation efforts going toward green research – with nearly twenty percent of its patent innovation in this space. From Table 3, our conclusions remain similar when we control for several important factors that could potentially contribute to the industry-level green patent production. These factors include average industry level investment, R&D spending level, average firm age in the industry, average firm size in the industry, average firm cash level, and average industry book leverage. Some of these on their own are not significantly related to the *Green Patent Ratio* on their own: industries that on average have higher overall investment, firms with more cash reserves, or book leverage – do not seem to have higher green innovation, whereas firms that are older and have higher R&D investments seem to have higher green innovation.

In Appendix Table A2, we repeat the same analysis using the 1980 to 2020 sample and find similar results, i.e. the coefficient of the *Energy Sector* dummy is 11.63% (t = 14.82). This implies that the energy sector has nearly two and half times the relative focus on green innovation in its innovation portfolio as the average industry, at 19.39% (11.63%+7.76%) vs. 7.76 % for all other firms also active in green patenting). In Appendix Table A3, we use the number of green patents as our dependent variable and include the total number of patents produced in the industry as a control variable. In this specification, results again indicate that energy industry firms are relatively more intensive green patent producers compared to all other industries active in the green patenting space.

One might worry that the patenting we are measuring in Table 3 has to do with broader green patenting outside of specific climate-mitigation technology with respect to energy sources. This might be especially true if energy firms were attempting to strategically appear engaged in green patenting but did not want to materially impact the fossil-fuel components of their businesses. In order to explore this, we subset our green patent universe to examine solely those green patents in the universe that directly address "*Climate change mitigation technologies related to energy generation, transmission, or distribution.*" The results of the analysis are reported in Appendix Table A4. Specifically, in Appendix Table A4 we run an identical regression to Table 3 but focus solely on these alternative energy patents. The results indicate that the *Energy Sector* appears to have a significantly larger percentage of its relative innovation efforts going specifically toward alternative energy innovation relative to all other industries. Specifically, the coefficient in Column 3 of 0.0229 (t = 4.51) implies that the energy sector has, even slightly larger than Table 3, an almost three times larger focus specifically on climate change mitigation technology innovation relative to all other industries.

While the results thus far support that the energy industry is dedicating a significant percentage of its intellectual property patenting to green patenting – it could be the case that the industry has only done so as a response to the groundswell of ESG and divestiture campaign activity. While the foundational solar cell technology patent from Exxon in Figure 2 suggests that some alternative energy

R&D has existed in traditional energy firms for decades, it might not be true more broadly. A nice aspect of our patenting data on green patent activity is that it goes back to 1980. This allows us to test for the patenting activity of traditional energy firms before the term "ESG" itself even existed (as mentioned before, it was coined in a 2004 UN Global Compact Report (United Nations (2004)).[12] In Appendix Table A5 we split our results to see behavior in the pre-2004 and post-2004 periods. From Table A5, the energy sector was large and significant green patentors in both (2.63 times the average industry pre, and 2.11 times the average industry post). This is important, as again, by definition pre-2004 could not have been driven by ESG or divestiture campaign pressure. Instead, this is consistent with energy firms, from a profit-maximizing perspective – and even in the 1970s – desiring to be the world's *energy* providers for the next 50 to 100 years, whether that energy derives from oil, natural gas, water, wind, solar, or other sources. Therefore, they may find it optimal to invest in IP surrounding many forms of these future types of energy to ensure that is the case.[13]

In Appendix Table A7, we then also explore to what extent firm-level emissions themselves interact with – and are associated with – green patenting activity. From Column 1 of Appendix Table A7, in general, there is a positive association between firm-level greenhouse gas emissions (GHG) and green patenting activity. From Column 2, even controlling for GHG emissions, the coefficient *Energy Sector* remains large and statistically significant – cementing the positive association from Tables 3. In fact, compared with other Top Green Patenting Industries (outside of Energy) from Column 3 of Appendix Table A7, it is interesting that a contrasting pattern emerges with regard to GHG emissions and green patenting. For all of these other top green patenting industries, they retain a positive association between their intensity of GHG emissions (likely due to usage or input in their production process of their ultimate final good or service), from the positive interaction term in Column 3 added to the main effect that is also positive Emissions. In contrast, traditional energy firms have a significantly negative interaction term that roughly cancels out the positive coefficient on Emissions, such that the combined total association of traditional energy firms' green patenting is statistically unrelated to emissions This is consistent with energy firms' need to innovate in green patents being driven by a more basic and fundamental survival motivation from a broad business-model perspective

[12] Divestiture campaigns from fossil fuels began even later in 2012, originating amongst university endowments and spreading from there (beginning first with Unity College of Maine (USA) (Mogilyanskaya (2013)).

[13] We also analyzed variation of firm level green patent ratio and tested whether firms in energy sector have markedly higher green patent ratios compared to firms in other industries. The results reported in Appendix Table A6 show that by and large energy firms have more green patents in their patent portfolios.

(and consistent with the leading innovation we see them undertaking in the space dating back to the 1970s, as in Figure 2, and from Appendix Table A5).

V. Who Is Rewarded for Green Patenting?

In this section, we turn our focus to the determinants of ESG scores. Specifically, we explore the widely used environmental metrics and how they are associated with the green patent production of firms. Put differently, the evidence thus far suggests that traditional energy sector firms (which have lower ESG scores, along with being explicitly restricted by many ESG-focused vehicles and campaigns) appear to be substantive contributors to the universe of the entirety of green patenting. We next ask whether energy firms get less "credit" in terms of incremental ESG scores for each green patent they produce.

To examine these questions, we estimate the following OLS model,

$$\begin{aligned} \textit{Environmental Score}_{it} = b_0 &+ b_1 \times \textit{Energy Sector}_i \\ &+ b_2 \times \textit{Green Patents Granted}_{it} \\ &+ b_3 \times (\textit{Energy Sector}_{it} \times \textit{Green Patents Granted}_{it}) \\ &+ b_4 \times \textit{Firm Size}_{it} \\ &+ \textit{Year Fixed Effects} \qquad (4) \end{aligned}$$

In this analysis, we work with firm-level data as public firm disclosures allow us to measure several research inputs, such as research and development expenditures, at the firm level. The data also allow us to control for important firm characteristics potentially related to green patent production. For instance, if the energy sector were dominated by large firms and green patents require a certain minimum scale, we could be attributing the higher green patent production result documented in Table 3 to being involved in energy, when in fact firm size is driving the results. We include firm size in this last specification, for instance, to help control for such factors.

-- Insert Table 4 here --

From Table 4, several empirical patterns emerge. First, *Energy Sector* firms as a whole have significantly lower ESG scores than firms in all other industries. The average ESG score for firms in our sample is 57, and thus the coefficient from Column 2 on *Energy Sector* of -5.56 (t=2.79) means that energy firms on average have roughly 10% lower ESG scores to begin with. Moreover, from Column 3, while the average green patenting firm gets a small penalty for green patenting (the coefficient on *Number of Green Patents Granted* of -0.0297 (*t*=-5.44) implies that a 1 standard deviation increase in green patents granted decreases the score by roughly a point), the interaction term of -0.2505 (*t*=-3.23) for (*Energy Sector x Number of Green Patents Granted*) implies a roughly 10X penalty for energy firms for the same behavior. Moreover, we again find that this is not something shared by all frequent green patentors, as other high green patenting industries have both: 1.) significantly *higher* ESG scores on average, and 2.) receive no incremental penalty relative to all other firms for additional green patenting (from Columns 4 and 5). This puts forward the potential that ESG rating agencies, and perhaps broader market participants who follow these agents, have allowed a gap to develop between outcomes and motivation of firms' to achieve these outcomes, in their resultant financial behavior (such as investment allocation, which we document results consistent with in Section VIII).[14]

In Appendix Table A8, we perform the identical analysis using environmental scores produced by a different data vendor, MSCI and find similar results – the *Energy Sector* has significantly lower ESG scores on average, and gets penalized relatively more for each green patent produced. In Appendix Table A9, we then split this ESG sample in half by time, i.e., pre- and post-2013, and find that the negative relationships between *Environmental Score* and number of granted green patents holds in both earlier and latter parts of the sample.[15]

VI. Quality Markers of Green Innovation

a. Citations to Green Innovation

One explanation that could potentially explain the results in Tables 3 and 4 is that traditional energy firms – potentially even strategically - produce lower quality (or less meaningful) innovation within the green innovation space. If this were true, we might expect to see exactly what is observed – that while the energy sector produces a large number of green patents (in quantity terms), the value of these patents is low, and thus *Environmental Scores* appropriately take this into account by not rewarding for this relatively low-quality innovation.

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[14] We would like to thank a referee for suggesting and highlighting this framing and interpretation.

[15] In Appendix Table A10, we provide a series of tests to check whether the negative correlation we document for energy sector's green patents is also observed in other sectors. Broadly, the energy industry is the only industry that both experiences an average lower ESG score across the entire industry coupled with significant penalty for each additional green patent.

In Table 5 we test this by investigating the quality of green innovation in the energy sector vs. other green innovations. We use the cumulative number of *adjusted citations* the green patent of a firm receives at the end of the sample period as our measure of patent quality. *Adjusted citations* adjusts for vintage (time since patenting) effects inherent in this, by dividing a patent's total citations, as of 2020, with the mean citations of all patents that are granted in the same year and are in the same CPC class of that patent (Hall, Jaffe and Trajtenberg (2001), and Das, Nanda, and Xiao (2017)). Further, patent citations are inherently limited to non-negative values. Moreover, they are highly right-skewed distributions with masses of values at zero, and further are incredibly vintage and time-sensitive. Given these concerns, we use a number of measures and methods to analyze the citations in order to accommodate and correct these inherent distributional properties. There are two metrics at the base of our analyses: the first metric is a simply log of one plus the number of accumulated citations to the given green patent. The second is a categorical variable taking the value of one if the number of green patent citations is above the 95th percentile of all green patents for that vintage of green patents (which we term *Blockbuster Patent*). We then also create a dummy variable, *Zero Cite*, which takes a value of 1 if the patent has no citations at the end of the sample period, and include this variable as a control variable. In addition, we use Poisson models along with linear regressions, in line with recent literature (Cohn, Liu, and Wardlaw 2022) in order to also address econometric concerns of the data.

Results are presented in Table 5. From Panel A of Table 5, energy firms do not appear to produce green patents of lower quality, with in fact, the opposite appearing to be true in the data. Green patents produced by the energy sector are significantly more highly cited than the average green patent. The coefficient in Column 3 of Panel A on the *Energy Sector* of 0.063 (t=3.28) implies on average 85% higher citations of energy firms' green patents than other green patentors in the same technology class-vintage (year). Similarly, the Poisson model reported in the fourth column of Panel A suggests that energy firms have close to 13.73% higher citations (*t*=3.45) compared to non-energy firms.

Panel B then runs a related test, but instead examining *Blockbuster Patents*. *Blockbuster Patents* is a non-parametric measure of patent success that past literature has shown to more closely capture commercializability of a patent, and more highly correlate with patent value, given the highly skewed distribution of patent citations mentioned above (Trajtenberg (1990), Sampat and Ziedonis (2004)). From Column 3 of Panel B in Table 5, a similar relationship emerges for the more highly valued *Blockbuster Patents*. Energy firms' green patents have a significantly higher likelihood of attaining blockbuster status, with the 0.0449 (*t*=4.77) coefficient implying a roughly doubling of the likelihood of blockbuster status for energy firms' green patents relative to the green patents of other patentors in the same green technology class-vintage (year).

Stepping back, the results of Tables 3-5 then suggest that energy producers in our sample appear to not only produce higher quantities of green innovation, but that this green innovation appears to be of higher quality, on average. Moreover, this is not simply a function of being ample producers of a large share of green patents, as other large-share producers of green patents exhibit quite different empirical dynamics.

-- Insert Table 5 here –

b. First Movers in Green Patenting

The fact that energy industry was active in green patenting dating back to the beginning of our sample (1980s) – decades before ESG was developed as a term - along with before many alternative energy spaces were developed, along with the fact that these energy patents receive significant citations, raises the possibility that perhaps they were early movers in green patent related technology areas. We explore this possibility in a number of ways.

We begin by investigating the sequence of patent numbers, i.e., within a given sub-class of green technologies, are earlier patents predominantly granted to energy firms? This is formalized in Table 6, Panel A in which we regress the average patent number in the class on a categorical variable for whether the patent was from an energy firm or not *Energy* (i.e., the first US Patent was awarded in 1790 to Samuel Hopkins for a fertilizer utilizing potash, signed directly by President George Washington; they started to be numbered in 1836 with US Patent #1, and have been increasing purely chronologically since then). From Table 6 Panel A, energy sector patents are significantly more likely to be early patents in the space as indicated by the negative coefficient of *Energy Sector* dummy in Column 1—the average patent in the green space for the average green patentor appears around patent # US 8.19 M. For energy firm green patents, by contrast, this is far earlier at US 7.5 M (t=91.73). In the second column of Panel A, we find that patents produced by other top green patenting industries (outside of energy) do not exhibit a similar pattern with respect to timing of their grants.

In the next two columns of Panel A, we test a similar idea, but using a slightly different specification. We define a dummy variable "*Earliest 10 percentile*" as the earliest ten percentile of patents within each green patenting sub-class as of 2020w (end of our sample period). This is meant to capture, in a non-parametric way, the foundational, earliest movers within each category of green patenting, as opposed to the simple linear earlier vs. later (anywhere in the distribution) metric in the first two columns. The 0.0799 (*t*=45.53) coefficient on *Energy Sector* in Column 3 implies a roughly 80% higher likelihood of energy firms being early foundation patents within a green category in which they innovate (vs. all other green innovators in the same technology category). Likewise, the negative coefficient in Column 4 indicates that other top green patenting industries outside of the energy sector are not similarly early movers within green energy patenting categories in which they take part.

-- Insert Table 6 here --

Next, we move on to explore whether the early mover patents produced by the energy sector are more influential than other early patents within the same green sub-class, controlling now for all considered patents being early, foundational patents. It could be that even though energy firms appear to be early innovators, and still frequently innovating, on average they are putting up more incremental innovation that doesn't have a substantive impact on others outside of energy. This analysis focuses solely upon early mover patents, thus contains only 5,592 patents. The totality of Panel B implies that even amongst the early foundational patents, green patents of energy firms within green patenting sub-classes are significantly more highly cited, and significantly more likely to be blockbuster early green patents.

c. Non-substitutability of the Energy Sector's Non-green Patents

Our analysis thus far focused on previously undocumented special features of green patents of the Energy Sector. However, these green innovations do not exist in a vacuum at any firm (including energy firms) and are parts of broader organizations innovating and producing across multiple dimensions. Indeed, many of the potential explanations for why energy firms may be able to innovate ubiquitously, in ways that others find helpful, and (as we will later show) to commercialize a significant amount of green innovation may have to do with the complementarity with its base of operations. The decades that many of these firms have spent in energy production, processing, and large-scale delivery may give them insights difficult to replicate or transport to other non-energy firms.

Given this, in this section we explore the energy industry's non-green patents, and their potential importance in the green patenting and development patterns we observe. In other words, are energy firms' non-green patents pivotal in determining the path of the green innovation for both themselves and other industries? We seek the examine these questions by analyzing energy firms' non-green patents usage relative to what may be expected. In Panel C of Table 6, we explore this using two measures. The first one is that the energy firms' non-green patents make up 2.03% of the "total non-green patents sample," i.e., only 2.03% of all the non-green patents are produced by the energy industry. However, the citations to these energy industry non-green patents constitute 5.45% of the citations of an average *green* patent. Put differently, on average non-green patents produced by energy firms contribute disproportionality more (roughly 2.5X) to the progress of green patenting compared to their share in the non-green patenting space. However, to further narrow down this analysis, we then sub-set to only those categories where energy firms and non-energy firms are both active in the non-green patenting category. We again find a significantly disproportionate amount of citations relative to their patent make-up, i.e. (6.05% vs. 2.45%, t=21.99). These results suggest that the non-green patents of energy firms show substantive importance for the entirety of the green innovation landscape, and even in relative terms, more so in a unique manner relative to other active green patenting firms.

Moreover, even within green patents, traditional energy firms may be contributing to technology spaces outside of purely energy creation and delivery.[16] To explore this possibility, in Appendix Table A1 in Panels B.1 and B.2 we breakdown the total patenting, and patenting of traditional energy firms, across green innovation categories. From these panels, we observe that energy firms are also actively contributing to technology related to: buildings, transportation, waste water treatment, and other biodiversity innovations, for instance. For example, over the 40-year sample period, energy firms have accounted for over 15% of the wastewater treatment and waste management related green patents.

VII. *Carbon Capture*

In this section we examine a branch of green and alternative energy technology that has been particularly explored and pushed forward by energy firms. Namely, that of carbon capture. One reason we focus on this is that nearly every scientific assessment of the ability of the world to address the glidepath toward a sustainable energy future involves the capture and sequestration of carbon dioxide (i.e., not allowing it to enter the atmospheric layer). More pointedly, carbon capture and sequestration

[16] We would like to thank a referee for suggesting and pointing us toward this analysis.

has been a mitigation technology consistently and strongly stressed by numerous international bodies tasked with solution generation, coordination, implementation, and enforcement. The Intergovernmental Panel on Climate Change (IPCC) - an intergovernmental body of the United Nations to advance scientific knowledge about climate change, co-awarded the Nobel Peace Prize in 2007 – include this as one of their most promising and impactful technologies for reducing net emissions by 2030 (IPCC (2022)). Moreover, numerous COP (Conference of the Parties) Meetings, along with the United Nations Framework Convention on Climate Change (UNFCCC) which proposed and ratified the Paris Accords on Climate Change in April 2016, continue to focus upon the importance of carbon capture and sequestration to meet stated reduction goals (IPCC (2022)). In addition to the UN, numerous other international organizations have stressed the importance as well. For instance, the OECD's International Energy Agency (IEA) (group of 42 OECD nations comprising 75% of global energy demand), the UK's Department of Energy & Climate Change, the US Department of Energy, and many more have published reports supporting the technology and its deployment in international- and regional-level projects.

An additional aspect of the carbon capture and sequestration technology and practical implementation space that makes it intriguing to explore is the scope and scale needed for success. In particular, intricate knowledge of efficient capture, transportation, and storage requires knowledge of large-scale carbon flow and movement. This has resulted in many of the world's largest and most ambitious carbon capture projects to date being implemented by traditional energy firms. For example, the Sleipner Carbon Capture and Storage (CCS) Project - the pioneering deep-sea storage facility in the North Sea in Norway - was the first large-scale CCS project in the world, beginning operations in 1996 (IPCC (2007)). It was created, and continues to be operated, by Equinor – a multinational energy company headquartered in Stavanger, and named Statoil at the time of Sleipner's building in 1996 - and has been awarded numerous prizes, along with serving as a model for future industrial-scale projects (MIT (2016 -https://sequestration.mit.edu/tools/projects/sleipner.html)).

Given the above, we explore the innovation branch of carbon capture, and in particular focus on the branch of subterranean or submarine CO2 capture/storage (Patent Class Y2C10/14) in our sample. We begin by exploring the time series of innovations in the branch from its genesis, shown in Figure 3. Figure 3 separates the patents in the category that were granted to both traditional energy (in blue) and non-energy (red) firms. What is immediately clear from this figure is the important role that the energy industry has played in this branch, both at its onset and continuing through to present day. This is formalized in Table 7 Panel A in which we regress the average patent number in the class on a categorical variable for whether the patent was from an energy firm or not *Energy*. From Table 7 Panel A, *Energy* patents are significantly more likely to be early patents in the space (while the average patent in the space appears around patent # US 8.2 M, for energy patents, this is far earlier at US 7.2 M (t=6.16). This is true also in the very first patents in the space: with 13 of the first 20 patents ever existing in the space being from energy (65%).

-- Insert Table 7 here –

More broadly, from Panel B of Table 7, throughout its entire life, energy firms have remained central figures in the innovation space. Of the top 10 patenting entities in the technology class, 8 of them are energy firms, including the top 7 (familiar large, global, integrated energy firms such as Shell, Exxon, etc.).

a. *Measuring Importance in the Carbon Capture Innovation Branch – Quantitative and Natural Language Processing (Actual Patent Text) Metrics.*

In this section, we explore the importance of energy patents in this carbon capture branch relative to non-energy firm patents. It could be that even though energy firms seemed to be early innovators, and still frequently innovating, on average they are putting up more incremental innovation that doesn't have a large impact on others outside of energy – or on the path of the space and adoption more broadly. We explore this question using multiple approaches. First, we examine the citations of carbon capture patents: those of energy and non-energy firms. We first examine how future innovators in the green patent landscape of carbon capture cite these patents. This comparison is shown in Panel C of Table 7. From Column 1, while the average non-energy carbon capture patent amasses roughly 12.54 citations per patent, the average energy patent in the same technology tree amasses 40.91 (12.54 +28.37 (t=6.86)). Interestingly, Column 2 shows that this same pattern of increased influence holds – if anything to an even larger extent - outside of the green patent space, as well (7.13 for non-energy firms' patents vs. 75.93 for energy firms).

However, we wanted to also move beyond measures of citations to examine the *content* of the patents themselves; along with the rich interconnections between these patents. We begin by examining the incidence and intensity of usage of various concepts and terms in energy firm carbon capture patents vs. those not from energy firms. We show this comparison in word cloud diagrams in Figure 4. From Figure 4, carbon capture patents of non-energy and energy firms do focus on different topics. Non-energy firm patents tend to focus on extraction of carbon dioxide, while energy firm carbon capture patents focus more on the nuts and bolts of implementing the actual process itself: such as efficient valving, pressure, and storage.

Moreover, in Panel D we formalize the textual association and interconnections of patents using measures of similarity from Natural Language Processing (NLP). In particular, we use the cosine similarity metric – a document size-independent measure of textual similarity – to examine the interrelatedness of innovation in this carbon capture branch to energy and non-energy patents. To do this, we first extract and code the entire corpus of text for the initial 20 patents that pioneered this sub-class. As mentioned above, there were 13 of these patents from energy firms, with 7 of the patents from non-energy firms. We next calculated the similarities of all future patents granted in the branch – who could observe the technologies and ideas outlined in these first 20 – to the contents of this pioneering set. Panel D then explores a number of comparisons amongst these. First, Panel D reports for the entire sample of patents that came after the first 20, their similarities in text to both energy and non-energy pioneering patents. These patents as a whole (304) are significantly more similar to pioneering energy patents language and text, roughly 23% (t=2.54) more similar. However, one might be concerned that this is simply driven by the fact that the bulk of these post-pioneering patents (following the first 20) come from the energy industry, driving their closeness. Thus, in Panel E we look at just the patents of non-energy firms (145 of them) and their similarity in of content to both the pioneering energy and non-energy patents. From Panel E, even these non-energy follow-on innovations in the carbon capture space are more similar, (even slightly more so in point estimate) at 42% (t=1.90) more similar to energy patents than to non-energy initial patents.

Lastly, researchers that have attempted to document the scientific evolution of the space, have also pointed to the focal importance of early energy firms' work in space, such as Li, Duan, Luebke, and Morreal (2013), that highlight Patent US4112052A, "Process for removing carbon dioxide containing acidic gases from gaseous mixtures using aqueous amine scrubbing solutions," granted in 1978 to *Exxon Research & Engineering Co.*

Stepping back, for all of these features and characteristics in the carbon capture technology innovation branch, traditional energy firms appeared to have served a unique purpose. Being first movers, non-replicable, and scale-permissive innovators in this important and expanding landscape that do not have a good substitute in terms of alternative innovators or innovation pathways.

VIII. *Additional Evidence – Patent Thickets, Impact Inside and Outside the Industry, Net Green Patenting, & Green Output Production*

a. Patent Thickets and Patent Impact

Even with evidence of the large and continued refreshing stock of highly cited patents by traditional energy firms, one might still be concerned that energy firms might be strategically green patenting simply to block other firms from innovating in the space. Alternatively, the firms might *themselves* be "self-citing" their patents enough to inflate citation statistics, without any real impact outside of their firms or industry.

In this section, we first explore the structure of patent citations to explore whether green patents of energy firms create a high barrier for potential entrants. For this purpose, we rely on the patent thicket concept introduced by Shapiro (2000). According to this definition, a patent thicket is "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology" (Shapiro, 2000). Patent thickets contain patents that protect different parts of modular and complex technology. In this particular definition – often used in the pharmaceutical industry - modular refers to different sets of components that need to be assembled to produce a range of products. Complex refers to the need to combine tens or hundreds of modular components to end up with desired product. *Patent thicket* thus aims to measure the degree of overlapping patent rights, making it more difficult for a new innovator to develop new technologies due to the complexity of licensing deals for multiple patents from multiple sources. Hall et al. (2014) shows that as patent thickets become denser, entry decreases, even after controlling for overall patenting activity in a technology area. Their findings suggest that patent thickets could constitute a barrier to entry into patenting. Motivated by these observations, we measure patent thickets in the green patenting space in an analogous metric: we count a firm's patent thicket by first identifying firm groups that cite each other. For example, consider 3 firms A, B, and C, where A cites B and C, B cites A and C, and C cites A and B. We say A, B, and C belong to one patent thicket. In Table 8, we define the dependent variable as the number of patent thickets that a firm belongs to. We then regress this metric on an *Energy Sector* dummy (in Columns 1-2) and a *Top 3 Sector (outside of Energy)* dummy (in Columns 3-4). The results indicate that the thickets are in fact economically less prevalent in the traditional energy sector than in other industries. In particular, the *Energy Sector* coefficient in Column 2 of -1.35 (t=2.72) implies that energy firms' green patents exhibit less thicket-like blocking than those green patents of the average green patenting firm. Column 4 suggests that in contrast, the green patents of other top green patenting industries (outside of energy) exhibit significantly more of the thicket-like intertwining that has been shown to block follow-on innovation. The sum of these results are inconsistent with the idea that energy firms' green patents are created with the purpose of elevating the entry barrier into the energy sector. In contrast, there is evidence of more thicket-like behavior among the green-patenting of firms outside of traditional energy.

-- Insert Table 8 here –

Next, we explore whether the green patents of energy companies are largely "self-cited," by the same firm to potentially inflate citation numbers, or perhaps considered important solely within the energy industry (as somewhat of an insulated idea echo-chamber). In Table 9, we analyze precisely this: comparing the percentage of citations that green patents of traditional energy firms receive coming from *within* the traditional energy sector versus outside of the sector. Panel A of Table 9 suggests that energy firms' patents have widespread citation impact across the green innovation space. Namely, green patents of energy companies receive roughly 74% of their citations from *outside* the energy industry and only 26% from within – a difference of 48.60% (t = 5.95). The analogous difference for non-energy firms' green patents is 71% of citations from outside their industry and 29% from within – a 42% difference. The diff-in-diff between these two (*Outside – Within Citations*) suggests significantly *more* of traditional energy firms' green patents come from outside of their industry than from within (6.46%, t = 2.69). These results suggest that green patents of energy firms have a broader impact across the green innovation space, outside of solely their industry.

-- Insert Table 9 here --

Next, we explore another characteristic of energy firms' green patents. Namely, while Figure 2 suggests that certain foundational green energy patents originate within energy firms' R&D departments, it could be that a large share is obtained through simply acquiring these patents from other firms and start-ups outside of their industry. If this were true, it would give a different interpretation of their role in the green-patenting universe and its evolution. Panel B of Table 9 thus explores precisely this – the percentage of energy firms' green patents that are developed in-house (organically) versus those that are obtained through external acquisition. From Panel B, the overwhelming majority of the energy sectors' green patents are produced organically: with over 98%

produced in-house, and less than 2% acquired from the outside. This tracks closely with other firms active in the green patenting space, from Panel B. It also suggests that the vast majority of the green patenting we observe from traditional energy firms originates from in-house research and development processes, as opposed to being acquired from the outside.

b. Net Green Patenting and Pressure from ESG Ratings

While we have examined the green patenting universe – including the producers of those patents and the characteristics of the patents produced – in this section, we explore in more depth the full patenting activity of green patent producers. In particular, while Table 3 finds that traditional energy firms allocate nearly twice as much of their patenting intensity to green patenting relative to other active green patentors, and Table 6 provides evidence that many of their non-green patents appear to be important for the green innovation space, it could be that the other non-green patents are so opposite of green as to completely off-set this heightened activity, its relative quality within the green innovation landscape, first mover status, etc. While it is difficult to measure this characteristic, we attempt to do so using a number of metrics. In particular, we create multiple measures of net green patenting.[17] Net green patenting measures the number of green patents that a firm produces minus the amount of "other" patenting done – where we vary "other" patenting to measure everything from all other patents produced, to solely patents produced in technology classes where the firm *could* have chosen to produce a green patent, but instead chose to patent something not-green.

Appendix Table A12 reports our tests of net green patenting across these various measures and across industries. As can be seen, much like green patenting broadly, the energy industry actually has significantly higher net green patenting than other industries. This is true even restricting solely to technology classes and industries that are more concentrated specifically in green patenting (Columns 3-6). Moreover, this is true even relative to other sectors that are also active and important in the green patenting space.

In Appendix Table A13, we focus specifically on the Top 100 Net Green Patentors amongst the universe of firms. The idea is that even if on average energy firms have greater net green patenting, they still might be under-represented amongst those firms that are leaders in the net green patenting space. Appendix Table A13 shows that, in contrast to this, energy firms are significantly over-represented amongst these top 100 firms. This is in contrast to other top patenting sectors in the green

[17] We thank our discussant, Harrison Hong, for suggesting this measure.

landscape, which are significantly under-represented amongst these top 100. Appendix Tables A14 and A15 corroborate these analyses at both the patent level.

c. Green Products and Green Investment Plans

In this section, we turn to a final central point: namely, whether traditional energy firms are in fact taking real actions (putting real investment dollars behind) the green patents they create. One might still be concerned that given the nature of a patent – a defensive legal contract by construction – that traditional energy firms are simply patenting in the green energy space to crowd-out investment and shelving the ideas without placing any investment dollars behind them. In this section, we therefore explore to what extent green patent production itself translates into real investment and production.

Specifically, we explore the extent to which firms with green patents also produce concurrent energy through alternative energy sources. We use S&P Global's TruCost Environmental Database to obtain information on green energy production. We compute a firm's green energy production (in GWh) by aggregating a company's power generation activities in the following energy types: Biomass Power Generation; Geothermal Power Generation; Hydroelectric Power Generation; Solar Power Generation; Wave & Tidal Power Generation; and Wind Power Generation. We regress this *Green Energy Production* variable on *the Green Patent Ratio* (number of green patents scaled by total patents). The sample period that TruCost Data exists is 2011 to 2019, so that is the horizon over which this analysis is run. Table 10 reports the findings. The idea of this analysis is to find out whether, within each industry (including the energy industry), firms that dedicate more resources to green energy innovation activities have higher production of alternative energy. The coefficient of 11,306.431 (t=2.72) in Column 2 implies a roughly 65% increase in green wattage production for every standard deviation (~11%) increase in green patent intensity by an energy firm. Column 1, in contrast, finds no such impact or relationship for other sectors. Both the sizable absolute differences, along with the alternative energy produced coupled with green patenting intensity, is evidence consistent with fossil fuel companies not solely being active in producing green patenting, but also pairing their green patenting activity with real, alternative energy production.

-- Insert Table 10 here –

We next turn to an analysis that utilizes responses given in the 2018 CDP Global Climate Change Report. CDP defines itself as "a not-for-profit charity that runs the global disclosure system for investors, companies, cities, states, and regions to manage their environmental impacts." The respondents of their survey include nearly all largest public firms (e.g., Tesla, Amazon, Microsoft, Apple, Citigroup), along with the largest oil firms (e.g., Exxon Mobil, Royal Dutch, BP Plc, Chevron). In this report, the respondents are asked, among other questions, to (1) "provide details of your products and/or services that you classify as low-carbon products or that enable a third party to avoid GHG emissions", and (2) "Break down your total planned CAPEX in your current CAPEX plan for products and services (e.g., smart grids, digitalization, etc.)." We use responses to these two questions to explore whether firms with a higher green patenting report that they have more (a) low carbon products (*Has Low Carbon Products*), and (b) plan to dedicate larger amounts of their capital expenditures to green products and services (*Has CAPEX in Green Products and Services*).

The results in the first two columns of Table 11 indicate that companies with higher green patenting intensity are also significantly more likely to produce low carbon products. Together the coefficients in Columns 1 and 2 imply that a 1 standard deviation increase in green patenting intensity increases low-carbon production by 12.70% outside of the energy sector and 28.71% inside the energy sector, respectively (with the estimates not statistically significantly different). Column 3 then measures purely within the energy sector whether firms with higher green patenting intensity pair this increased innovation intensity with higher CAPEX in green products and services. The coefficient of 0.2258 (t=3.33) in Column 3 implies that energy firms that concentrate more of their innovation in green patenting follow this up with significantly more green capital expenditures - a 1 standard deviation increase in green patenting intensity increases the likelihood of significant green capital expenditures by nearly 90%.

-- Insert Table 11 here –

c.ii. Green Technology Adoption and ESG Ratings

In this section, we tie back and explore investment in the production and adoption of green technology to the previous exploration surrounding ESG Ratings.[18] In particular, while we have found

[18] We would like to thank a referee for suggesting this, and pointing us in this line of inquiry.

that ESG Ratings (and "E" ratings in particular) do not appear to reward or acknowledge idea creation in the form of green patent creation (broadly penalizing the energy industry, including on this dimension), it could be because there is a distinction in their ratings and assessments between commercialization of technology and creation of the technology and innovation that founds it. In order to explore this more fully, we first explore in detail the manuals of each of the major ESG ratings firms (Sustainalytics, MSCI, Moody's, KLD, S&P Global, and Refinitiv). In particular, we examine the individual components of the "E" metric that each use to score this component in their respective ratings. While environmental ratings vary across agencies, they broadly encompass the following: they incorporate information largely focusing on emissions and environmental penalties, such as greenhouse gas (GHG) emissions, non-GHG emissions, ozone-depleting gases, and environmental fines paid (perhaps related to their ease of access in measurement). However, they lack clear references to innovation, adoption, or investment in environmental innovation, along with relatively thin evidence of implementation or adoption.[19]

To more formally test the assertion that ESG ratings could incorporate information on technology adoption/commercialization as opposed to technology creation, however, we explore through an explicit analysis reported in Appendix Table A11. For this analysis, we combine two of our datasets: the CDP data used above in Tables 10 and 11, and data on ESG Ratings. From the CDP data report, we identified three sets of questions that could be potentially related to green technology adoption/commercialization:

(1) Disclose your organization's low-carbon investments for (i) cement production activities, (ii) chemical production activities, (iii) metals and mining production activities, or (iv) for steel production activities; Disclose your investments in low-carbon research and development (R&D), equipment, products, and services.

We defined a is a dummy variable (*Has Low Carbon Investment*) that takes the value of one if a firm has provided an answer to any of these questions.

(2) Please provide details of your products and/or services that you classify as low-carbon products or that enable a third party to avoid GHG emissions.

We defined "*Percent Revenue From Low Carbon Products*" from the value given to this question.

(3) Does your organization use climate-related scenario analysis to inform your business strategy?

While this is more tangential, it does touch upon the production strategy being impacted by

[19] Having said this, after the release of our paper in 2021, we have engaged in conversations with two of these rating agencies regarding how to incorporate green innovation related metrics into their framework. As a result, in recent years, at least one of the rating agencies promoted using "low carbon" patents as one of the indicators in their revised framework. https://www.msci.com/our-solutions/esg-investing/climate-solutions/climate-data-metrics

environmental considerations, so we included it, in addition. We defined a dummy variable (*Has Climate Business Strategy*) that takes the value of one if a firm answers Yes to this question.

The analysis reported in Appendix Table A11 indicates that ESG ratings are not positively correlated with any of these metrics of implementation as indicted by the coefficients of the main effects (*Has Low Carbon Investment, Percent Revenue From Low Carbon Products, and Has Climate Business Strategy*), with Measure *(1)* even being negatively related, and the interaction with the energy industry also insignificant across measures.

d. Fund Flow Analysis

In this analysis, we explore the capital allocations of investors specifically focused on environmental (and ESG motives) toward energy firms. For this purpose, we conduct two tests. First, we investigate whether green funds are investing less in energy firms in comparison to other funds. In other words, after conditioning on a firm being in the energy sector, do we observe ESG funds invest *less* in energy than other types of (otherwise equivalent) funds. Secondly, we ask whether energy firms constitute a lower weight of the portfolio of ESG funds compared to their other investments, i.e., if we solely focus on ESG or green funds, do we observe a lower weight is given to firms that operate in the energy sector.

To conduct these two tests, we need to identify the funds that are likely to be considered "green funds," or "ESG funds," by investors. We identify these green funds using two methods. First, we classify based on each of the fund names. We label a fund as a green fund if its name contains "ESG" or "green". We then manually go through this list and eliminate names that are false positives, i.e., we do not label the "Evergreen Money Market Fund" as a green fund. Second, we look at the lists that are publicized by two well-known market participants in this space - The Forum for Sustainable and Responsible Investment (USSIF) and Charles Schwab.

Appendix Table A16 contains our analysis. From Appendix Table A16, the answers to the questions posed above with regard to underweighting appear to be "yes." Specifically, across Columns 1-3 of Panel A, the coefficients on *Green Fund* indicate that controlling for other determinants of holding, energy firms are: i.) significantly less likely to be held at all; ii.) are held in significantly smaller amounts, and iii.) are held in significantly smaller weights relative to their index-weight; by *Green Funds* vs. all other funds. Each of these effects is large in magnitude (25% to 100% differences) and highly statistically significant.[20]

Columns 4-6 then show that the exact opposite is true of other highly active green patenting firms outside of the energy sector. Finally, Panel C shows from the perspective of conditioning on a *Green Fund* and reinforces these findings: controlling for other firm-level determinants of holdings, *Green Funds* significantly underweight energy sector firms, and overweight other green patenting firms.

Stepping back, Appendix Table A16 shows a real, capital markets flow implication of being an energy firm in terms of investment underweighting (and avoidance) by *Green Funds*. This is despite the evidence in Tables 3-11 regarding the large, central, and non-substitutable role they have, and continue to play in the green innovation landscape.

IX. Conclusion

We conduct the first large-scale study documenting the landscape of green innovation – its most active patentors, their patent quality, accompanying investment, first-movers in the space, and capital allocation with regard to these. A reason this is so central, particularly to the class of environmental concerns is that substantive innovation is still required to address the most pressing environmental concerns (i.e., it is not that we have a ubiquity of scalable and cost-efficient global solutions and are simply lacking distribution capabilities – fundamental aspects of energy production, usage, delivery, and storage still need to be innovated and produced).

We find consistent and robust markers that the quantity and quality of green patenting is higher for traditional energy firms. Perhaps surprisingly, energy producers produce more — and significantly higher quality — green innovation, on average. Moreover, in many green technology spaces, they appear to be first movers, not easily substitutable, and to produce ongoing foundational aspects of innovation on which other alternative energy innovators build – being early and influential patentors and producers in certain of the most central technology branches (e.g., carbon capture).

Further, their green patents are overwhelmingly produced in-house (organically from internal R&D teams), and appear foundational particularly outside of their industry, being both cited highly and having their wording and structure mimicked by green innovators outside of the traditional energy industry. And yet in spite of this, these firms are precisely those to which capital is often restricted by mandates and campaigns whose directive is to solve the important problems linked to green

[20] These results are consistent with Raghunandan and Rajgopal (2022) and Gibson et al. (2021) surrounding the relationship between ESG funds and holdings.

innovation. Our analysis thus suggests there is a, perhaps surprisingly, negative relationship between the generators of innovation that can help us confront environmental challenges and where capital is being directed.

Moreover, we broadly find that firms generating green patents create real products that help abate carbon emissions, including energy firms. Second, energy firms do not appear to be "strategically patenting" in a manner to create patent thickets that deter new entrants, nor in a manner that solely benefits and can be built upon by their industry firms alone. Further, traditional energy firms are even over-represented amongst the top net green patenting firms in the economy, in addition to being over-represented – and having the significantly more impactful on average – pioneering patents within green technology classes.

We present a simple framework in which these behaviors might be expected, in a world in which an incumbent rationally predicts the sunset of its existing product vector at some point, and so is willing to cannibalize existing sales, by investing in – and then producing – innovation that displaces its existing product offerings. As long horizon firms with decades of experience in energy production, sourcing, distribution, flow, and servicing, these incumbents might then be observed to be first movers in many of these innovation categories.

Stepping back, the paper brings to the forefront evidence across the universe of green patenting, along with through the exploration of certain central environmental technology branches in particular, the surprising role that the energy industry has played – and continues to play – in the green patenting and implementation space. As influential early movers, continued ongoing innovators, and foundational patentors and commercializers on which other outside green innovators build, they appear to be important and not easily substitutable players in this first-order landscape. And yet, fund flows, along with other financial agents' behaviors (such as ratings' agencies) do not match to the real green patenting activity or commercialization patterns observed by firms. This puts forward the potential that these influential agents, and perhaps broader markets in following, have allowed a gap to develop between outcomes and motivation of firms to achieve these outcomes, that requires careful consideration.

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Appendix I.

Conceptual Framework for an Incumbent Firm: Innovation versus Obsolescence

In this section, we provide a simple framework for the research development decisions of an incumbent firm (traditional energy firms in our context) facing competition from a potential entrant. The main set of propositions distilled shows that, rather intuitively: (a) the more likely the technology breakthrough from the entrant is, the more intensely the incumbent engages in innovation; and (b) the higher value that consumers place on the new technology, the more the incumbent engages in innovation. We test these predictions of the model, along with additional dynamics, in Section IV. [21]

In our simplified setting, time is discrete, and the horizon is infinite. A firm produces a good at zero marginal cost in each period t. A unit continuum of consumers values the existing good as $v > 0$ and price is $p = \alpha v$, where $\alpha \in (0, 1)$, is a reduced form bargaining parameter (i.e., the higher the market power of the incumbent (α) the more of the total consumer surplus it can capture). Each period, with probability $\delta \in (0, 1)$ the world ends, and the game is over. Furthermore, in each period, with probability $\lambda \in (0, 1)$, there is a breakthrough and the incumbent firm's technology becomes obsolete. In addition to the existing good, new technology can be invested in which produces a good valued by consumers at $V \geq v$ at a price $p = \alpha V$.[22]

The incumbent may preempt new entrants from acquiring the breakthrough technology by investing c each period into innovative activities. This cost could be imagined taking several forms including the actual cost of creating innovation, such as the costs of bureaucratization (Schumpeter 1934), information screening (Arrow 1974), hierarchy (Sah and Stiglitz 1986), loss of managerial control (Scherer and Ross 1990), cognitive or relationship costs (Grove 1996; Christensen 1997), or the cost of acquisition of early-stage start-ups. The sum of these potentially substantive costs pushes against innovation and toward incumbent inertia. Given these simple parameters, one can compare the value of the incumbent based on its two potential decisions:

1. Value of the firm without investing in the innovation:

[21] We thank Shaun Davies for his suggestions in sketching out this simple frame and setting.

[22] While one could imagine λ being correlated with α, many innovative settings – even with substantive incumbents – are characterized by sufficiently low entry costs relative to entry gains such that new entrants innovate and incubate intensely irrespective of potentially high α of existing incumbents.

$$\sum_{t=1}^{\infty}(1-\delta)^t(1-\lambda)^t\alpha v \quad (1)$$

2. Value of the firm with the innovation:

$$\sum_{t=1}^{\infty}(1-\delta)^t[(1-\lambda)^t(\alpha v - c) + (1-\lambda)^{t-1}\lambda B] \quad (2)$$

in which $B = \alpha V(1-\delta)/\delta$ is the perpetuity value of the new technology.

In each period, we multiply that period's profit ($\alpha v - c$w) with the probability that there will be no breakthrough technology (i.e., $1-\lambda$) and with the probability that there is at least one more time period to continue the game (i.e., $1-\delta$)

We can rewrite (1) as follows: $\sum_{t=1}^{\infty}(1-\delta)^t(1-\lambda)^t\alpha v = \frac{\alpha v\,(1-\delta-\lambda+\delta\lambda)}{\delta+\lambda-\delta\lambda}$

Likewise, we can simplify (2) as follows:

$$\sum_{t=1}^{\infty}[(1-\delta)^t((1-\lambda)^t(\alpha v - c) + (1-\lambda)^{t-1}\lambda B)] = \frac{(1-\delta)\,[\,\delta(1-\lambda)(\alpha v - c) + \alpha(1-\delta)\,\lambda V\,]}{\delta(\delta(1-\lambda)+\lambda)}$$

The net benefit of the innovation is then given by the difference between these values, i.e.

$$\alpha V(1-\delta)\lambda - c\delta(1-\lambda)$$

This expression is increasing in λ, i.e., the more likely the technology breakthrough is, the more the incumbent engages in innovation. Likewise, the more consumers value the new technology (i.e., higher V), the more the incumbent engages in innovation. Finally, the more market power the firm has (higher α), the more consumer surplus it captures and so the more important it is to protect it; thus, it has a higher benefit of engaging in innovation.

Translated to our specific context of traditional energy firms, provided that: (1) increased competition in research and development and patenting is positively related to breakthrough; (2) consumers value clean energy (as their capital allocation, related real good purchase behavior, survey responses, and their explicit policy support suggest); and (3) a cheap, renewable energy breakthrough could contribute to displacing traditional fossil fuels; incumbent traditional energy firms might be expected to respond to this challenge-set by innovation in order to maximize firm value.

Figure 1: Total Number of Green Patents Granted to Publicly Traded Firms over Time

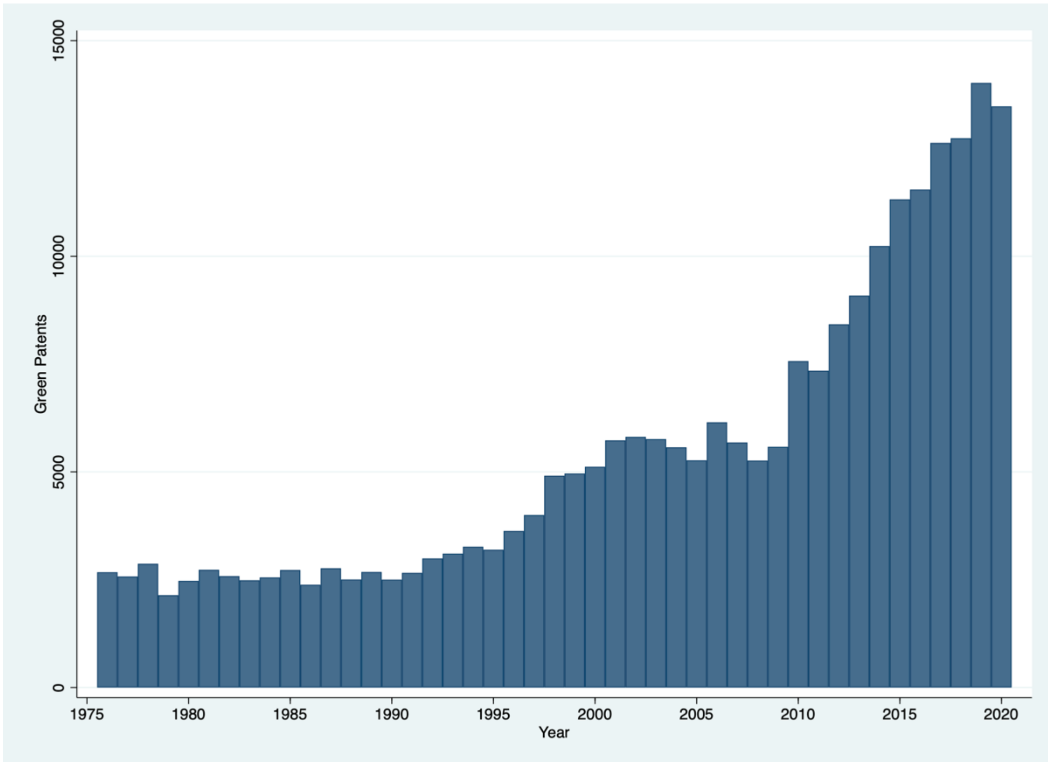
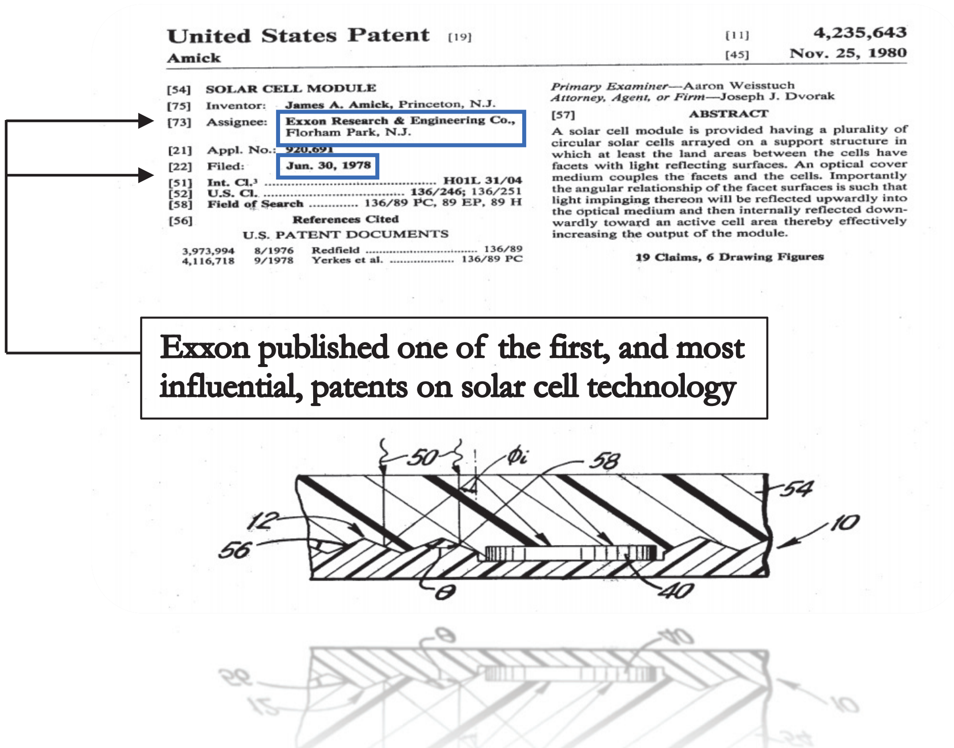


Figure 2: Example of Early Green Patenting at Exxon - Solar Technology & Photovoltaics in 1973 and 1978

Figure 2.A: A Foundational Solar Cell Patent Discovered and Filed by a Research Team at Exxon in 1978



United States Patent [19] [11] **4,235,643**
Amick [45] **Nov. 25, 1980**

[54] SOLAR CELL MODULE
[75] Inventor: James A. Amick, Princeton, N.J.
[73] Assignee: Exxon Research & Engineering Co., Florham Park, N.J.
[21] Appl. No.: 920,691
[22] Filed: Jun. 30, 1978
[51] Int. Cl.³ H01L 31/04
[52] U.S. Cl. 136/246; 136/251
[58] Field of Search .... 136/89 PC, 89 EP, 89 H
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Primary Examiner—Aaron Weisstuch
Attorney, Agent, or Firm—Joseph J. Dvorak
[57] ABSTRACT
A solar cell module is provided having a plurality of circular solar cells arrayed on a support structure in which at least the land areas between the cells have facets with light reflecting surfaces. An optical cover medium couples the facets and the cells. Importantly the angular relationship of the facet surfaces is such that light impinging thereon will be reflected upwardly into the optical medium and then internally reflected downwardly toward an active cell area thereby effectively increasing the output of the module.
19 Claims, 6 Drawing Figures

Figure 2.B: A Different Team at Exxon working on Photovoltaics in 1973

Elliot Berman (center, in patterned tie) and his team at Solar Power Corp. pose outside their office and manufacturing facility in Braintree, Mass., in 1973. John Perlin, author of *Let It Shine: The 6,000-Year Story of Solar Energy*, credits Berman, Solar Power Corp. and Exxon with "planting the flag of photovoltaics throughout the world."

Robert Willis/Solar Power Corp. via John Perlin

Figure 3: Total Number of "Subterranean or Submarine CO2 Capture and Storage" Green Patents Granted to Publicly Traded Firms over Time

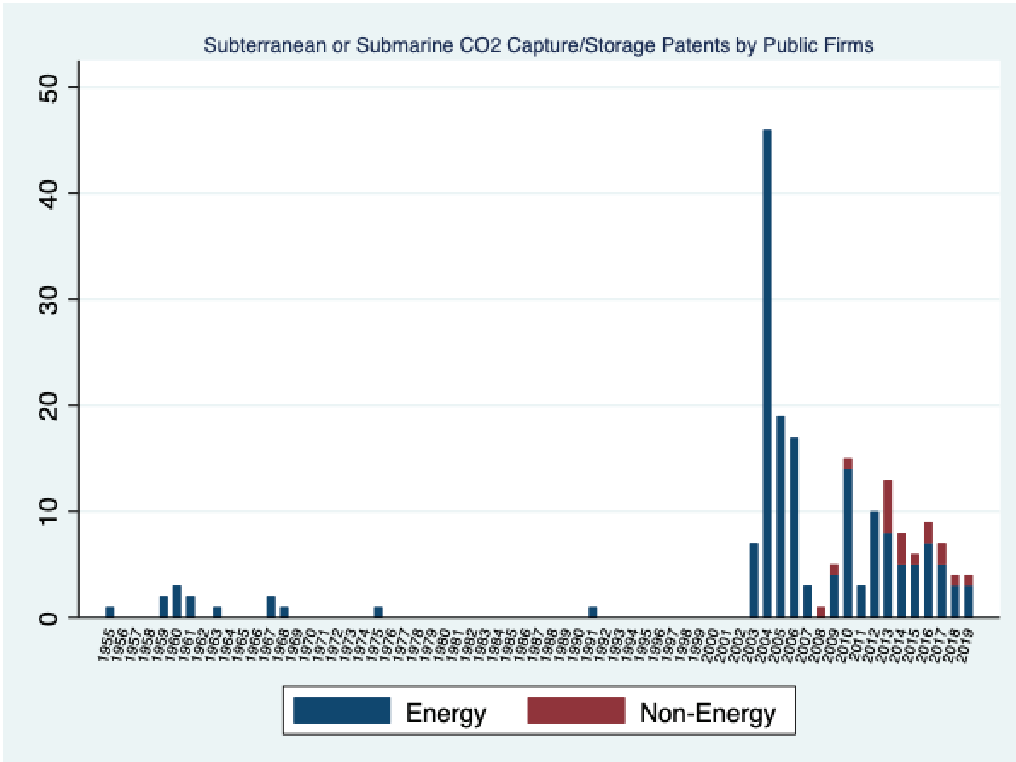

Figure 4. Word Clouds of "Subterranean or Submarine CO2 Capture/Storage" Green Patents by Energy Firms and Non-Energy Firms

Figure 4.A: Top Keywords for Energy Firms' Patents

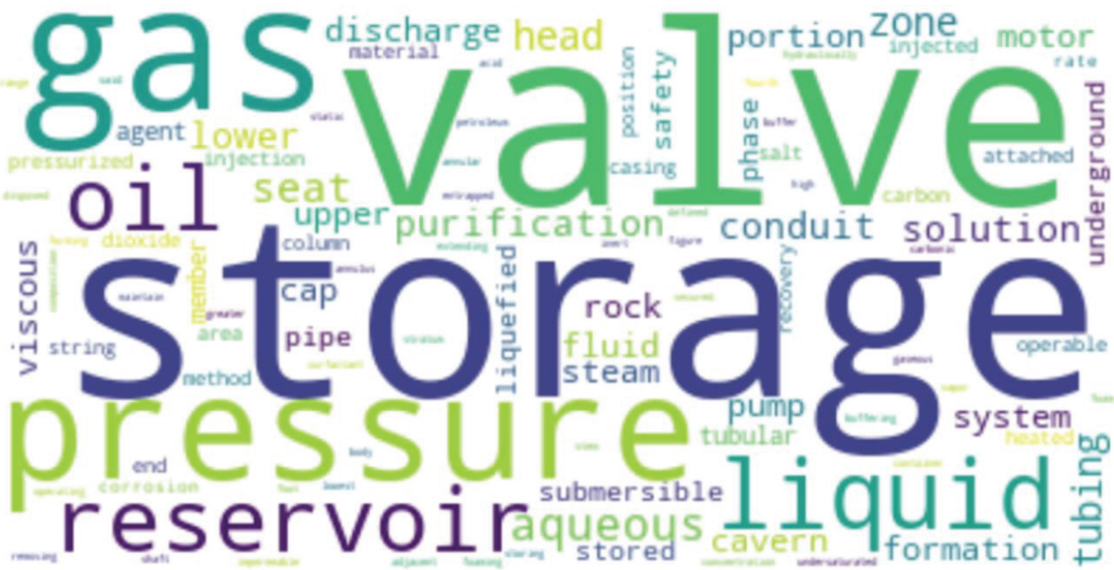

Figure 4.B: Top Keywords for Non-Energy Firms' Patents

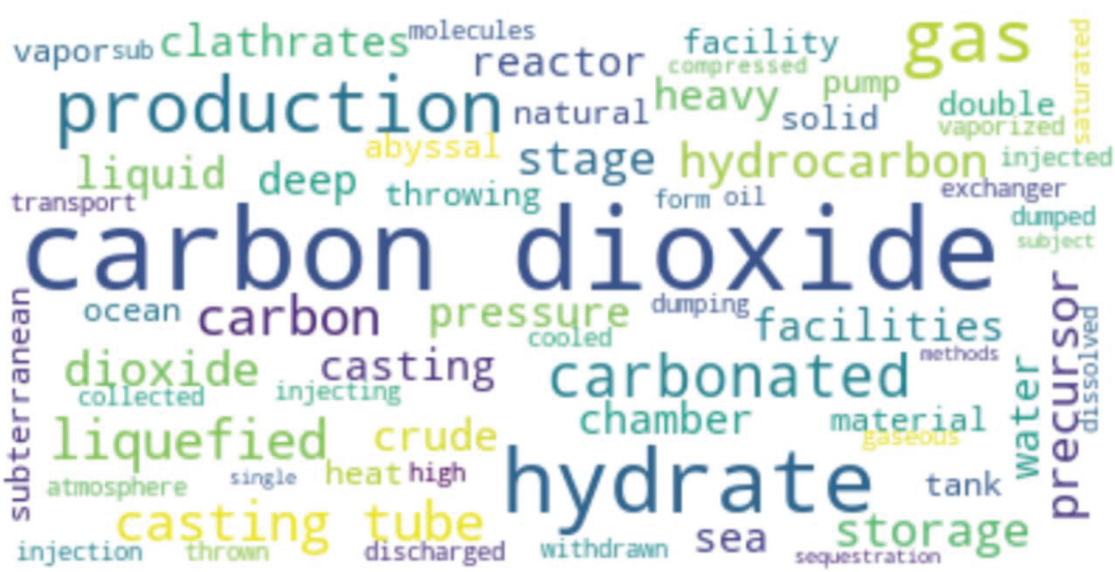

Table 1: Companies and Industry Sectors with the Most Green Patents.

Panel A shows the total green patents held by industry sectors in 2020. Panel B shows the list of the top 50 public companies by green patent holders in 2020. A firm is in the Energy Sector when its two-digit Standard Industrial Classification (SIC) is 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Green patents are patents that are in environment-related technologies. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection, and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Green patent classification is constructed and developed by the European Patent Office using the algorithm by the OECD.[1]

Panel A: Green Patents by Industry Sectors

Industry Sectors	Total Green Patents
Manufacturing	187240
Energy	17276
Services	9586
Transportation & Public Utilities	4862
Finance, Insurance, & Real Estate	3289
Wholesale Trade	2974
Agriculture, Forestry, & Fishing	1833
Retail Trade	1632
Construction	605

[1] A more detailed description of green patent classification can be found on OECD's website: https://www.oecd.org/env/indicators-modelling-outlooks/green-patents.htm

Panel B: Green Patents by Publicly Traded Companies

Company	Total Green Patent	Rank
TOYOTA MOTOR CORP	12574	1
GENERAL ELECTRIC CO	11815	2
HONDA MOTOR CO LTD	7780	3
FORD MOTOR CO	7744	4
HITACHI LTD	6276	5
PANASONIC CORP	6199	6
DUPONT DE NEMOURS INC	5879	7
UNITED TECHNOLOGIES CORP	5818	8
SIEMENS AG	4825	9
GENERAL MOTORS CO	4421	10
EXXON MOBIL CORP	4018	11
NISSAN MOTOR CO LTD	3766	12
GENERAL MOTORS CO	2912	13
BOEING CO	2790	14
HONEYWELL INTERNATIONAL INC	2689	15
INTL BUSINESS MACHINES CORP	2621	16
SONY CORP	2447	17
VIACOMCBS INC	2176	18
CANON INC	2066	19
CATERPILLAR INC	1871	20
SANYO ELECTRIC CO LTD	1814	21
LG DISPLAY CO LTD	1805	22
ROYAL DUTCH SHELL PLC	1719	23
CHEVRON CORP	1564	24
CUMMINS INC	1442	25
3M CO	1421	26
FUJIFILM HLDGS CORP	1343	27
DAIMLER AG	1261	28
MONSANTO CO	1160	29
BAYER AG	1102	30
MERCK & CO	1054	31
CONOCOPHILLIPS	1034	32
CORNING INC	1025	33
BP PLC	1008	34
MOTOROLA SOLUTIONS INC	975	35
AIR PRODUCTS & CHEMICALS INC	974	36
ASAHI/AMERICA INC	895	37
NEC CORP	891	38
IONIS PHARMACEUTICALS INC	886	39
INTEL CORP	849	40
MICRON TECHNOLOGY INC	826	41
LOCKHEED MARTIN CORP	820	42
NIKE INC	804	43
TEXAS INSTRUMENTS INC	798	44
ALSTOM SA	793	45
APPLIED INDUSTRIAL TECH INC	781	46
DONALDSON CO INC	777	47
PARKER-HANNIFIN CORP	748	48
MITSUI & CO LTD	742	49
PFIZER INC	735	50

Table 2: Green and Non-green Patents by Year.

This table shows the total number of green and non-green patents granted to public firms by year. Green patents are patents that are in environment-related technologies. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Green patent classification is constructed and developed by the European Patent Office using the algorithm by the OECD.

Year	Green Patent	Non-Green Patent	All Patents
1980	2,472	25,364	27,836
1981	2,729	27,164	29,893
1982	2,582	24,071	26,653
1983	2,486	23,931	26,417
1984	2,552	25,826	28,378
1985	2,723	29,667	32,390
1986	2,382	28,778	31,160
1987	2,764	33,242	36,006
1988	2,504	31,096	33,600
1989	2,678	37,084	39,762
1990	2,499	34,404	36,903
1991	2,657	36,832	39,489
1992	2,992	37,978	40,970
1993	3,105	39,073	42,178
1994	3,265	40,629	43,894
1995	3,194	40,864	44,058
1996	3,629	45,115	48,744
1997	3,999	45,871	49,870
1998	4,910	61,557	66,467
1999	4,962	64,917	69,879
2000	5,119	67,805	72,924
2001	5,731	72,477	78,208
2002	5,813	74,118	79,931
2003	5,760	75,846	81,606
2004	5,570	74,544	80,114
2005	5,268	70,714	75,982
2006	6,151	85,826	91,977
2007	5,681	76,406	82,087
2008	5,261	77,414	82,675
2009	5,582	82,759	88,341
2010	7,567	104,351	111,918
2011	7,345	97,291	104,636
2012	8,421	108,583	117,004
2013	9,086	118,580	127,666
2014	10,236	127,398	137,634
2015	11,318	122,005	133,323
2016	11,546	121,117	132,663
2017	12,628	124,165	136,793
2018	12,737	116,804	129,541
2019	14,018	133,592	147,610
2020	13,477	131,954	145,431
Total	235,399	2,797,212	3,032,611

Table 3: Green Patent Production and Energy Sector.

This table reports the results of OLS regressions where the dependent variable is the Industry Green Patent Ratio, which is the percentage of green patents granted in a given industry, defined by a 2-digit SIC code, in that particular year. Energy Sector is a dummy variable if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. The unit of observation is industry (2-digit SIC code) and year. The sample covers 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
VARIABLES		Industry Patent Ratio	
Energy Sector	0.0741***	0.0904***	0.0901***
	(6.63)	(7.77)	(7.69)
Average Industry Investment		0.0000	0.0054
		(0.17)	(0.91)
Average Industry R&D Investment		0.0001**	0.0001**
		(2.42)	(2.39)
Average Industry Log Age		0.0543***	0.0544***
		(3.38)	(3.37)
Average Industry Log Total Asset		-0.0094*	-0.0093*
		(2.13)	(2.10)
Average Industry Cash			0.0010
			(0.86)
Average Industry Book Leverage			-0.0012
			(0.91)
Constant	0.0938***	-0.0417	-0.0435
	(89.12)	(0.82)	(0.85)
Observations	722	709	709
R-squared	0.034	0.069	0.070
Year FE	YES	YES	YES

Table 4: Environmental Score and Green Effort – Firm-Level Analysis.

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (by Sustain-Analytics and is out of 100). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection, and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). *Top 3 Sectors (outside of Energy)* is a dummy variable equal to one if the sector is among the top 3 sectors in green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)
VARIABLES			Environment Score		
Number of Green Patents Granted	-0.0306***		-0.0297***		-0.0337**
	(5.56)		(5.44)		(2.36)
Energy Sector		-5.5641***	-3.5748**		
		(2.79)	(2.00)		
Energy Sector x Number of Green Patents Granted			-0.2505***		
			(3.23)		
Top 3 Sectors (outside of Energy)				5.0803***	4.6335***
				(3.48)	(3.16)
Top 3 Sectors x Number of Green Patents Granted					0.0091
					(0.56)
Log Total Asset	3.4474***	3.3408***	3.6854***	3.7468***	3.9259***
	(10.75)	(10.64)	(12.09)	(12.12)	(12.83)
Log Age	2.6233***	2.7142***	2.6997***	2.6047***	2.6003***
	(4.19)	(4.26)	(4.38)	(4.11)	(4.19)
Cash	1.0279	0.7000	0.4146	1.7602	1.5394
	(0.65)	(0.44)	(0.27)	(1.10)	(0.98)
Book Leverage	1.2962	0.8691	0.6624	0.2057	0.4908
	(0.79)	(0.53)	(0.42)	(0.13)	(0.31)
Investment	0.2409	13.5373	15.2768	3.1283	4.3603
	(0.02)	(1.30)	(1.46)	(0.33)	(0.45)
Log R&D	1.6632***	1.4235***	1.6450***	1.1118***	1.2722***
	(8.82)	(7.50)	(8.62)	(5.10)	(5.65)
Constant	10.0170***	11.4285***	7.7483**	5.2950	3.5449
	(2.91)	(3.34)	(2.38)	(1.48)	(1.01)
Observations	3,531	3,531	3,531	3,531	3,531
R-squared	0.317	0.315	0.336	0.320	0.329
Year FE	YES	YES	YES	YES	YES

Table 5: Green Patent Citations and the Energy Sector.

This table reports the results of regressions where the dependent variable in Panel A is the log of green patent *Adjusted Citations* plus one, and the dependent variable in Panel B, Blockbuster Green Patents, is an indicator variable that equals to one if the green patent adjusted citation is the top 95 percentile of adjusted citation. Columns (1), (2), and (3) report OLS regressions. Column (4) reports Poisson regression. We compute *Adjusted Citations* by dividing a patent's total citations, as of 2020, with the mean citations of all patents that are granted in the same year and are in the same CPC class of that patent. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) is 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable that equals to one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by class x year.

Panel A: Green Patent Citations and the Energy Sector

	(1)	(2)	(3)	(4)
VARIABLES	Log (1 + Adjusted Citations)			
Energy Sector	0.0534***	0.0729***	0.0630***	0.1287***
	(2.81)	(4.90)	(3.28)	(3.45)
Zero Cite		-0.7522***	-0.7503***	-23.6419***
		(36.25)	(34.94)	(143.36)
Investment			-0.1409***	-0.4371***
			(3.12)	(3.80)
Log R&D			-0.0206***	-0.0444***
			(5.29)	(6.00)
Log Age			0.0112**	0.0113
			(2.39)	(1.08)
Log Total Asset			0.0032	0.0114
			(0.72)	(1.36)
Cash			0.2803***	0.5193***
			(10.38)	(9.254)
Book Leverage			0.0737***	0.1204***
			(3.56)	(3.38)
Constant	0.4196***	0.7494***	0.7944***	-0.1491***
	(54.93)	(35.44)	(27.65)	(3.02)
Sample Firms	All	Public	Public	Public
Observations	335,610	92,277	92,277	92,277
R-squared	0.000	0.412	0.421	
Year FE	YES	YES	YES	YES

Panel B: Blockbuster Green Patents and Energy Sector

VARIABLES	(1)	(2)	(3)	(4)
	Blockbuster Green Patents			
Energy Sector	0.0325***	0.0450***	0.0449***	0.5374***
	(4.22)	(6.22)	(4.77)	(5.75)
Zero Cite		-0.1022***	-0.1007***	-20.2557***
		(-16.43)	(15.95)	(109.04)
Investment			-0.0336**	-0.8070***
			(2.16)	(2.97)
Log R&D			-0.0064***	-0.1043***
			(3.18)	(4.42)
Log Age			0.0016	-0.0085
			(0.75)	(0.23)
Log Total Asset			-0.0018	-0.0020
			(0.83)	(0.08)
Cash			0.1003***	1.0221***
			(8.95)	(8.45)
Book Leverage			0.0119	0.0767
			(1.39)	(0.87)
Constant	0.0588***	0.1005***	0.1490***	-1.5398***
	(44.00)	(15.87)	(13.04)	(11.22)
Sample Firms	All	Public	Public	Public
Observations	335,615	92,277	92,277	92,277
R-squared	0.000	0.044	0.053	
Year FE	YES	YES	YES	YES

Table 6: First Mover and Non-Substitutability Analysis of The Energy Sector

Panel A reports results that show firms in the Energy Sector are the early movers in green patenting Activities. Columns (1) and (2) reports OLS regressions where the dependent variable is the USPTO patent number. Column (3) and (4) reports OLS regression where the dependent variable is a dummy that takes the value of 1 if the patent is among the earliest 10 percentile of patents within a green category. Panel B reports results that show the earliest green patents of the energy sector are impactful. The independent variable in columns (1) and (2) is the log of Adjusted Citation plus one and the independent variable in columns (3) and (4) is Blockbuster Green Patents, an indicator variable that equals one if the green patent's Adjusted Citation is the top 95 percentile of adjusted citation. Panel B restricts our sample to just the earliest 10 percentile of green patents within each green category. Panel C reports the percentage of brown patents from the energy sector that a green patent cites and compares that to the percentage of brown patents from the energy sector. We compute Adjusted Citations by dividing a patent's total citation, as of 2020, with the mean citations of all patents granted in the same year and in the same CPC class of that patent. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection, and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable that equals to one if the sector is among the top 3 sectors in green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

Panel A: Companies in the Energy Sector are Early Movers in Green Patenting

	(1)	(2)	(3)	(4)
VARIABLES	USPTO Patent Number		Earliest 10 percentile	
Energy Sector	-634,595.91***		0.0799***	
	(91.73)		(45.53)	
Top 3 Sectors (outside of Energy)		140,921.49***		-0.0166***
		(33.84)		(15.77)
Constant	8,192,259.08***	7,992,127.36***	0.3961***	0.4206***
	(111.17)	(108.09)	(21.18)	(22.46)
Observations	1,364,058	1,364,058	1,364,058	1,364,058
R-squared	0.085	0.081	0.060	0.058
Green Category FE	YES	YES	YES	YES

Panel B: The Earliest Green Patetns of the Energy Sector are Important

VARIABLES	(1)	(2)	(3)	(4)
	Log (1 + Adjusted Citations)		Blockbuster Green Patents	
Energy Sector	0.0554***		0.0280***	
	(3.31)		(4.14)	
Top 3 Sectors (outside of Energy)		0.0109		-0.0130***
		(0.89)		(2.61)
Constant	0.6642***	0.6644***	0.0261***	0.0390***
	(108.95)	(65.23)	(10.59)	(9.46)
Observations	5,592	5,592	5,592	5,592
R-squared	0.007	0.005	0.005	0.003
Green Category FE	YES	YES	YES	YES

Panel C: Importance

Percentage of non-green patents from the Energy Sector that a green patent cites	5.47% t = 17.63
Percentage of non-green patents that come from the Energy Sector	2.03% t = 12.47
Difference	3.44% t = 20.49
Percentage of non-green patents from the Energy Sector that a green patent cites conditioning on: each sub-class of "non-green patent" must have at least 1 energy firm patenting in that class	6.54% t = 18.79
Percentage of non-green patents that come from the Energy Sector conditioning on: each sub-class of "non-green patent" must have at least 1 energy firm patenting in that class	2.45% t = 12.52
Difference	4.09% t = 21.99

Table 7: First Mover and Non-Substitutability Analysis of "Subterranean Submarine CO2 Capture and Storage" by the Energy Sector

Panel A reports results that show Energy Sector are early mover in "Subterranean Submarine CO2 Capture and Storage" patenting activities. The dependent variable is the USPTO patent number. Panel B reports the total and the rank of Frequent "Subterranean Submarine CO2 Capture and Storage" Patents for the most active firms in this patent class. Panel C reports results that show "Subterranean Submarine CO2 Capture and Storage" patents of the energy sector are impactful. The independent variable in column (1) is Total Citations by other green patents and the independent variable in column (2) is Total Citations by other brown patents. Panel D reports the similarity of the patent language of subsequent patents to early patents by energy and non-energy firms. For each patent, we first extract the top 20 most important keywords and count the number of times each keyword is used, which we call the corpus count of that patent. We then compute the cosine similarity between the corpus count between each patent pair. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: environmental management, water-related adaptation technologies, biodiversity protection, and ecosystem health, climate change mitigation technologies related to energy generation, transmission or distribution, transportation, buildings, waste-water treatment or waste management, and production or processing of goods. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable equal to one if the sector is among the top 3 sectors in green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

Panel A: Energy Firms are the Earliest "Subterranean Submarine CO2 Capture and Storage" Patenting Entities

	(1)
VARIABLES	USPTO Patent Number
Energy Sector	-970,515.3460***
	(6.16)
Constant	8,196,303.6755***
	(71.20)
Observations	324
R-squared	0.105
Year FE	YES

Panel B: Energy Firms are the Most Frequent "Subterranean Submarine CO2 Capture and Storage" Patent Entities

Company	Energy Sector	Total
SHELL OIL CO	1	90
EXXON MOBIL CORP	1	25
SCHLUMBERGER LTD	1	15
CONOCOPHILLIPS	1	11
BAKER HUGHES CO	1	10
EQUINOR ASA	1	7
PIONEER ENERGY SERVICES CORP	1	6
LINDE PLC	0	5
GENERAL ELECTRIC CO	0	4
UNOCAL CORP	1	4

Panel C: "Subterranean Submarine CO2 Capture and Storage" Patents by Energy Firms are most cited.

	(1)	(2)
VARIABLES	Total Cited by Green	Total Cited by Brown
Energy Sector	28.3702***	68.8048***
	(6.86)	(11.25)
Constant	12.5430***	7.1258
	(4.15)	(1.59)
Observations	324	324
R-squared	0.127	0.282
Year FE	YES	YES

Panel D: Similarity of all Subsequent Patents to Early Patents by Energy and Non-Energy Patents

	Observation	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
Keywords Similarity with Energy Patents	304	0.0349	0.0015	0.0253	0.0320	0.0377
Keywords Similarity with Non-Energy Patents	304	0.0283	0.0020	0.0350	0.0243	0.0322
Difference	304	0.0066	0.0026	0.0452	0.0015	0.0117
Mean(Difference)						t = 2.55

Panel E: Similarity of all Subsequent Non-Energy Patents to Early Patents by Energy and Non-Energy

	Observation	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
Keywords Similarity with Energy Patents	145	0.0286	0.0024	0.0290	0.0238	0.0333
Keywords Similarity with Non-Energy Patents	145	0.0201	0.0034	0.0405	0.0135	0.0267
Difference	145	0.0085	0.0045	0.0537	-0.0003	0.0173
Mean(Difference)						t = 1.90

Table 8: Thickets

This table reports the results of OLS regressions where the dependent variable is the number of patent thickets that a firm belongs to. Patent thicket measures the degree of overlapping patent rights, which makes it harder for a new innovator to develop new technologies due to the complexity of licensing deals for multiple patents from multiple sources. We count a firm's patent thicket by first identifying firm groups that cite each other. For example, consider 3 firms A, B, and C, where A cites B and C, B cites A and C, and C cites A and B. We say A, B, and C belong to one patent thicket. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable equal to one if the sector is among the top 3 sectors in green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)
VARIABLES	Thickets/Total Patents			
Energy Sector	-5.0785***	-1.3548***		
	(10.19)	(2.72)		
Top 3 Sectors (outside of Energy)			9.8678***	3.2920***
			(34.27)	(10.08)
Log Total Asset		-0.0519		0.1006
		(0.73)		(1.39)
Log Age		3.6501***		3.6170***
		(21.55)		(21.41)
Cash		-0.0002		0.0028
		(0.01)		(0.23)
Book Leverage		-0.0040		-0.0031
		(0.88)		(0.68)
Investment		0.5151		0.4052
		(1.31)		(1.04)
Log R&D		5.6817***		5.2719***
		(61.62)		(52.10)
Constant	8.6342***	-4.1123***	2.2537***	-6.6356***
	(57.07)	(8.86)	(10.13)	(12.65)
Observations	22,453	20,195	22,453	20,195
R-squared	0.025	0.201	0.069	0.204
Year FE	YES	YES	YES	YES

Table 9: Citations Outside vs Within Sectors

This table reports the percentage of citations within a sector and the percentage of citations outside a sector. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable equal to one if the sector is among the top 3 sectors in green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

Panel A: Citation within vs outside Own Sector of Green Patents

	Cited by		
	% Citation within Energy Sector	% Citation outside Energy Sector	Difference Energy Sector
Energy Sector	25.70%	74.30%	48.60%
	(6.27)	(18.16)	(5.95)
	Cited by		
	% Citating within own Sector	% Citation outside Own Sectors	Difference Outside
Top 3 Sectors (outside of Energy)	28.90%	71.10%	42.20%
	(88.62)	(218.05)	(64.72)
	(OUTSIDE – INSIDE Citations) Diff-in-Diff		6.46%
			(2.69)

Panel B: Organically Developed vs Acquired Green Patents

	% Organically Developed Energy Sector	% Acquired Energy Sector	Difference Energy Sector
Energy Sector	98.05%	1.95%	96.10%
	(308.69)	(6.15)	(151.27)
	% Organically Developed own Sector	% Acquired Own Sectors	Difference Outside
Top 3 Sectors (outside of Energy)	97.45%	2.54%	94.91%
	(548.64)	(14.32)	(267.16)
	(ORGANIC – ACQUIRED Patent %) Diff-in-Diff		1.19%
			(1.94)

Table 10: Green Energy Production and Green Patents

This table reports the results of OLS regressions where the dependent variable is Green Energy Production by a firm and the independent variable is the green patenting activities by a firm. Green Energy Production data is obtained from S&P Global's TruCost Environmental Database. We compute a firm's Green Energy Production (in GWhs) by aggregating a company's power generation activities in Biomass Power Generation; Geothermal Power Generation; Hydroelectric Power Generation; Solar Power Generation; Wave & Tidal Power Generation; and Wind Power Generation. Green Patent Ratio is the total number of green patents divide by the total number of patents. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). The sample covers 2011 to 2019. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)
	Green Energy Production	
	All Firms Outside Energy	Energy Sector
Green Patent/All Patent	-3.6751	11,306.4310***
	(0.36)	(6.49)
Log Total Asset	2.0317***	1,390.5161***
	(4.30)	(13.60)
Log Age	-1.7938	974.8443***
	(1.63)	(4.77)
Cash	0.0161	2,510.8971***
	(0.12)	(2.69)
Book Leverage	-0.0185	81.6269
	(0.12)	(0.38)
Investment	0.1766	-1,353.9879
	(0.02)	(1.33)
Log R&D	-0.2122	-1,609.8279***
	(0.43)	(9.50)
Constant	-6.8546*	-10,987.4672***
	(1.80)	(13.08)
Observations	35,685	3,836
R-squared	0.001	0.089
Year FE	YES	YES

Table 11: Green Products and Green Patents

This table reports the results of OLS regressions where the dependent variables are proxies for green production activities and the independent variable is the green patenting activities by a firm. The data for green production activities is obtained from CDP Global Climate Change Report in 2018. For Columns 1 and 2, Has Low Carbon Products is a dummy variable that equals 1 if a firm has an answer to the question "(C4.5a) Please provide details of your products and/or services that you classify as low-carbon products or that enable a third party to avoid GHG emissions." For Column 3, Has CAPEX in Green Products and Services is a dummy variable that equals 1, if a firm has an answer to the question "(C-EU9.5b), Break down your total planned CAPEX in your current CAPEX plan for products and services (e.g., smart grids, digitalization, etc.)" Green Patent Ratio is the total number of green patents divide by the total number of patents. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). The sample covers 2018. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
	Has Low Carbon Products		Has CAPEX in Green Products and Services
	All Firms Outside Energy	Energy Sector	Within Energy Sector
Green Patent/All Patent	0.0618**	0.2148*	0.2258***
	(2.06)	(1.95)	(3.32)
Log Total Asset	0.0320***	0.0400***	0.0182***
	(20.94)	(5.34)	(3.92)
Log Age	0.0150***	0.0290*	0.0102
	(3.97)	(1.91)	(1.09)
Cash	0.0014	0.0081	-0.0028
	(0.80)	(0.06)	(0.04)
Book Leverage	-0.0074	-0.0147	-0.0155
	(1.12)	(0.25)	(0.42)
Investment	0.0998**	-0.0717	-0.0435
	(2.11)	(0.71)	(0.70)
Log R&D	0.0191***	0.0092	-0.0245***
	(12.24)	(0.78)	(3.36)
Constant	-0.2381***	-0.2841***	-0.1224**
	(19.01)	(4.08)	(2.84)
Observations	3,957	387	387
R-squared	0.169	0.171	0.113
Year FE	YES	YES	YES

Internet Appendix
to
"The ESG-Innovation Disconnect: Evidence from Green Patenting"

LAUREN H. COHEN, UMIT G. GURUN, and QUOC H. NGUYEN

Appendix Table A1: Green Patents by Year by Industry and Green Categories

Panel A.1 reports the total green patents by industry and year. Panel A.2 reports the percentage of green patents by industry and year. Panel B.1 reports the total green patents by green categories by year for all firms. Panel B.2 reports the total green patents by green categories by year for all energy sector firms.

Panel A.1: Total Green Patents By Industry

Year	Agriculture, Forestry, & Fishing	Mining & Energy	Construction	Manufacturing	Transportation & Public Utilities	Wholesale Trade	Retail Trade	Finance, Insurance, & Real Estate	Services
1980	1	426	21	1582	104	24	13	38	43
1981	0	534	17	1698	115	17	5	26	59
1982	0	519	13	1657	82	28	6	17	52
1983	1	538	12	1519	88	23	5	22	49
1984	0	508	15	1600	97	34	3	27	37
1985	1	554	6	1642	123	28	4	44	32
1986	1	388	13	1458	176	34	5	34	46
1987	2	331	13	1755	305	29	9	28	33
1988	8	348	13	1617	187	28	6	40	43
1989	3	361	9	1683	182	32	9	37	63
1990	6	290	13	1609	151	34	8	45	50
1991	14	306	7	1702	142	32	7	40	50
1992	15	338	14	1882	143	49	9	62	51
1993	15	322	11	2032	108	60	11	71	59
1994	17	361	22	2146	115	40	11	63	80
1995	21	287	12	2273	79	41	10	62	79
1996	40	292	20	2607	80	38	16	83	90
1997	33	263	15	2947	61	54	12	94	141
1998	28	299	12	3676	65	68	16	111	168
1999	29	277	10	3700	42	59	17	122	228
2000	40	275	8	3872	42	65	25	89	218
2001	34	254	18	4318	47	53	24	106	241
2002	43	262	17	4391	52	62	30	57	182
2003	53	244	16	4324	32	63	15	67	209
2004	43	260	18	4247	29	68	30	57	178
2005	29	235	18	4045	42	54	20	44	142
2006	48	278	15	4699	54	48	26	52	186
2007	64	260	13	4341	63	48	14	54	175
2008	33	259	12	3968	42	43	18	40	154
2009	51	233	9	4115	74	68	24	48	182
2010	76	366	8	5580	61	99	49	64	242
2011	60	323	5	5419	43	112	59	73	223
2012	67	310	10	6305	63	124	76	73	260
2013	65	445	15	6717	81	145	51	71	344
2014	76	518	9	7637	85	122	54	111	372
2015	211	501	8	8416	104	149	63	146	448
2016	217	465	18	8455	134	145	94	138	522
2017	202	498	8	9186	158	154	107	137	606
2018	104	404	12	9547	162	123	121	152	695
2019	22	839	6	10131	196	123	160	164	699
2020	20	404	11	10096	166	113	152	162	789

Panel A.2: Percentage of Green Patents By Industry

Year	Agriculture, Forestry, & Fishing	Mining & Energy	Construction	Manufacturing	Transportation & Public Utilities	Wholesale Trade	Retail Trade	Finance, Insurance, & Real Estate	Services
1980	0.200	0.170	0.188	0.080	0.095	0.074	0.114	0.083	0.040
1981	0.000	0.193	0.195	0.081	0.102	0.049	0.043	0.053	0.046
1982	0.000	0.219	0.260	0.089	0.082	0.075	0.054	0.039	0.048
1983	0.250	0.202	0.250	0.083	0.082	0.071	0.046	0.049	0.042
1984	0.000	0.183	0.283	0.082	0.089	0.111	0.023	0.053	0.029
1985	0.200	0.187	0.130	0.073	0.095	0.075	0.024	0.072	0.022
1986	0.143	0.147	0.176	0.067	0.139	0.104	0.040	0.063	0.029
1987	0.133	0.126	0.217	0.069	0.199	0.078	0.063	0.046	0.017
1988	0.286	0.155	0.260	0.068	0.145	0.064	0.046	0.068	0.026
1989	0.136	0.128	0.164	0.060	0.136	0.059	0.049	0.049	0.032
1990	0.261	0.119	0.245	0.062	0.111	0.058	0.052	0.056	0.027
1991	0.350	0.119	0.132	0.060	0.106	0.046	0.041	0.049	0.026
1992	0.385	0.131	0.222	0.064	0.114	0.067	0.047	0.069	0.024
1993	0.326	0.132	0.212	0.067	0.094	0.069	0.053	0.070	0.024
1994	0.405	0.155	0.301	0.068	0.090	0.048	0.056	0.059	0.027
1995	0.396	0.147	0.226	0.071	0.060	0.055	0.052	0.058	0.024
1996	0.606	0.160	0.286	0.074	0.063	0.053	0.074	0.073	0.021
1997	0.524	0.165	0.211	0.080	0.073	0.074	0.056	0.077	0.028
1998	0.452	0.155	0.188	0.076	0.052	0.069	0.062	0.070	0.022
1999	0.284	0.144	0.154	0.073	0.032	0.061	0.059	0.078	0.028
2000	0.328	0.131	0.084	0.074	0.033	0.072	0.076	0.060	0.025
2001	0.304	0.125	0.175	0.076	0.036	0.057	0.075	0.071	0.026
2002	0.406	0.142	0.191	0.075	0.039	0.063	0.093	0.046	0.021
2003	0.477	0.135	0.232	0.071	0.027	0.087	0.047	0.053	0.024
2004	0.381	0.136	0.214	0.071	0.022	0.105	0.088	0.050	0.022
2005	0.167	0.139	0.300	0.071	0.031	0.097	0.085	0.061	0.019
2006	0.225	0.133	0.300	0.070	0.028	0.068	0.086	0.051	0.018
2007	0.245	0.134	0.236	0.073	0.033	0.071	0.047	0.059	0.019
2008	0.128	0.137	0.231	0.068	0.022	0.066	0.057	0.040	0.014
2009	0.155	0.120	0.153	0.067	0.035	0.085	0.062	0.040	0.014
2010	0.185	0.136	0.160	0.073	0.021	0.100	0.074	0.037	0.014
2011	0.173	0.131	0.119	0.076	0.013	0.122	0.069	0.037	0.014
2012	0.152	0.126	0.152	0.080	0.015	0.120	0.075	0.030	0.014
2013	0.135	0.151	0.195	0.079	0.017	0.135	0.041	0.025	0.016
2014	0.144	0.160	0.125	0.083	0.016	0.123	0.037	0.037	0.016
2015	0.414	0.156	0.090	0.094	0.021	0.153	0.033	0.056	0.020
2016	0.409	0.141	0.176	0.096	0.029	0.166	0.039	0.055	0.022
2017	0.386	0.140	0.105	0.103	0.034	0.181	0.038	0.050	0.024
2018	0.344	0.121	0.143	0.114	0.036	0.159	0.042	0.050	0.029
2019	0.198	0.163	0.060	0.109	0.039	0.154	0.044	0.038	0.025
2020	0.142	0.125	0.106	0.110	0.034	0.155	0.043	0.035	0.027
Average	0.264	0.147	0.191	0.078	0.062	0.090	0.056	0.054	0.025

Panel B.1: Total Green Patents by Green Categories - All Firms

	Climate Change Mitigation						Selected Environment-Related Technologies
Year	Capture, Storage, Sequestration or Disposal of Greenhouse Gases	Climate Change Mitigation Technologies Related to Buildings	Climate Change Mitigation Technologies Related to Energy Generation, Transmission, or Distribution	Climate Change Mitigation Technologies Related to Production or Processing of Goods	Climate Change Mitigation Technologies Related to Transportation	Climate Change Mitigation Technologies Related to Wastewater Treatment or Waste Management	Environmental Management, Water-Related Adaptation Technologies, and Biodiversity Protection and Ecosystem Health
1980	16	87	612	433	277	77	2472
1981	18	102	634	481	323	77	2729
1982	26	109	633	491	275	68	2582
1983	21	85	524	483	317	65	2486
1984	30	100	518	450	376	69	2552
1985	20	111	571	453	381	61	2723
1986	19	93	603	447	282	49	2382
1987	25	120	805	444	397	58	2764
1988	35	90	586	453	356	47	2504
1989	30	105	611	478	362	87	2678
1990	29	109	468	446	368	64	2499
1991	17	114	525	448	400	83	2657
1992	33	127	588	490	486	102	2992
1993	23	125	636	505	467	151	3105
1994	20	145	745	558	486	176	3265
1995	14	166	698	596	511	152	3194
1996	18	187	761	652	552	142	3629
1997	22	160	857	673	522	154	3999
1998	29	262	893	830	705	149	4910
1999	51	283	922	876	770	154	4962
2000	51	293	985	928	810	145	5119
2001	63	304	1168	956	1071	119	5731
2002	51	322	1194	1040	1143	130	5813
2003	60	282	1319	1059	1128	121	5760
2004	92	312	1217	1062	1086	104	5570
2005	62	320	1103	988	1239	103	5268
2006	53	402	1293	1176	1399	114	6151
2007	38	395	1175	1011	1285	123	5681
2008	45	365	1253	912	1214	123	5261
2009	47	379	1413	1016	1236	109	5582
2010	92	522	2221	1346	1659	164	7567
2011	73	558	2246	1259	1784	121	7345
2012	92	687	2755	1402	2252	148	8421
2013	125	827	2806	1513	2418	167	9086
2014	135	976	3286	1633	2853	153	10236
2015	128	1089	3509	1748	3246	151	11318
2016	112	1338	3514	1804	3283	142	11546
2017	155	1367	3680	1942	3654	175	12628
2018	115	1448	3307	1789	3971	185	12737
2019	117	1498	3650	2160	4517	175	14018
2020	99	1387	3535	2100	4179	190	13477

Panel B.2: Total Green Patents by Green Categories – Energy Firms Only

	Climate Change Mitigation						Selected Environment-Related Technologies
Year	Capture, Storage, Sequestration or Disposal of Greenhouse Gases	Climate Change Mitigation Technologies Related to Buildings	Climate Change Mitigation Technologies Related to Energy Generation, Transmission, or Distribution	Climate Change Mitigation Technologies Related to Production or Processing of Goods	Climate Change Mitigation Technologies Related to Transportation	Climate Change Mitigation Technologies Related to Wastewater Treatment or Waste Management	Environmental Management, Water-Related Adaptation Technologies, and Biodiversity Protection and Ecosystem Health
1980	9	6	58	122	16	7	426
1981	7	8	68	129	17	17	534
1982	12	12	70	138	12	8	519
1983	12	12	72	123	20	6	538
1984	7	8	51	136	26	12	508
1985	5	8	68	130	16	8	554
1986	2	2	57	98	8	6	388
1987	3	5	50	93	9	9	331
1988	5	5	44	101	5	8	348
1989	4	6	29	96	12	14	361
1990	9	2	15	85	12	11	290
1991	3	4	23	85	8	15	306
1992	5	6	19	83	9	15	338
1993	4	9	25	63	7	28	322
1994	4	6	30	107	7	46	361
1995	0	7	31	73	7	26	287
1996	1	8	22	83	8	25	292
1997	1	3	47	81	13	8	263
1998	1	4	31	72	6	21	299
1999	5	11	37	76	5	13	277
2000	4	5	34	88	6	11	275
2001	10	3	34	62	8	16	254
2002	3	7	31	108	7	16	262
2003	14	2	37	102	4	19	244
2004	51	1	40	129	4	14	260
2005	23	4	46	111	6	15	235
2006	23	4	36	134	2	20	278
2007	6	4	38	120	3	25	260
2008	6	5	34	108	5	38	259
2009	9	6	27	95	5	22	233
2010	25	4	44	151	12	32	366
2011	14	1	77	150	7	19	323
2012	22	5	73	126	8	31	310
2013	34	9	85	195	12	35	445
2014	35	13	135	238	30	32	518
2015	37	13	117	225	21	37	501
2016	24	23	118	210	37	28	465
2017	55	26	131	178	28	35	498
2018	42	17	79	142	24	36	404
2019	47	26	154	154	326	28	839
2020	30	26	78	110	15	32	404

Appendix Table A2: Green Patent Production and Energy Sector 1980-2020 – Industry Green Patent Ratio

This table reports the results of OLS regressions where the dependent variable is the Industry Green Patent Ratio, which is the percentage of green patents granted in a given industry, defined by a two-digit SIC code, in that particular year. Energy Sector is a dummy variable if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. The unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
	Industry Green Patent Ratio		
Energy Sector	0.1126***	0.1161***	0.1163***
	(13.83)	(15.18)	(14.82)
Average Industry Investment		-0.0001**	-0.0002
		(2.06)	(0.07)
Average Industry R&D Investment		0.0001***	0.0001***
		(2.87)	(2.86)
Average Industry Log Firm Age		0.0391***	0.0389***
		(3.91)	(3.80)
Average Industry Log Total Asset		-0.0083***	-0.0080***
		(3.45)	(3.27)
Average Industry Cash			-0.0001
			(0.15)
Average Industry Book Leverage			0.0000
			(0.06)
Observations	2,413	2,372	2,311
R-squared	0.072	0.087	0.088
Year FE	YES	YES	YES

Appendix Table A3: Green Patent Production and Energy Sector 1980-2020 – Industry Green Patents

This table reports the results of OLS regressions where the dependent variable is the Industry Green Patent. Energy Sector is a dummy variable if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. The unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
VARIABLES	Industry Green Patents		
Industry Total Patents	0.0962***	0.0348***	0.0348***
	(22.35)	(5.00)	(4.98)
Energy Industry	53.2051***	12.2520***	11.7295***
	(10.65)	(3.58)	(3.46)
Average Industry Investment		0.0244	1.2578
		(1.57)	(0.73)
Average Industry R&D Investment		1.4443***	1.4441***
		(2.72)	(2.71)
Average Industry Log Age		39.4301**	40.1150**
		(2.38)	(2.37)
Average Industry Log Total Asset		-7.4363**	-7.6008**
		(-2.21)	(-2.19)
Average Industry Cash			0.2839
			(0.85)
Average Industry Book Leverage			-0.2750
			(-0.72)
Constant	-33.8568***	-89.3909	-90.9555
	(-2.77)	(-1.43)	(-1.41)
Observations	2,413	2,372	2,311
R-squared	0.956	0.628	0.628
Year FE	YES	YES	YES

Appendix Table A4. Green Patent Production and Energy Sector:
"Climate change mitigation technologies related to energy generation, transmission or distribution."

This table reports the results of OLS regressions where the dependent variable is the Industry Green Patent Ratio, which is the percentage of green patents granted in a given industry, defined by a 2-digit SIC code, in that particular year. Energy Sector is a dummy variable if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). We identify green patents that are "Climate Change Mitigation Technologies Related to Energy Generation, Transmission, or Distribution" using OECD's IPC classification, i.e., green patents that have patent classification "Y02E". The unit of observation is industry (2-digit SIC code) and year. The sample covers 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
VARIABLES		Industry Patent Ratio	
Energy Industry	0.0202***	0.0231***	0.0229***
	(4.62)	(4.50)	(4.51)
Average Industry Investment		-0.0001***	0.0027
		(11.18)	(1.39)
Average Industry R&D Investment		0.0000*	0.0000*
		(1.84)	(1.81)
Average Industry Log Age		0.0014	0.0015
		(0.17)	(0.18)
Average Industry Log Total Asset		-0.0014	-0.0013
		(0.67)	(0.63)
Average Industry Cash			0.0005
			(1.35)
Average Industry Book Leverage			-0.0006
			(1.42)
Constant	0.0171***	0.0193	0.0184
	(41.67)	(0.71)	(0.67)
Observations	722	709	709
R-squared	0.029	0.039	0.040
Year FE	YES	YES	YES

Appendix Table A5. Sub-period Analyses:
Before and After 2004 (The first time the term "ESG" was coined in the 2004 United Nations Global Compact Report)

This table reports the results of OLS regressions where the dependent variable is the Industry Green Patent Ratio, which is the percentage of green patents granted in a given industry, defined by a 2-digit SIC code, in that particular year, separately before 2004 and on/after 2004 and by each decade since 1980. Energy Sector is a dummy variable if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. The unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

Panel A: Before and After 2004

	Before 2004			2004 Onward		
	Industry Patent Ratio			Industry Patent Ratio		
Energy Industry	0.1300***	0.1329***	0.1340***	0.0847***	0.0972***	0.0970***
	(14.48)	(14.31)	(13.79)	(6.75)	(8.59)	(8.57)
Average Industry Investment		-0.0075***	-0.0051***		-0.0000	0.0035
		(-16.00)	(-7.81)		(0.45)	(0.99)
Average Industry R&D Investment		0.0002***	0.0002***		0.0001**	0.0001**
		(6.06)	(6.12)		(2.55)	(2.52)
Average Industry Log Age		0.0269**	0.0257*		0.0465***	0.0467***
		(2.22)	(2.06)		(3.09)	(3.10)
Average Industry Log Total Asset		-0.0081***	-0.0077**		-0.0071*	-0.0069*
		(-2.84)	(-2.61)		(1.81)	(1.78)
Average Industry Cash			-0.0023***			0.0006
			(-3.29)			(0.91)
Average Industry Book Leverage			-0.0002**			-0.0008
			(-2.67)			(0.99)
Observations	1,510	1,485	1,424	903	887	887
R-squared	0.097	0.108	0.112	0.039	0.064	0.065
Year FE	YES	YES	YES	YES	YES	YES

Panel B

	(1)	(2)	(3)	(4)
	1980-1989	1990-1999	2000-2009	2010-2020
	Industry Patent Ratio			
Energy Industry	0.1207***	0.1565***	0.1247***	0.0926***
	(8.08)	(8.91)	(8.50)	(6.88)
Average Industry Investment	-0.0272	-0.0047*	-0.0806	0.0026
	(-0.85)	(-1.89)	(-1.73)	(0.45)
Average Industry R&D Investment	0.0003***	0.0001	0.0002***	0.0001**
	(3.45)	(1.65)	(9.07)	(2.28)
Average Industry Log Age	0.0125	0.0242	0.0254	0.0621***
	(1.32)	(0.80)	(1.48)	(3.42)
Average Industry Log Total Asset	-0.0021	-0.0198***	0.0015	-0.0102*
	(-0.66)	(-4.07)	(0.52)	(-1.86)
Average Industry Cash	-0.0173**	-0.0033	-0.0001	0.0005
	(-2.62)	(-0.94)	(-0.19)	(0.40)
Average Industry Book Leverage	-0.0003	-0.0002**	-0.0006	-0.0006
	(-0.22)	(-2.58)	(-0.12)	(-0.44)
Observations	522	601	598	590
R-squared	0.128	0.112	0.089	0.069
Year FE	YES	YES	YES	YES

Appendix Table A6: Cross-Sectional Green Patenting Activities - Firm-level analysis.

This table reports the results of OLS regressions where the dependent variable is the number of green patents divided by all patents by a firm. We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Green Patent Ratio					
Energy Sector	0.0418***	0.0079	0.0261***	0.0570***	0.0189	0.0438***
	(7.30)	(0.32)	(3.58)	(5.16)	(1.22)	(7.46)
Energy Sector x Log Total Asset		0.0039				
		(1.59)				
Energy Sector x Cash			0.1860**			
			(2.32)			
Energy Sector x Invest				-0.1671		
				(1.48)		
Energy Sector x Book Leverage					0.0768	
					(1.43)	
Energy Sector x Log R&D						-0.0013
						(0.99)
Log Total Asset	-0.0011**	-0.0013***	-0.0010**	-0.0012***	-0.0011**	-0.0011**
	(2.91)	(3.34)	(2.77)	(3.21)	(2.68)	(2.86)
Log Age	-0.0005	-0.0005	-0.0003	-0.0005	-0.0006	-0.0005
	(0.62)	(0.60)	(0.40)	(0.56)	(0.72)	(0.62)
Cash	-0.0007**	-0.0007*	-0.0006**	-0.0007*	-0.0006**	-0.0007**
	(2.23)	(2.19)	(2.20)	(2.18)	(2.22)	(2.23)
Book Leverage	0.0113***	0.0116***	0.0115***	0.0111***	0.0099***	0.0113***
	(4.66)	(4.99)	(4.61)	(4.48)	(4.32)	(4.59)
Investment	0.1473***	0.1495***	0.1395***	0.1846***	0.1435***	0.1469***
	(3.99)	(3.94)	(4.10)	(4.17)	(3.76)	(3.99)
Log R&D	-0.0012***	-0.0012***	-0.0013***	-0.0012***	-0.0011***	-0.0011***
	(3.40)	(3.48)	(4.01)	(3.36)	(3.17)	(3.23)
Constant	0.0251***	0.0264***	0.0242***	0.0243***	0.0252***	0.0248***
	(10.72)	(13.32)	(11.36)	(10.10)	(10.80)	(10.73)
Observations	17,178	17,178	17,178	17,178	17,178	17,178
R-squared	0.018	0.019	0.021	0.020	0.019	0.019
Year FE	YES	YES	YES	YES	YES	YES

Appendix Table A7: Greenhouse Gas Emissions and Green Patenting Activity.

This table reports the results of OLS regressions where the dependent variable is the log of Green Patents Granted, as defined in the description of Table 1. The independent variable is Emissions, which measures the greenhouse gas (GHG) emissions (in kilograms) from sources that are owned or controlled by the company, from consumption of purchased electricity, heat, or steam by the company, and from other upstream activities, divided by the company's revenue. The unit of Emissions is tCO2e/$M. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). *Top 3 Sector (outside of Energy)* is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by firm.

	(1)	(2)	(3)
VARIABLES	Log of Green Patents Granted		
Log Emission	0.0258***	0.0368***	0.0122**
	(4.80)	(5.04)	(2.07)
Energy Sector		0.2818***	
		(3.08)	
Energy Sector x Log Emission		-0.0489***	
		(3.30)	
Top 3 Sectors (outside of Energy)			-0.2659***
			(3.78)
Top 3 Sectors x Log Emission			0.0410***
			(3.03)
Log Total Asset	0.0504***	0.0525***	0.0448***
	(7.03)	(7.17)	(6.51)
Log Age	0.0287***	0.0292***	0.0280***
	(3.17)	(3.21)	(3.09)
Cash	-0.0358***	-0.0309***	-0.0289***
	(2.95)	(2.73)	(2.61)
Book Leverage	0.0002	-0.0002	0.0001
	(0.12)	(0.08)	(0.08)
Investment	0.2210***	0.2179***	0.2511***
	(2.93)	(2.68)	(3.03)
Log R&D	0.0797***	0.0778***	0.0864***
	(10.10)	(10.15)	(10.22)
Constant	-0.6669***	-0.7335***	-0.5356***
	(8.49)	(8.46)	(7.27)
Observations	22,085	22,085	22,085
R-squared	0.201	0.202	0.204
Year FE	YES	YES	YES

Appendix Table A8: Using MSCI Index

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (by MSCI and is out of 100). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)
VARIABLES	MSCI Environmental Score	
Green Patents Granted	-0.0048***	-0.0041***
	(2.92)	(2.61)
Energy Sector	-0.8012***	-0.6007***
	(4.23)	(3.52)
Energy Sector x Green Patents Granted		-0.0489***
		(5.66)
Log Total Asset	0.0551***	0.0592***
	(3.72)	(4.09)
Log Age	0.0429	0.0434
	(1.47)	(1.49)
Cash	0.0270	0.0303
	(0.91)	(1.03)
Book Leverage	-0.1125*	-0.1521**
	(1.67)	(2.45)
Investment	0.8632***	0.8905***
	(2.92)	(3.06)
Log R&D	0.0368***	0.0430***
	(2.78)	(3.33)
Constant	-0.5376***	-0.5878***
	(3.91)	(4.45)
Observations	9,304	9,304
R-squared	0.166	0.182
Year FE	YES	YES

Appendix Table A9: Split Sample in Half by Time.

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (by Sustain-Analytics and is out of 100). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (Outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)
	Year < 2013		Year >= 2013	
VARIABLES	Environmental Score			
Green Patents Granted	-0.0252***	-0.0222***	-0.0322***	-0.0312***
	(3.72)	(3.37)	(5.60)	(5.27)
Energy Sector	-5.7320***	-3.5394*	-6.0087***	-4.0954**
	(2.66)	(1.81)	(2.99)	(2.18)
Energy Sector x Green Patents Granted		-0.3326***		-0.1902***
		(3.06)		(2.93)
Log Total Asset	3.3227***	3.4403***	3.5705***	3.6328***
	(10.41)	(11.08)	(10.24)	(10.49)
Log Age	1.8110***	1.8144***	3.4513***	3.4503***
	(2.77)	(2.79)	(5.34)	(5.36)
Cash	0.1176	0.1024	0.2257	0.1927
	(0.08)	(0.07)	(0.16)	(0.13)
Book Leverage	-0.0751	-0.6972	0.6398	0.4390
	(0.04)	(0.34)	(0.44)	(0.31)
Investment	28.5966**	30.0165***	10.7121	9.1172
	(2.51)	(2.65)	(1.05)	(0.89)
Log R&D	1.6435***	1.7372***	1.4531***	1.5159***
	(7.88)	(8.49)	(7.17)	(7.47)
Constant	11.6839***	10.3025***	8.2724**	7.5578**
	(3.41)	(3.12)	(2.27)	(2.09)
Observations	2,004	2,004	1,907	1,907
R-squared	0.336	0.349	0.330	0.337
Year FE	YES	YES	YES	YES

Appendix Table A10: Interactions

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (by Sustain-Analytics and is out of 100). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (Outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					Environmental Score				
Green Patents Granted	-0.0297***	-0.0305***	-0.0255**	-0.0303***	-0.0307***	-0.0312***	-0.0316***	-0.0330***	0.1503
	(5.44)	(5.55)	(2.57)	(5.49)	(5.56)	(5.76)	(5.88)	(6.13)	(1.16)
Energy Sector	-0.2505***								
	(3.23)								
Green Patents Granted x Energy Sector	-3.5748**								
	(2.00)								
Construction		-2.7435***							
		(2.99)							
Green Patents Granted x Construction		0.8417							
		(1.36)							
Manufacturing			4.8222***						
			(3.64)						
Green Patents Granted x Manufacturing			-0.0057						
			(0.50)						
Transportation & Public Utilities				0.7003					
				(0.34)					
Green Patents Granted x Transportation & Public Utilities				0.2583					
				(0.99)					
Wholesale Trade					5.8592				
					(1.42)				
Green Patents Granted x Wholesale Trade					-6.6772				
					(1.34)				
Retail Trade						2.953			
						(1.05)			
Green Patents Granted x Retail Trade						-1.1348***			
						(7.78)			
Finance, Insurance, & Real Estate							-5.1692***		
							(2.90)		
Green Patents Granted x Finance, Insurance, & Real Estate							0.4988		
							(0.51)		
Services								-2.9042**	
								(2.02)	
Green Patents Granted x Services								0.1130***	
								(8.59)	
Green Patents Granted x Log Total Asset									-0.015
									(1.40)

Log Total Asset	3.6854***	3.4455***	3.9313***	3.4104***	3.4509***	3.4907***	3.8209***	3.3615***	3.4704***
	(12.09)	(10.73)	(12.15)	(10.44)	(10.76)	(11.17)	(11.54)	(10.47)	(10.85)
Log Age	2.6997***	2.6203***	2.0964***	2.6363***	2.5840***	2.5444***	2.3727***	2.3368***	2.5741***
	(4.38)	(4.19)	(3.37)	(4.21)	(4.13)	(4.05)	(3.71)	(3.71)	(4.13)
Cash	0.4146	1.0124	2.4363	1.0582	1.1126	1.0488	1.9683	1.6305	1.1430
	(0.27)	(0.64)	(1.58)	(0.66)	(0.70)	(0.66)	(1.25)	(1.03)	(0.72)
Book Leverage	0.6624	1.2684	0.2401	1.2584	1.4738	1.2378	0.6613	1.0195	1.4235
	(0.42)	(0.77)	(0.15)	(0.77)	(0.90)	(0.74)	(0.40)	(0.63)	(0.87)
Investment	15.2768	0.2413	4.2308	-0.5952	1.3622	1.3942	-9.5413	-1.6033	-0.6934
	(1.46)	(0.02)	(0.42)	(0.06)	(0.13)	(0.14)	(0.91)	(0.16)	(-0.07)
Log R&D	1.6450***	1.6608***	1.2010***	1.6703***	1.6979***	1.7347***	1.4503***	1.6456***	1.6250***
	(8.62)	(8.77)	(5.08)	(8.68)	(8.98)	(9.22)	(7.37)	(8.78)	(8.46)
Constant	7.7483**	10.0684***	6.0355*	10.2760***	9.7711***	9.4964***	9.0389***	12.2004***	3.4704***
	(2.38)	(2.92)	(1.79)	(2.97)	(2.85)	(2.83)	(2.65)	(3.47)	(10.85)
Observations	3,531	3,531	3,531	3,531	3,531	3,531	3,531	3,531	3,531
R-squared	0.336	0.317	0.334	0.317	0.32	0.324	0.324	0.324	0.319
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

Appendix Table A11: Technology Implementation

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (by Sustain-Analytics and is out of 100). We identify green patents using OECD's IPC classification, i.e., green patents are the ones that contain one of the following environmental technologies: Environmental Management, Water-related Adaptation Technologies, Biodiversity Protection, Ecosystem Health; Climate Change Mitigation Technologies Related to Energy Generation, Transmission or Distribution, Transportation, Buildings, Waste-water Treatment or Waste Management, and Production or Processing of Goods; and Capture, Storage, Sequestration or Disposal of Greenhouse Gases. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Has Climate Business Strategy, Has Low Carbon Investment, and Percent Revenue From Low Carbon Product are values taken from Disclosure Insight Action (CDP) Global Climate Change Report in 2018, thus the sample period is for 2018. Has Climate Business Strategy is a dummy variable that takes the value of one if a firm answers Yes to the question "Does your organization use climate-related scenario analysis to inform your business strategy?". Has Low Carbon Investment is a dummy variable that takes the value of one if a firm has an answer to one of these questions: "Disclose your organization's low-carbon investments for cement production activities.", "Disclose your organization's low-carbon investments for chemical production activities.", "Disclose your organization's low-carbon investments for metals and mining production activities.", "Disclose your organization's low-carbon investments for steel production activities.", or "Disclose your investments in low-carbon research and development (R&D), equipment, products, and services." Percent Revenue From Low Carbon Products is the percentage value from the answer to the question: "Please provide details of your products and/or services that you classify as low-carbon products or that enable a third party to avoid GHG emissions." Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)
VARIABLES		Environmental Score	
Energy Sector	-11.3959*	-10.2994**	-9.5384***
	(-1.84)	(-2.40)	(-2.778)
Has Climate Business Strategy	-1.3916		
	(-0.85)		
Has Climate Business Strategy x Energy Sector	1.4770		
	(0.22)		
Has Low Carbon Investment		-7.0073***	
		(-2.93)	
Has Low Carbon Investment x Energy Sector		4.9211	
		(0.89)	
Percent Revenue From Low Carbon Products			0.0472
			(1.56)
Percent Revenue From Low Carbon Products x Energy Sector			-0.0938
			(-0.66)
Log Total Asset	1.8360***	1.9033***	1.7529***
	(3.16)	(3.43)	(3.12)
Log Age	0.4569	0.7061	0.6044
	(0.38)	(0.60)	(0.50)
Cash	8.5781	6.4733	8.6731
	(1.55)	(1.19)	(1.58)
Book Leverage	-4.3255*	-4.3221*	-3.8450*
	(-1.87)	(-1.91)	(-1.67)
Investment	-22.3596	-16.4306	-32.4000
	(-0.92)	(-0.68)	(-1.30)
Log R&D	0.8561***	1.0299***	0.7727***
	(3.22)	(3.87)	(2.91)
Constant	47.4737***	45.4479***	47.2784***
	(6.77)	(6.60)	(6.74)
Observations	176	176	176
R-squared	0.309	0.341	0.316
Year FE	YES	YES	YES

Appendix Table 12. Net Green Patenting – Firm-level Analysis

This table reports the results of OLS regressions where the dependent variable is the number of green patents ratio by a firm: for columns (1) and (2), the Green Ratio is the number of green patents divided by all patents by a firm; for columns (3) and (4), Green Ratio is the number of green patents that have the classification group that also has as least one green classification at least 5 years ago divide by all patents by a firm has the classification group that also has as least one green classification at least 5 years ago; for columns (5) and (6), Green Ratio is the number of green patents that has the classification group that also has as least one green classification at least 5 years ago divide by all patents by a firm has the classification group that also has as least 5% green classification at least 5 years ago divide by all patents by a firm has the classification group that also has at least 5% green classification at least 5 years ago. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sector (Outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Green Ratio		Green Ratio | Patent Class Has One Green Option		Green Ratio | Patent Class Has 5%+ Green Option	
Energy Industry	0.1418***		0.1446***		0.1698***	
	(26.30)		(26.56)		(29.31)	
Top 3 Sectors (Outside of Energy)		-0.0572***		-0.0587***		-0.0856***
		(15.86)		(15.44)		(18.66)
Constant	0.0741***	0.1303***	0.0778***	0.1354***	0.1075***	0.1905***
	(266.58)	(42.32)	(278.42)	(41.63)	(343.52)	(48.15)
Observations	63,844	63,844	61,101	61,101	50,472	50,472
R-squared	0.026	0.013	0.025	0.013	0.026	0.016
Year FE	YES	YES	YES	YES	YES	YES

Appendix Table 13: Net Green Patenting Firms among the Top 100 Green Patent Producers

Columns (1), (3), and (5) of this table report the differences in the percentage of Energy Sector firms that are in the top 100 Green Patenting firms and the percentage of Energy Sector firms that are in the entire sample. Columns (2), (4), and (6) of this table report the differences in the percentage of Top 3 Sector firms that are in the top 100 Green Patenting firms and the percentage of Top 3 Sector (Outside of Energy) firms that are in the entire sample. We measure and define Top Green Patenting firms in three ways: columns (1) and (2) - Total Green Patent Granted divided by Total Patent Granted; columns (3) and (4): Total Green Patent Granted divided by Total Patent Granted, conditioning on Patent Class Has One Green Option, where we count only patents in patent classifications that have at least one green patent at least five years prior; columns (5) and (6): Total Green Patent Granted divided by Total Patent Granted, conditioning on Patent Class Has 5%+ Green Option, where we count patents in patent classifications that has at least 5% green patent at least five years prior. The sample period is from 2008 to 2020. Reported t-statistics in parentheses are from two-sample t-tests.

(1)	(2)	(3)	(4)	(5)	(6)
Top 100: Green Ratio		Top 100: Green Ratio | Patent Class Has One Green Option		Top 100: Green Ratio | Patent Class Has 5%+ Green Option	
% Energy in Top 100 - % Energy All	% Top 3 in Top 100 - % Top 3	% Energy in Top 100 - % Energy All	% Top 3 in Top 100 - % Top 3	% Energy in Top 100 - % Energy All	% Top 3 in Top 100 - % Top 3
0.1050***	-0.1167***	0.0982***	-0.1100***	0.0924***	-0.1056***
(17.30)	(13.52)	(15.86)	(13.41)	(16.24)	(13.45)

Appendix Table A14: Net Green Patenting for Top 100 Green Patent Producers

This table reports the results of OLS regressions where the dependent variable is the number of green patents ratio by the annual top 100 green patent producers: for columns (1) and (2), Green Ratio is the number of green patents divided by all patents by a firm; for columns (3) and (4), Green Ratio is the number of green patents that have the classification group that also has as least one green classification at least 5 years ago divide by all patents by a firm has the classification group that also has as least one green classification at least 5 years ago; for columns (5) and (6), Green Ratio is the number of green patents that have the classification group that also has as least one green classification at least 5 years ago divide by all patents by a firm has the classification group that also has as least 5% green classification at least 5 years ago divide by all patents by a firm has the classification group that also has at least 5% green classification at least 5 years ago. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sector (Outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)	(6)
	Green Ratio		Green Ratio | Patent Class Has One Green Option		Green Ratio | Patent Class Has 5%+ Green Option	
Energy Industry	0.0821***		0.0706***		0.0311***	
	(7.04)		(6.28)		(3.44)	
Top 3 Sectors (Outside of Energy)		-0.0668***		-0.0602***		-0.0420***
		(6.47)		(6.11)		(5.64)
Constant	0.7149***	0.7766***	0.7460***	0.8012***	0.8300***	0.8658***
	(423.62)	(100.80)	(451.34)	(109.42)	(623.39)	(156.49)
Observations	4,300	4,300	4,200	4,200	4,200	4,200
R-squared	0.295	0.295	0.204	0.204	0.295	0.299
Year FE	YES	YES	YES	YES	YES	YES

Table A15: Net Green Patenting – Patent level analysis

This table reports the results of OLS regressions where the dependent variable is a dummy variable that takes a value of one if: for columns (1) and (2), the granted patent is a green patent, as defined in the description of Table 1; for columns (3) and (4), the granted patent is a green patent, and the classification group of that green patent also has as least one green classification at least 5 years ago; for columns (5) and (6), the granted patent is a green patent, and the classification group of that green patent also has as least 5% green classification at least 5 years ago. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) is 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sector (Outside of Energy) is a dummy variable that equals one if the sector is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample period is from 1980 to 2020. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Green Patent		Green Patent | Patent Class Has One Green Option		Green Patent | Patent Class Has 5%+ Green Option	
Energy Industry	0.0721***		0.0704***		0.0839***	
	(14.41)		(14.42)		(13.04)	
Top 3 Sectors (Outside of Energy)		-0.0548***		-0.0549***		-0.0731***
		(26.27)		(26.12)		(25.92)
Constant	0.0712***	0.1213***	0.0729***	0.1230***	0.1128***	0.1790***
	(427.39)	(66.78)	(456.63)	(67.23)	(477.39)	(73.54)
Observations	2,516,582	2,516,582	2,435,422	2,435,422	1,557,393	1,557,393
R-squared	0.004	0.006	0.004	0.007	0.004	0.008
Year FE	YES	YES	YES	YES	YES	YES

Table A16: Green Funds Investment in Energy Sector

The first three columns of Panel A report OLS regressions of fund ownership in a firm on whether the fund is a green fund, conditioning on a firm being in the Energy Sector. The last three columns of Panel A report OLS regression of fund ownership in a firm on whether the fund is a green fund, conditioning on a firm being in the Top 3 Sectors (outside of Energy). Panel B reports OLS regression of fund ownership in a firm on whether the firm is in the Energy Sector, conditioning on the fund being a green fund. A fund is considered green if it has "ESG" or "green" in its name, is in the list of USSIF (The Forum of Sustainable and Responsible Investment), or it is in the list of Charles Schwab's Green Funds. Energy Sector is a dummy variable that equals one if the first two digits of Standard Industrial Classification (SIC) are 10 (Metal, Mining), 12 (Coal Mining), 13 (Oil & Gas Extraction), 14 (Nonmetallic Minerals, Except Fuels), 29 (Petroleum & Coal Products), or 49 (Electric, Gas, & Sanitary Services). Top 3 Sectors (Outside of Energy) is a dummy variable that equals one if the industry is among the top 3 sectors in terms of green patent production, excluding the Energy Sector: Manufacturing, Services, and Transportation & Public Utilities. The sample covers 2005 to 2017 (Our patent data goes back to 1980, our ESG ranking data goes back to 2008, and our institutional ownership data goes back to 2005). All regressions include year-quarter fixed effects. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by fund x firm.

Panel A: Fund ownership in a firm *conditional on the firm type*

	(1)	(2)	(3)	(4)	(5)	(6)
	%fund holding	I[%fund holding > 0]	I[%fund holding > %index]	%fund holding	I [%fund holding > 0]	I [%fund holding > %index]
Green Fund	-0.0706***	-0.0454***	-0.0131***	0.0282***	0.0219***	0.0321***
	(9.25)	(10.15)	(3.97)	(19.66)	(22.25)	(38.16)
Log MVE	0.0947***	0.0372***	0.0103***	0.0683***	0.0343***	0.0146***
	(80.44)	(75.53)	(32.14)	(238.61)	(264.05)	(165.54)
Log Age	0.0238***	0.0071***	0.0027***	-0.0034***	0.0039***	0.0012***
	(24.11)	(10.19)	(5.40)	(16.93)	(24.81)	(10.26)
Cash	0.0901***	0.0283***	0.0771***	0.0787***	0.0428***	0.0314***
	(6.35)	(3.86)	(14.17)	(85.77)	(71.14)	(70.38)
Book Leverage	-0.3754***	-0.0238***	0.0734***	-0.0223***	-0.0020***	-0.0032***
	(29.70)	(4.00)	(17.24)	(35.59)	(4.37)	(9.18)
Investment	0.1016***	0.1083***	0.1236***	0.0848***	0.0203***	-0.0043
	(5.59)	(11.69)	(18.58)	(15.24)	(5.52)	(1.63)
Lag Return	0.0102***	0.0207***	0.0170***	0.0476***	0.0287***	0.0197***
	(5.13)	(17.75)	(17.62)	(144.29)	(136.29)	(111.32)
Observations	4,559,019	4,559,019	4,559,019	105,609,003	105,609,003	105,609,003
R-squared	0.05	0.031	0.006	0.036	0.021	0.008
Year-Quarter FE	YES	YES	YES	YES	YES	YES

Panel B: Fund ownership in a firm on whether the firm is in the Energy Sector, *conditioning on the fund being a green fund.*

	(1)	(2)	(3)	(4)	(5)	(6)
	%fund holding	I[%fund holding > 0]	I[%fund holding > %index]	%fund holding	I[%fund holding > 0]	I[%fund holding > %index]
Energy Sector	-0.0739***	-0.0600***	-0.0538***			
	(9.55)	(12.60)	(14.67)			
Top 3 Sectors (outside of Energy)				0.0215***	0.0115***	0.0107***
				(7.09)	(5.47)	(6.11)
Log MVE	0.0755***	0.0286***	0.0159***	0.0747***	0.0278***	0.0151***
	(44.84)	(35.14)	(24.57)	(44.45)	(34.12)	(23.51)
Log Age	0.0059***	0.0123***	0.0096***	0.0042**	0.0113***	0.0087***
	(3.65)	(11.03)	(10.05)	(2.53)	(10.16)	(9.11)
Cash	0.0847***	0.0545***	0.0384***	0.0809***	0.0549***	0.0385***
	(12.12)	(12.16)	(10.11)	(11.29)	(11.95)	(9.86)
Book Leverage	-0.0335***	-0.0240***	-0.0209***	-0.0267***	-0.0187***	-0.0161***
	(7.79)	(8.15)	(8.30)	(6.28)	(6.34)	(6.41)
Investment	0.2578***	0.2447***	0.1821***	0.1878***	0.1737***	0.1197***
	(7.76)	(10.48)	(9.09)	(5.61)	(7.75)	(6.24)
Lag Return	0.0337***	0.0145***	0.0127***	0.0342***	0.0150***	0.0132***
	(15.09)	(10.13)	(9.88)	(15.25)	(10.44)	(10.19)
Observations	2,674,767	2,674,767	2,674,767	2,674,767	2,674,767	2,674,767
R-squared	0.037	0.017	0.008	0.037	0.016	0.007
Year-Quarter FE	YES	YES	YES	YES	YES	YES