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# THE ESG-INNOVATION DISCONNECT: EVIDENCE FROM GREEN PATENTING

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The ESG-Innovation Disconnect: Evidence from Green Patenting
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**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. Our findings raise important questions as to whether the current exclusions of many ESG-focused policies – along with the increasing incidence of explicit divestiture campaigns – are optimal, or whether reward-based incentives would lead to more efficient innovative outcomes.

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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, good ESG 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 2017 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 their 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. In addition, the green patents of energy-producing firms are significantly higher quality, in terms of being more highly cited. Energy producing firms are also significantly more likely to produce "blockbuster" green patents than other firms. Yet, these

[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 then. However, for every test that does not rely on the ESG data, the sample is from 1980 to 2017. Our overall institutional ownership data goes back to 2005, and hence for every test that rely on institutional ownership, the sample is from 2005-2017.

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.

A natural question that arises at this point is whether the patents energy companies create are seen as important contributions to technological innovations that shape the green energy space. If green patents of energy companies are narrowly focused, not meaningful, and/or are not consequential, then their incremental green patenting activity wouldn't be considered to have high real-world significance. We find that, in contrast, energy firms' patents were cited not only by other fossil fuel company patents but also by other innovators. Green patents of energy companies, in fact, receive 74% of the citations from *outside* the industry whereas, by comparison, non-energy firms' green patents receive if anything slightly less (71%). 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 97%) 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.

While the investigation of patenting structure is informative to understand the importance of patents produced by a group of companies, it is also 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 than among fossil fuel companies.

[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.

Lastly, we investigate whether green patent production 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.

Stepping back, our findings suggest that energy firms have been a major and influential player in the green patent production during our sample period – when ESG investing was increasingly attracting investor and policy capital and attention. A potential endogeneity concern for our findings is that energy firms are simply responding to this public pressure, forcing them to make cosmetic changes in their research and development efforts to attract ESG fund flow.

There are two empirical regularities from our results that point against this particular form of endogeneity in our setting. First, the results we find are that green patents of energy firms are of significantly higher quality, more impactful, particularly in the view of firms *outside* of the energy industry, and are accompanied by several other environmentally friendly markers, such as the production of energy from alternative energy sources. Second, our findings indicate that fossil fuel companies were major innovators in the green energy space well before the term "ESG" even existed. The term itself traces its origin to a 2004 United Nations Global Compact Report (United Nations (2004)). Our results on green patenting by the traditional energy industry, relative intensity, and green patent quality – range back to the 1980s, decades before the existence of ESG as a term or movement (including any related divestiture efforts). As an illustration of this, in 1978, one of the central, foundational patents in the solar cell space 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). This, and many other follow-on green patents now play a crucial role in solar energy.

**-- Insert Figure 2 here --**

The remainder of the paper proceeds as follows. Section II provides background for our study, while Section III develops certain of our predictions using a stylized model for an incumbent firm incentivized to innovate when facing the possibility of becoming obsolete. Section IV describes the data we collect on patents along with ESG metrics used in our analyses. Section V presents our main results on green patenting, including the most frequent patenting entities, the quality of this patenting, and the reward the market places upon it. Section VI concludes.

## II. 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. [5]

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 ($\alpha$) 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 $p = \alpha V$.[6]

The incumbent may preempt new entrants from acquiring the breakthrough technology by investing $c$ each period into innovative activities. This cost could be imagined to take 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

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

[6] While one could imagine $\lambda$ being correlated with $\alpha$, 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 $\alpha$ of existing incumbents.

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:

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

2. Value of the firm with the innovation:

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

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

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 $\lambda$, 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 $\alpha$), 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.

## III. 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.[7] 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 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.[8]

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

[7] Similarly, a New York Times (2014) article notes that Stanford's divestment from coal stocks had little effect on stock prices.
[8] 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.

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.

## IV. Data

Our analysis relies on two main streams of data: (1) The Patent Citation and Patent Assignment databases, and (2) Environmental Score data from the Sustainalytics 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 2017.[9] 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.[10] 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.[11] 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.[12]

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

Additionally, we use Sustainalytics' Environmental, Social, and Governance (ESG) Ratings Database 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 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.

## V. Main Results on Green Patenting

### *a. Top Green Patenting Firms and the Time Series of Green Patenting*

We begin our analysis by examining the top green patent-holding firms as of 2017. 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, 14% 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, Honeywell International, Royal Dutch Shell, BP, Conoco Phillips, Chevron, and US Oil. These seven firms collectively produced 6,969 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. Our final sample, containing all public firms from 1980 to 2017 that produce at least one patent is 11,397 public firms. These firms produce 2,077,832 patents, with 5.61% classified as green patents. In looking at the time series, the percentage of green patents peaks in total number in the last year of the sample, with 5,251 patents produced (representing 6.32% of all patents produced by publicly traded firms in 2017).

**-- Insert Table 2 here --**

### *b. Green Patenting at the Industry Level*

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:

$$Green\ Patent\ Ratio_{it} = b_0 + b_1 \times Energy\ Sector_{it} + Year\ Fixed\ Effects \qquad (1)$$

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. Our sample spans from 1980 to 2017. *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 2,143 industry-year observations, 197 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. In this sample, 8.30 % of the patents are green patents. We find that the coefficient of the *Energy Sector* dummy is 13.95% ($t$ = 15.28). This implies that the energy sector has nearly three times the relative focus on green innovation in its innovation portfolio as the average industry, at 22.25% (vs. 8.30%).

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 a quarter 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. Moreover, nearly all of these on their own are not significantly related to the *Green Patent Ratio* on their own. This is to say that it is not industries that on average have higher overall investment, specifically higher R&D investment industries, industries with older firms, larger firms, or firms with more cash reserves - that focus disproportionately on green innovation. The only industry-level variable that appears related is average book leverage, with industries focusing on green patenting being slightly more highly levered on average.

One might worry that the patenting we are measuring in Table 3 has to do 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 A1. Specifically, in Appendix Table A1 we run an identical regression to Table 3 but focus solely on these alternative energy patents. From Appendix Table A1, 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 0.0221 ($t$ = 5.02) implies that the energy sector has, like Table 3, an almost three times larger focus specifically on climate change mitigation technology innovation relative to all other industries.

In Table A2, we then also explore to what extent firm-level emissions themselves interact with – and are associated with – green patenting activity. From Column 1 of Table A2, 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 and 4. In fact, compared with other Top Green Patenting Industries (outside of Energy) from Column 3 of Table

A2, 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 (and consistent with the leading innovation we see them undertaking in the space dating back to the 1970s, as in Figure 2).

### *c. Which Environmental Score firms are Green Patenting?*

We now turn our focus to the link between incremental green patent production and environmental metrics many investors focus on to allocate their capital in this space. We begin by asking the simple question of whether firms with better *Environmental Scores* contribute more to green patent production in general, i.e., we ask if the incremental green patent is more likely to come from better or worse scored ESG firms. Relatedly, we also examine whether the incremental green patent is more likely to come from companies in the energy sector to check whether Table 3's industry-level analysis - which suggested that the energy industry dedicates a significantly larger percentage of their patenting activity to green research - is also echoed at a more granular, firm-level analysis. We conduct this analysis using the patent level data and use the following linear probability models:

$$Green\ Patent_{i} = b_0 + b_1 \times Environmental\ Score_{it} + Year\ Fixed\ Effects \qquad (2)$$

and

$$Green\ Patent_{i} = b_0 + b_1 \times Energy\ Sector_{it} + Year\ Fixed\ Effects \qquad (3)$$

Our initial findings, summarized in Table 4, demonstrate two strong patterns. First, the coefficient of *Environmental Score* in Column 1 is negative, indicating that the incremental green patent is more likely to come from more poorly scored ESG firms. More specifically, the negative coefficient of *Environmental Score* (-0.011, $t$ = 3.70). In particular, this coefficient implies that a firm that has one standard deviation higher *Environmental Score* (13.807) is 24% *less* likely to green patent (1.52% less likely from a mean of 6.38%). In Column 2, we then explore to what extent this might be driven by the relation from Table 3 – that energy firms have both significantly lower *Environmental Scores* but also are large and important producers of green patents.

**-- Insert Table 4 here --**

Column 2 of Table 4 suggests that the incremental green patent is more likely to come from firms in the energy sector. More specifically, the positive coefficient on the *Energy Sector* of 0.1364 ($t = 5.50$) implies that green patents are over three times more likely to be produced by energy firms than by firms in other industries (20.02% vs. 6.38%).

Lastly, one might argue that given that we know energy firms are active in green patenting, perhaps this is simply a mechanical relationship – and would hold with any industry we know is active in the green patenting space. In order to test this thesis, we run the identical specification in Table 4, but instead, include a categorical variable for whether the firm is from one of the Top 3 Industries in green patenting activity (excluding the Energy Sector):

$$Green\ Patent_{i} = b_0 + b_1 \times Top\ 3\ Sectors\ (Outside\ of\ Energy)_{it} + Year\ Fixed\ Effects \quad (4)$$

The results are shown in Column 3 of Table 4. In sharp contrast to the *Energy Sector*, the coefficient on other active sectors is negative and highly significant. This suggests that these industries, while active in green patenting, are even *more* active in patenting other types of technologies. Thus, these industries are simply higher frequency patentors across all technologies, and in fact, appear to actually proportionately concentrate on activities outside of green innovation. Again, this is the opposite of the relative concentration in this activity for energy firms.

These results collectively reinforce those from Table 3, suggesting that the incremental green patent is significantly more likely to come from traditional energy firms than other green patentors.

### *d. 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: i.) 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; and ii.) that firms with higher environmental scoring seem to produce fewer green patents, on average. Given these two facts, we next ask whether energy firms are driving the negative relationship in general between ESG scores and green patents we document in Table 4; and relatedly, 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,

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

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 expenses, 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 Tables 3 and 4 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 5 here --**

Our main variable of interest in Table 5 is *Green Effort*, which measures a firm's effort to produce green patents. We use three metrics for this purpose: (1) *Number of Green Patents Granted* in a given year, (2) *Number of Green Patent Applications* in a given year, and (3) *Number of Citations per Green Patent*, in that particular year. With the first two metrics, the number of patent applications, and patents granted, we seek to capture the green patent production activity at different points of the patenting process. The last metric, the number of citations per green patent, proxies for a measure of green patent quality produced. For all measures, to examine relative percentage differences across firms and years, we take the log of one plus the metrics (1)-(3).

From Table 5, several empirical patterns emerge. First, once *Energy Sector* firms are stripped out, for all other firms there is a positive relationship between *Environmental Score* and green effort metrics. For instance, the coefficient of the number of green patents granted from Column 1 suggests that a firm with one-standard deviation higher green patenting receives a 2.1 point higher *Environmental Score* ($t$ = 2.03). This same positive and significant relationship with *Environmental Score* holds across the other measures of green effort for firms outside of the *Energy Sector*: number of green patents applied for and number of citations per green patent.

Second, the energy sector seems to be an exception to this general positive reward that is given for green patenting efforts by firms. In particular, both the main effect coefficient on a firm being in the *Energy Sector* is negative, along with the interaction term, *Energy Sector x Green Effort*, being negative across specifications. While marginally statistically significant, the coefficients imply large economic magnitudes across each of the respective *Green Effort* metrics. For instance, the results in Column 1 suggest that an energy firm with a one-standard-deviation larger number of green patents granted in a given year compared to the average firm in the sample is associated with a -5.26 ($t$ = 1.93) lower *Environmental Score*. Compared to the mean Environmental Score of 56, this magnitude corresponds to a roughly 10% lower score. Put differently, assuming that environmental scores are useful metrics to capture environmental efforts of energy firms like those of the non-energy companies, our findings suggest energy firms get less credit in terms of incremental ESG scores for each green patent they are granted, apply for, or even citation per green patent awarded.

Panel B of Table 5 performs the identical analysis as Panel A, but again with the placebo grouping of other frequent green patenting sectors. In sharp contrast to energy sector firms, other top green patenting firms both have significantly higher ESG scores on average and are rewarded more for green patenting activity, than the average firm. Thus, it appears again to be a special characteristic of energy firms regarding the association of their green patenting vs. all other firms - even other frequent green patentors.

### *e. Quality Markers of Green Innovation*

One explanation that could potentially explain the results in Tables 3-5 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 number), 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.

In Table 6 we test this by investigating the quality of green innovation in the energy sector vs. other green innovations. For this purpose, we define two variables. Our first metric is the number of citations the green patents of a firm receive. The second one is a dummy variable that takes a value of one of the percentages of green patent citations above the 95$^{th}$ percentile of all green patents for that year (which we term *Blockbuster Patent*). Results presented in Table 6 show that energy firms do not appear to produce green patents of lower quality. In fact, the opposite appears to be true. Green patents produced by the energy sector are significantly more highly cited than the average green patent and are significantly more likely to be *Blockbuster Patents*. The coefficient in Column 3 of Panel A on the *Energy sector* suggests that the green patents of energy firms have 9.14% ($t$ = 4.28) more citations on average than other green patents. Relatedly, Column 3 of Panel B suggests that energy firms are 12.36% ($t$ = 4.90) more likely to produce a blockbuster green patent.

In Columns 4-6 of Panels A and B, we also test this same alternative for other industries that produce large amounts of green patents. Again, these industries appear to be producing different kinds of green patents. For these other industries, even though they are large producers of green patents, the green patents seem to be of significantly lower quality on average (Panel A). Moreover, they are also significantly less likely to be blockbuster green patents (Panel B).

Stepping back, the results of Tables 3-6 then suggest that energy producers in our sample appear to produce more, and significantly higher quality, green innovation. Further, this is not a function of them being simply producers of a large share of green patents, as other large share producers of green patents exhibit quite different empirical dynamics.

**-- Insert Table 6 here --**

### *f. Fund Flow Analysis*

In our next analysis, we investigate whether energy firms – who empirically appear to be both large producers of green innovation and in particular high-quality green innovation - are getting disproportionally more (or less) capital from ESG funds. 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 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.

Table 7 contains our analysis. From Table 7, 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.

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, Table 7 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 3-6 regarding their relative role in green patenting, and the relative quality of this green patenting.

**-- Insert Table 7 here --**

### *g. Patent Thickets and Patent Impact*

Even with evidence of a large production of highly cited patents by traditional energy firms, one could still worry 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 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. Hall et al. (2014) show 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. This is 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, we find somewhat more evidence of 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 their industry (as somewhat of an insulated idea echo-chamber). In contrast, traditional energy industry green patents could experience more widespread acceptance as important contributions outside of their industry in the broader green energy space. 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 acceptance as being important for built-upon innovation in the green energy 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 are broadly consequential, and impact innovative thought outside of their space.

**-- Insert Table 9 here --**

Next, we explore another characteristic of energy firms' green patents. Namely, while Figure 2 suggests that some of traditional energy firms' research is initiated within their firms, it could be that the majority 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 that has been documented thus far. Panel B of Table 9 thus explores precisely this – the percentage of energy firms' green patents that are developed in-house (organically) versus the percentage of green patents that are obtained through external acquisition. From Panel B, the overwhelming majority of energy sectors' green patents are produced organically, with over 97% produced in-house ($t$ = 6.27), and less than 3% 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.

### *h. 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 Tables 3 and 4 find that traditional energy firms allocate nearly 3 times their patenting intensity to green patenting versus other active green patentors (22.25% of their patents are green patents vs. 8.30% for other industries active in green patenting), it might still be the case that the other patents of these firms are so anti-green as to completely off-set this heightened activity, its relative quality markers, etc. While it is difficult to measure anti-green, we attempt to do so using a number of metrics. In particular, we create multiple measures of net green patenting.[13] 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.

Table 10 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.

**-- Insert Table 10 here --**

In Table 11, 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. Table 11 shows that, in contrast to this, energy firms are significantly over-represented amongst these top 100 firms. This is in contrast to other top sectors in the green sector space, which are significantly under-represented amongst these top 100. Appendix Tables A6 and A7 corroborate these analyses at both the patent level and include a full battery of firm- and industry-level controls.

**-- Insert Table 11 here --**

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

While the results thus far support that the energy industry is dedicating a significant percentage of its intellectual property patenting to green patenting and that these patents both have markers of higher quality and are widely cited outside of their industry – 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)).[14] 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 (2.52 times the average industry pre, and 2.83 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, as we lay out in the model in Section II, this is consistent with energy firms, from a profit-maximizing perspective – and even in the 1970s – wanting to be the world's *energy* providers in 50 to 100 years, whether that energy derives from oil, natural gas, water, wind, solar, or other sources. Therefore, they might find it optimal to invest in IP surrounding many forms of these future types of energy to ensure that is the case.

### *i. Green Products and Green Investment Plans*

In this final 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 patents - defensive legal contracts 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 product.

[14] 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)).

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 first column of Table 12 indicates that companies with more green patents produce significantly more kilowatts of alternative energy than other firms. A one standard deviation increase in the green patent ratio corresponds to 154.6 GWh, which is a sizable amount compared to the average green energy production (200.86 GWh) ($t$ = 7.86). In the second column, we restrict the sample to the energy sector only. The idea of this analysis is to find out whether, within the energy industry, firms that dedicate more resources to green energy innovation activities have higher production of alternative energy. In this within-industry test, we continue to find the same result: firms with more green energy patenting intensity produce more kilowatts of alternative energy than those of green-energy firms. Within the energy industry, a one standard deviation increase in the green patent ratio corresponds to 1044 GWh, which is a sizable amount compared to the average green energy production (1904 GWh) ($t$ = 5.70). Both the sizable absolute differences (nearly 10x the GWh), along with the alternative energy produced coupled with green patenting intensity, are evidence consistent with fossil fuel companies not solely being active in producing green patenting, but also pairing their green patenting activity with alternative energy production.

**-- Insert Table 12 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, and (b) plan to dedicate larger amounts of their capital expenditures to green products and services. The results in the first two columns of Table 13 indicate that companies with higher green patent ratios also are significantly more likely to produce low carbon products. In the first column, on average, 6.2% of the respondents say they have low carbon products, whereas one standard deviation increase in the green patent ratio corresponds to a 1.95% higher chance of reporting low carbon product production ($t$ = 5.85). When we restrict the sample to traditional energy sector firms, we find somewhat larger magnitudes: on average, 11% of the respondents say they have low carbon products, and a one standard deviation increase in green patent ratio corresponds to a 5.2% higher chance of reporting low carbon products ($t$ = 3.76). The last two columns of Table 13 then show an analogous relationship between green patenting intensity and capital expenditure dedicated specifically to green products and services. Among traditional energy firms, for instance (Column 4), a company that has a one standard deviation higher green patent ratio has a 6.5% chance of low carbon emissions-related capital expenditures ($t$ = 3.09), which is significantly higher than the average rate of 3.7%.

**-- Insert Table 13 here --**

## VI. Conclusion

We conduct the first large-scale study documenting the landscape of green innovation – its most active patentors, their patent quality, accompanying investment, 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. Paradoxically, 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 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.

The findings in this paper also speak to the welfare implications of fund flows that are not matching up to the real green patenting activity of firms. Our results imply substantial benefits associated with energy firms' green patent production, having been present for decades (pre-dating increased focus upon, and even the term itself, "ESG."). 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. They generate nearly all (97%) of their green patents "organically" (in-house), with traditional energy firms even over-represented amongst the top net green patenting firms in the economy.

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, these incumbents might then be observed to be first movers in many of these innovation categories (as we saw with energy firms, such as Exxon's foundational patenting in solar cell technology in the 1970s).

Stepping back, our findings raise important questions as to whether the current exclusions of many ESG-focused policies – along with the increasing incidence of explicit divestiture campaigns - are optimal, or whether reward-based incentives would lead to more efficient innovative outcomes.

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

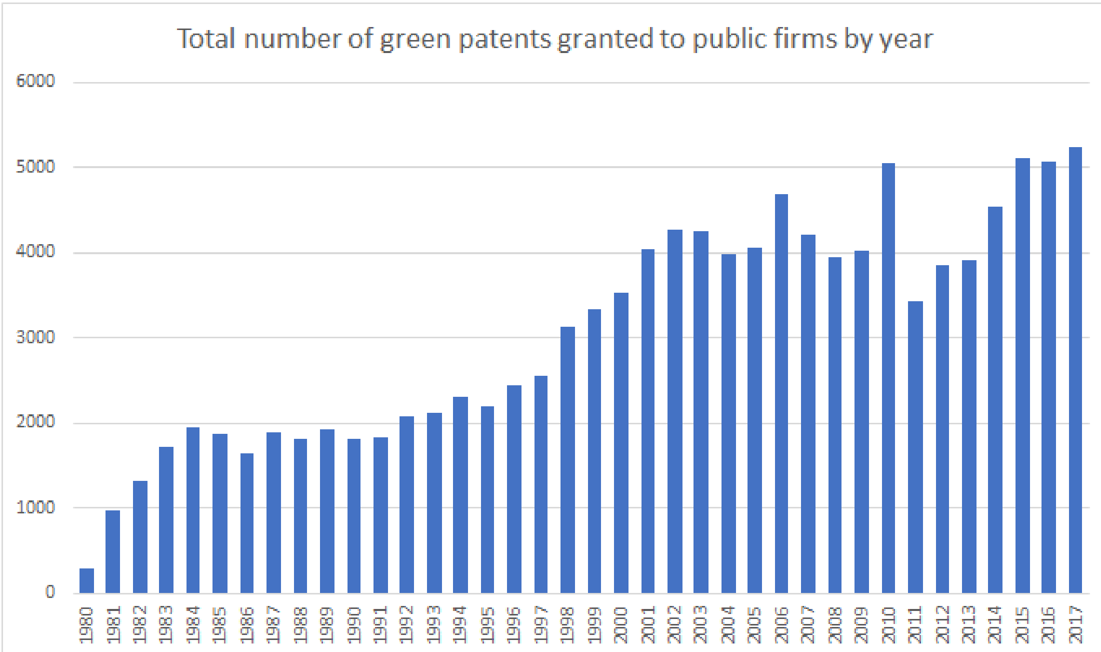
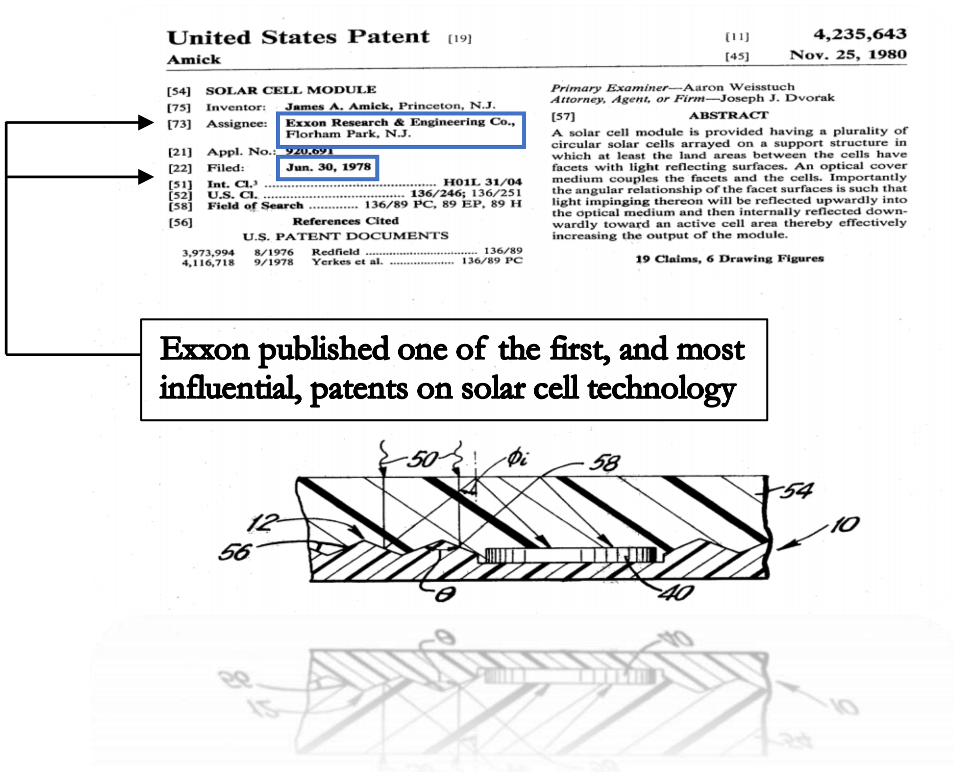


**Figure 2. Example of Early Green Patenting at Exxon - Solar Technology & Photovoltaics: 1973 and 1978**

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


United States Patent [19]
Amick

[11] 4,235,643
[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



Panel 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*

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

Panel A shows the number of green patents held by industry sectors in 2017. Panel B shows the list of top 50 public companies by green patent holders in 2017. 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.[15]

*Panel* A. Industry Breakdown

| Industry Sectors | Total Green Patents |
|---|---:|
| Manufacturing | 83,828 |
| Energy and Mining | 8,838 |
| Services | 4551 |
| Finance, Insurance, & Real Estate | 1519 |
| Transportation & Public Utilities | 1236 |
| Wholesale Trade | 1012 |
| Agriculture, Forestry, & Fishing | 674 |
| Construction | 463 |
| Retail Trade | 217 |

[15] 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. Top 50 Public Firms Producing Green Patents

| Company Name | Total green patents | Rank |
|---|---|---|
| GENERAL ELECTRIC CO | 7,520 | 1 |
| HONDA MOTOR CO LTD | 4,685 | 2 |
| PANASONIC CORP | 4,576 | 3 |
| HITACHI LTD | 3,921 | 4 |
| FORD MOTOR CO | 2,633 | 5 |
| DUPONT DE NEMOURS INC | 2,617 | 6 |
| UNITED TECHNOLOGIES CORP | 2,302 | 7 |
| GENERAL MOTORS CO | 2,118 | 8 |
| NISSAN MOTOR CO LTD | 2,084 | 9 |
| CATERPILLAR INC | 1,712 | 10 |
| **EXXON MOBIL CORP** | **1,670** | **11** |
| SONY CORP | 1,640 | 12 |
| **HONEYWELL INTERNATIONAL INC** | **1,631** | **13** |
| SIEMENS AG | 1,486 | 14 |
| INTL BUSINESS MACHINES CORP | 1,469 | 15 |
| SANYO ELECTRIC CO LTD | 1,315 | 16 |
| VIACOMCBS INC | 1,240 | 17 |
| **ROYAL DUTCH SHELL PLC** | **1,199** | **18** |
| DAIMLER AG | 1,038 | 19 |
| PARKER-HANNIFIN CORP | 990 | 20 |
| CANON INC | 974 | 21 |
| KONINKLIJKE PHILIPS NV | 903 | 22 |
| AIR PRODUCTS & CHEMICALS INC | 863 | 23 |
| CUMMINS INC | 804 | 24 |
| BOEING CO | 743 | 25 |
| MOTOROLA SOLUTIONS INC | 712 | 26 |
| **BP PLC** | **631** | **27** |
| **CONOCOPHILLIPS** | **629** | **28** |
| IONIS PHARMACEUTICALS INC | 621 | 29 |
| **CHEVRON CORP** | **614** | **30** |
| BASF SE | 604 | 31 |
| **US OIL CO** | **595** | **32** |
| DELPHI TECHNOLOGIES PLC | 585 | 33 |
| NEC CORP | 549 | 34 |
| APPLIED INDUSTRIAL TECH INC | 548 | 35 |
| PFIZER INC | 546 | 36 |
| APTIV PLC | 542 | 37 |
| BAYER AG | 527 | 38 |
| FUJIFILM HLDGS CORP | 418 | 39 |
| INTEL CORP | 417 | 40 |
| CHRYSLER CORP | 401 | 41 |
| MICRON TECHNOLOGY INC | 398 | 42 |
| LOCKHEED MARTIN CORP | 395 | 43 |
| LINDE PLC | 392 | 44 |
| EASTMAN KODAK CO | 364 | 45 |
| APPLIED MATERIALS INC | 359 | 46 |
| ROCKWELL AUTOMATION | 355 | 47 |
| LG DISPLAY CO LTD | 346 | 48 |
| DEERE & CO | 337 | 49 |
| VERIZON COMMUNICATIONS INC | 336 | 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 Patents | Non-Green Patents | Total Granted Patents |
|---|---|---|---|
| 1980 | 288 | 4,496 | 4,784 |
| 1981 | 975 | tb13,257 | 14,232 |
| 1982 | 1,323 | 17,033 | 18,356 |
| 1983 | 1,724 | 21,613 | 23,337 |
| 1984 | 1,958 | 25,940 | 27,898 |
| 1985 | 1,878 | 27,532 | 29,410 |
| 1986 | 1,646 | 27,036 | 28,682 |
| 1987 | 1,900 | 30,747 | 32,647 |
| 1988 | 1,813 | 28,129 | 29,942 |
| 1989 | 1,936 | 33,071 | 35,007 |
| 1990 | 1,809 | 30,084 | 31,893 |
| 1991 | 1,837 | 32,364 | 34,201 |
| 1992 | 2,085 | 33,210 | 35,295 |
| 1993 | 2,130 | 34,156 | 36,286 |
| 1994 | 2,306 | 35,637 | 37,943 |
| 1995 | 2,204 | 35,205 | 37,409 |
| 1996 | 2,448 | 37,850 | 40,298 |
| 1997 | 2,565 | 38,293 | 40,858 |
| 1998 | 3,133 | 53,121 | 56,254 |
| 1999 | 3,338 | 58,124 | 61,462 |
| 2000 | 3,523 | 62,289 | 65,812 |
| 2001 | 4,041 | 66,924 | 70,965 |
| 2002 | 4,269 | 67,920 | 72,189 |
| 2003 | 4,261 | 70,240 | 74,501 |
| 2004 | 3,983 | 69,268 | 73,251 |
| 2005 | 4,067 | 66,453 | 70,520 |
| 2006 | 4,701 | 80,709 | 85,410 |
| 2007 | 4,224 | 72,295 | 76,519 |
| 2008 | 3,942 | 72,418 | 76,360 |
| 2009 | 4,024 | 76,956 | 80,980 |
| 2010 | 5,050 | 93,215 | 98,265 |
| 2011 | 3,446 | 67,938 | 71,384 |
| 2012 | 3,847 | 74,659 | 78,506 |
| 2013 | 3,907 | 79,469 | 83,376 |
| 2014 | 4,536 | 84,938 | 89,474 |
| 2015 | 5,119 | 81,165 | 86,284 |
| 2016 | 5,066 | 79,751 | 84,817 |
| 2017 | 5,251 | 77,774 | 83,025 |
| | 116,553 | 1,961,279 | 2,077,832 |

**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 two-digit SIC code, in that particular year. Energy Sector is a dummy variable 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). 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. Unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1) | (2) | (3) |
|---|---|---|---|
| | Industry Green Patent Ratio | | |
| Energy Sector | 0.1337*** | 0.1349*** | 0.1395*** |
| | (14.39) | (14.22) | (15.28) |
| Average Industry Investment | | -0.0013 | -0.0164 |
| | | (-0.08) | (-1.15) |
| Average Industry R&D Investment | | 0.0126 | 0.0186 |
| | | (0.51) | (0.75) |
| Average Industry Log Firm Age | | -0.0164 | -0.0153 |
| | | (-1.63) | (-1.45) |
| Average Industry Log MVE | | 0.0021 | 0.0019 |
| | | (0.84) | (0.77) |
| Average Industry Cash | | | 0.0001 |
| | | | (0.27) |
| Average Industry Book Leverage | | | 0.0021** |
| | | | (2.36) |
| Observations | 2,143 | 2,105 | 2,059 |
| R-squared | 0.094 | 0.097 | 0.102 |
| Year FE | YES | YES | YES |

**Table 4. Green Patent Production, Environmental Score, and Energy Sector – 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 the granted patent is a green patent, as defined in the description of Table 1. The independent variable is the Environmental Score (out of 100) which shows how well companies proactively manage the environmental issues that are the most material to their business. 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 2008 to 2017. 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)<br>Green Patent | (2)<br>Green Patent | (3)<br>Green Patent |
|---|---|---|---|
| *Environmental Score* | -0.0011*** | | |
| | (-3.70) | | |
| *Energy Sector* | | 0.1364*** | |
| | | (5.50) | |
| *Top 3 Sectors (outside of Energy)* | | | -0.1620*** |
| | | | (-13.76) |
| Observations | 217,083 | 199,557 | 199,557 |
| R-squared | 0.006 | 0.007 | 0.053 |
| Year FE | YES | YES | YES |

**Table 5. Environmental Score and Green Effort – Firm-level Analysis**

This table reports the results of OLS regressions where the dependent variable is the Environmental Score (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) 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 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 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

*Panel A*. Environmental Score and Energy Sector

| | (1) | (2) | (3) |
|---|---|---|---|
| | | Environment Score | |
| Energy Sector | -3.1051* | -2.9417 | -3.9103** |
| | (-1.68) | (-1.63) | (-2.13) |
| Number of Green Patents Granted | 1.0720** | | |
| | (2.03) | | |
| Energy Sector x Number of Green Patents Granted | -3.0077* | | |
| | (-1.93) | | |
| Number of Green Patents Appl. | | 1.7659*** | |
| | | (3.04) | |
| Energy Sector x Number of Green Patents Appl. | | -3.3171* | |
| | | (-1.77) | |
| Number of Cite per Green Patent | | | 0.7814*** |
| | | | (2.71) |
| Energy Sector x Number of Cite per Green Patent | | | -0.6674 |
| | | | (-1.24) |
| Log MVE | 1.9351*** | 1.8274*** | 1.9102*** |
| | (4.86) | (4.67) | (4.94) |
| Log Age | 2.6707*** | 2.7095*** | 2.6964*** |
| | (3.75) | (3.84) | (3.77) |
| Cash | -0.7874 | -0.7494 | -0.7431 |
| | (-0.53) | (-0.51) | (-0.50) |
| Book Leverage | -1.8511 | -1.7258 | -1.7458 |
| | (-0.76) | (-0.73) | (-0.73) |
| Investment | -4.2532 | -4.9355 | -4.5034 |
| | (-0.30) | (-0.35) | (-0.32) |
| Observations | 2,332 | 2,332 | 2,332 |
| R-squared | 0.172 | 0.179 | 0.173 |
| Year FE | YES | YES | YES |

*Panel B.* Environmental Score and Top 3 Sectors *(outside of Energy)*

| | (1) | (2) | (3) |
|---|---|---|---|
| | | Environment Score | |
| Top 3 Sectors (outside of Energy) | 2.9442** | 2.7686* | 3.2243** |
| | (1.98) | (1.89) | (2.12) |
| Number of Green Patents Granted | -0.9585 | | |
| | (-1.17) | | |
| Top 3 Sectors (outside of Energy) x Number of Green Patents Granted | 2.3771** | | |
| | (2.51) | | |
| Number of Green Patents Appl. | | -0.3154 | |
| | | (-0.34) | |
| Top 3 Sectors (outside of Energy) x Number of Green Patents Appl. | | 2.3969** | |
| | | (2.24) | |
| Number of Cite per Green Patent | | | -0.1836 |
| | | | (-0.39) |
| Top 3 Sectors (outside of Energy) x Number of Cite per Green Patent | | | 0.9289* |
| | | | (1.69) |
| Log MVE | 2.0458*** | 1.9303*** | 2.0426*** |
| | (5.08) | (4.82) | (5.12) |
| Log Age | 2.6363*** | 2.7119*** | 2.6397*** |
| | (3.72) | (3.85) | (3.72) |
| Cash | -0.8538 | -0.7585 | -0.9080 |
| | (-0.58) | (-0.52) | (-0.62) |
| Book Leverage | -1.7496 | -1.5649 | -1.9131 |
| | (-0.72) | (-0.67) | (-0.79) |
| Investment | -11.4386 | -12.1102 | -10.5919 |
| | (-0.91) | (-0.96) | (-0.85) |
| Observations | 2,332 | 2,332 | 2,332 |
| R-squared | 0.182 | 0.186 | 0.179 |
| Year FE | YES | YES | YES |

**Table 6. Green Patent Citations and Energy Sector**

This table reports the results of OLS regressions where the dependent variable in Panel A is the log of green patent citations normalized by all patent citations by a firm, and the dependent variable in Panel B is an indicator variable that equals one if the percentage of green patent citation is the top 95 percentile. 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 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 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year. *Panel A*. Green Patent Citations and Energy Sector

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Energy Sector | 0.0915*** | 0.0881*** | 0.0914*** | | | |
| | (4.41) | (4.16) | (4.28) | | | |
| Top 3 Sectors (outside of Energy) | | | | -0.0318*** | -0.0306*** | -0.0345*** |
| | | | | (-3.07) | (-2.96) | (-3.21) |
| Investment | | 0.0551 | 0.0636 | | 0.0992** | 0.1087** |
| | | (1.25) | (1.39) | | (2.04) | (2.12) |
| R&D Investment | | 0.0007 | 0.0034 | | 0.0003 | 0.0054 |
| | | (0.29) | (0.44) | | (0.14) | (0.71) |
| Log Age | | | 0.0036 | | | 0.0047* |
| | | | (1.53) | | | (1.95) |
| Log MVE | | | -0.0031*** | | | -0.0029** |
| | | | (-2.77) | | | (-2.49) |
| Cash | | | -0.0007 | | | -0.0011 |
| | | | (-0.66) | | | (-0.96) |
| Book Leverage | | | 0.008 | | | 0.0078 |
| | | | (0.60) | | | (0.59) |
| Observations | 15,134 | 15,134 | 14,927 | 15,134 | 15,134 | 14,927 |
| R-squared | 0.01 | 0.01 | 0.012 | 0.004 | 0.005 | 0.007 |
| Year FE | YES | YES | YES | YES | YES | YES |

*Panel B.* Blockbuster Green Patents and Energy Sector

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Energy Sector | 0.1198*** | 0.1172*** | 0.1236*** | | | |
| | (4.87) | (4.68) | (4.90) | | | |
| Top 3 Sectors (outside of Energy) | | | | -0.0440*** | -0.0428*** | -0.0484*** |
| | | | | (-3.44) | (-3.37) | (-3.70) |
| Investment | | 0.0464 | 0.0593 | | 0.1027* | 0.1182* |
| | | (0.89) | (1.12) | | (1.78) | (1.95) |
| R&D Investment | | 0.0029 | 0.0082 | | 0.0011 | 0.0088 |
| | | (0.82) | (0.78) | | (0.324) | (0.81) |
| Log Age | | | 0.0017 | | | 0.0049 |
| | | | (0.58) | | | (1.50) |
| Log MVE | | | -0.0042*** | | | -0.0041*** |
| | | | (-3.66) | | | (-3.15) |
| Cash | | | -0.0016 | | | -0.0018 |
| | | | (-1.01) | | | (-1.10) |
| Book Leverage | | | 0.0046 | | | 0.006 |
| | | | (0.38) | | | (0.48) |
| Observations | 15,134 | 15,134 | 14,927 | 15,134 | 15,134 | 14,927 |
| R-squared | 0.013 | 0.014 | 0.016 | 0.005 | 0.006 | 0.008 |
| Year FE | YES | YES | YES | YES | YES | YES |

**Table 7. 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) 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 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)<br>%fund holding | (2)<br>I[%fund holding > 0] | (3)<br>I[%fund holding > %index] | (4)<br>%fund holding | (5)<br>I[%fund holding > 0] | (6)<br>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 |

**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) 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 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 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1)<br>Thickets | (2)<br>Thickets | (3)<br>Thickets | (4)<br>Thickets |
|---|---|---|---|---|
| Energy Sector | -6.1893*** | -8.6256*** | | |
| | (-4.78) | (-6.35) | | |
| Top 3 Sectors (outside of Energy) | | | 9.2757*** | 10.3371*** |
| | | | (12.14) | (12.51) |
| Log MVE | | 4.3777*** | | 4.2900*** |
| | | (21.99) | | (21.64) |
| Log Age | | 4.6204*** | | 4.7610*** |
| | | (9.70) | | (10.02) |
| Cash | | -0.0090 | | 0.0029 |
| | | (-0.26) | | (0.08) |
| Book Leverage | | -0.0007 | | 0.0028 |
| | | (-0.05) | | (0.21) |
| Investment | | 0.4889 | | -0.0090 |
| | | (0.43) | | (-0.01) |
| Constant | 7.5454*** | -22.0879*** | 1.4155** | -29.2565*** |
| | (19.18) | (-16.76) | (2.40) | (-20.58) |
| Observations | 22,452 | 20,653 | 22,452 | 20,653 |
| R-squared | 0.021 | 0.052 | 0.026 | 0.057 |

**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) 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 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 2017. 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%<br>(6.27) | 74.30%<br>(18.16) | 48.60%<br>(5.95) |
| | Cited by | | |
| | % Citating within own Sector | % Citation outside Own Sectors | Difference Outside |
| Top 3 Sectors<br>(Outside of Energy) | 28.90%<br>(88.62) | 71.10%<br>(218.05) | 42.20%<br>(64.72) |
| | (Outside – Within Citations) Diff-in-Diff | | 6.46%<br>(2.69) |

*Panel* B: Organically Developed vs Acquired Green Patents

| | % In House Developed (Organically) | % Acquired (External) | Difference Energy Sector |
|---|---|---|---|
| Energy Sector | 97.70%<br>(6.27) | 2.29%<br>(18.16) | 92.70%<br>(5.95) |
| | % In House Developed (Organically) | % Acquired (External) | Difference Outside |
| Top 3 Sectors<br>(Outside of Energy) | 96.30%<br>(88.62) | 3.70%<br>(218.05) | 95.40%<br>(64.72) |
| | (In House Developed – Acquired Patent %) Diff-in-Diff | | 2.70%<br>(1.12) |

**Table 10. 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), 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) 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 2017. 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 | 0.1429*** | | 0.1508*** | | 0.1580*** | |
| | (21.41) | | (22.22) | | (21.97) | |
| Top 3 Sectors (outside of Energy) | | -0.0581*** | | -0.0649*** | | -0.0719*** |
| | | (-14.90) | | (-14.77) | | (-17.24) |
| Constant | 0.0620*** | 0.1191*** | 0.0712*** | 0.1347*** | 0.0871*** | 0.1574*** |
| | (183.94) | (35.57) | (205.25) | (35.64) | (227.20) | (43.84) |
| Observations | 54,333 | 54,333 | 49,941 | 49,941 | 43,542 | 43,542 |
| R-squared | 0.029 | 0.014 | 0.031 | 0.018 | 0.030 | 0.017 |
| Year FE | YES | YES | YES | YES | YES | YES |

**Table 11. 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 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 has 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 2017. 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 |
| 0.1100*** | -0.1217*** | 0.1055*** | -0.1178*** | 0.1000*** | -0.1096*** |
| (16.624) | (-13.82) | (19.28) | (-14.86) | (17.66) | (-16.09) |

**Table 12. 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 GWh) 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) 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). The sample covers 2011 to 2019. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1) | (2) |
|---|---|---|
| | Green Energy Production | |
| | All | Energy Sector |
| Green Patent Ratio | 3,865.8761*** | 21,753.4081*** |
| | (7.86) | (5.70) |
| Log MVE | 118.8837*** | 861.7856*** |
| | (12.65) | (9.82) |
| Log Age | 154.0308*** | 1,070.1678*** |
| | (7.22) | (5.53) |
| Cash | 0.6297 | 106.9618 |
| | (0.22) | (0.24) |
| Book Leverage | -0.7243 | 310.1543 |
| | (-0.22) | (1.52) |
| Investment | 3.0673 | -1,457.0785 |
| | (0.22) | (-1.55) |
| Observations | 40,444 | 4,225 |
| R-squared | 0.009 | 0.057 |
| Year FE | YES | YES |

**Table 13. 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. Has Low Carbon Products is a dummy variable that equals to 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." Has CAPEX in Green Products and Services is a dummy variable that equals one 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) 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). The sample covers 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1) | (2) | (5) | (6) |
|---|---|---|---|---|
| | Has Low Carbon Products | | Has CAPEX in Green Products and Services | |
| | All | Energy Sector | All | Energy Sector |
| Green Patent Ratio | 0.4431*** | 0.6905*** | 0.1352*** | 0.3692*** |
| | (5.85) | (3.76) | (6.73) | (3.09) |
| Log MVE | 0.0360*** | 0.0453*** | 0.0019*** | 0.0151*** |
| | (23.47) | (7.19) | (4.72) | (3.68) |
| Log Age | 0.0197*** | 0.0240 | 0.0016 | 0.0085 |
| | (5.24) | (1.59) | (1.56) | (0.87) |
| Cash | 0.0005 | -0.0437 | -0.0000 | -0.0404 |
| | (0.28) | (-0.52) | (-0.09) | (-0.73) |
| Book Leverage | -0.0037 | 0.0074 | 0.0005 | 0.0030 |
| | (-0.54) | (0.14) | (0.29) | (0.09) |
| Investment | 0.0160 | -0.1199 | 0.0070 | -0.0598 |
| | (0.40) | (-1.25) | (0.67) | (-0.96) |
| Constant | -0.2277*** | -0.2640*** | -0.0141*** | -0.0853** |
| | (-18.25) | (-4.55) | (-4.25) | (-2.26) |
| Observations | 4,465 | 429 | 4,465 | 429 |
| R-squared | 0.147 | 0.203 | 0.018 | 0.084 |

**Internet Appendix**
**to**
**"The ESG-Innovation Disconnect: Evidence from Green Patenting"**
**LAUREN COHEN, UMIT G. GURUN, and QUOC NGUYEN**

**Table A1. 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) 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). We identify green patents using OECD's IPC classification, i.e., green patents climate change mitigation technologies related to energy generation, transmission, or distribution. Unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1) | (2) | (3) |
|---|---|---|---|
| | Industry Green Patent Ratio | | |
| Energy Sector | 0.0227*** | 0.0214*** | 0.0221*** |
| | (5.30) | (4.95) | (5.02) |
| Average Industry Investment | | -0.0001*** | 0.0009 |
| | | (-16.29) | (1.64) |
| Average Industry R&D Investment | | -0.0080* | -0.0083* |
| | | (-1.82) | (-1.84) |
| Average Industry Log Firm Age | | 0.0014 | 0.0014 |
| | | (0.37) | (0.38) |
| Average Industry Log MVE | | 0.0019* | 0.0018* |
| | | (1.92) | (1.87) |
| Average Industry Cash | | | 0.0002 |
| | | | (1.54) |
| Average Industry Book Leverage | | | -0.0002* |
| | | | (-1.78) |
| Observations | 2,143 | 2,105 | 2,059 |
| R-squared | 0.038 | 0.041 | 0.041 |
| Year FE | YES | YES | YES |

**Table A2. Greenhouse Gas Emissions and Green Patenting Activity.**

This table reports the results of OLS regressions where the dependent variable is a dummy variable that takes a value of one if the granted patent is a green patent, 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) 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 2008 to 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by firm. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by firm.

| | (1) | (2) | (3) |
|---|---|---|---|
| | Green Patent | Green Patent | Green Patent |
| Emissions | 0.1345*** | 0.1402*** | 0.0510*** |
| | (7.29) | (5.82) | (1.91) |
| Energy Sector | | 0.1560*** | |
| | | (2.29) | |
| Energy Sector x Emissions | | -0.0989*** | |
| | | (-3.14) | |
| Top 3 Sectors (outside of Energy) | | | -0.1259*** |
| | | | (-2.85) |
| Top 3 Sectors (outside of Energy) x Emissions | | | 0.0862*** |
| | | | (2.48) |
| Constant | 0.0244*** | 0.0222*** | 0.1418*** |
| | (26.08) | (25.04) | (6.41) |
| Observations | 206,446 | 192,629 | 192,629 |
| R-squared | 0.031 | 0.035 | 0.048 |
| Year FE | YES | YES | YES |

**Table A3. Organically Produced Green Patent Production and Energy Sector – Industry Level Analysis**

This table reports the results of OLS regressions where the dependent variable is the Industry Organically Produced Green Patent Ratio, which is the percentage of organically produced green patents 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) 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). 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. Unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1) | (2) | (3) |
|---|---|---|---|
| | | Industry Green Patent Ratio | |
| Energy Sector | 0.1505*** | 0.1510*** | 0.1548*** |
| | (11.86) | (11.30) | (11.68) |
| Average Industry Investment | | 0.0001*** | 0.0032 |
| | | (4.17) | (1.23) |
| Average Industry R&D Investment | | -0.0064 | -0.0070 |
| | | (-0.43) | (-0.46) |
| Average Industry Log Firm Age | | 0.0262** | 0.0265** |
| | | (2.58) | (2.56) |
| Average Industry Log MVE | | -0.0039 | -0.0041 |
| | | (-1.36) | (-1.41) |
| Average Industry Cash | | | 0.0005 |
| | | | (0.95) |
| Average Industry Book Leverage | | | -0.0007 |
| | | | (-1.17) |
| Observations | 2,143 | 2,105 | 2,059 |
| R-squared | 0.117 | 0.120 | 0.123 |
| Year FE | YES | YES | YES |

**Table A4. 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 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 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 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | (1)<br>Green Patent | (2)<br>Green Patent | (3)<br>Green Patent | (4)<br>Green Patent |
|---|---|---|---|---|
| Energy Sector | 0.1599*** | 0.1591*** | 0.1466*** | 0.1354*** |
| | (4.36) | (4.46) | (12.02) | (4.84) |
| Energy Sector x Log Age | -0.0033 | | | |
| | (-0.26) | | | |
| Energy Sector x Log MVE | | -0.0011 | | |
| | | (-0.26) | | |
| Energy Sector x Cash | | | 0.0388*** | |
| | | | (3.16) | |
| Energy Sector x Emissions | | | | -0.0000** |
| | | | | (-2.40) |
| Emissions | | | | 0.0001*** |
| | | | | (5.30) |
| Log Age | 0.0021 | 0.0020 | 0.0021 | -0.0001 |
| | (1.14) | (1.05) | (1.11) | (-0.02) |
| Log MVE | -0.0022*** | -0.0021*** | -0.0021*** | -0.0120*** |
| | (-2.69) | (-2.62) | (-2.65) | (-3.08) |
| Investment | 0.0046 | 0.0046 | 0.0048 | 0.1045 |
| | (0.83) | (0.83) | (0.89) | (1.19) |
| R&D Investment | 0.0062 | 0.0062 | 0.0066 | -0.0241 |
| | (1.14) | (1.13) | (1.23) | (-0.55) |
| Cash | -0.0008 | -0.0008 | -0.0010 | 0.0153 |
| | (-0.84) | (-0.85) | (-1.09) | (0.93) |
| Book Leverage | 0.0048 | 0.0048 | 0.0043 | -0.0146 |
| | (1.51) | (1.50) | (1.36) | (-1.18) |
| Observations | 51,353 | 51,353 | 51,353 | 8,220 |
| R-squared | 0.031 | 0.031 | 0.032 | 0.090 |
| Year FE | YES | YES | YES | YES |

**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 2005 and on/after 2005. Energy Sector is a dummy variable 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). 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. Unit of observation is industry (2-digit SIC code) and year. The sample covers 1980 to 2017. Reported t-statistics in parentheses are heteroscedasticity-robust and clustered by year.

| | Before 2005<br>Industry Patent Ratio | | | After 2005<br>Industry Patent Ratio | | |
|---|---|---|---|---|---|---|
| Energy Industry | 0.1222***<br>(10.51) | 0.1227***<br>(9.21) | 0.1273***<br>(9.63) | 0.2036***<br>(7.74) | 0.2125***<br>(7.87) | 0.2124***<br>(7.86) |
| Average Industry Investment | | -0.0036**<br>(-2.21) | -0.0010<br>(-1.18) | | 0.0000<br>(1.32) | 0.0063*<br>(1.87) |
| Average Industry R&D Investment | | -0.0168<br>(-0.90) | -0.0148<br>(-0.81) | | 0.0275<br>(0.93) | 0.0236<br>(0.75) |
| Average Industry Log Age | | 0.0293**<br>(2.14) | 0.0289*<br>(2.06) | | 0.0442**<br>(2.35) | 0.0453**<br>(2.42) |
| Average Industry Log MVE | | -0.0069**<br>(-2.23) | -0.0072**<br>(-2.28) | | -0.0040<br>(-0.677) | -0.0041<br>(-0.69) |
| Average Industry Cash | | | -0.0007<br>(-1.12) | | | 0.0011<br>(1.69) |
| Average Industry Book Leverage | | | -0.0006***<br>(-4.87) | | | -0.0014*<br>(-1.84) |
| Observations | 1,547 | 1,494 | 1,450 | 779 | 765 | 765 |
| R-squared | 0.093 | 0.096 | 0.099 | 0.139 | 0.145 | 0.146 |
| Year FE | YES | YES | YES | YES | YES | YES |

**Table A6. 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) 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 2017. 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 | 0.0990*** | | 0.0755*** | | 0.0557*** | |
| | (6.52) | | (4.96) | | (4.57) | |
| Top 3 Sectors (outside of Energy) | | -0.0730*** | | -0.0580*** | | -0.0480*** |
| | | (-5.47) | | (-4.59) | | (-4.91) |
| Constant | 0.6427*** | 0.7123*** | 0.6890*** | 0.7438*** | 0.7402*** | 0.7845*** |
| | (277.30) | (71.51) | (296.46) | (78.98) | (398.06) | (107.60) |
| Observations | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 |
| R-squared | 0.178 | 0.175 | 0.090 | 0.089 | 0.107 | 0.107 |
| Year FE | YES | YES | YES | YES | YES | YES |

**Table A7. 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 2017. 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 | 0.0772*** | | 0.0785*** | | 0.0842*** | |
| | (16.06) | | (12.90) | | (10.28) | |
| Top 3 Sectors (outside of Energy) | | -0.0740*** | | -0.0782*** | | -0.0922*** |
| | | (-13.78) | | (-13.00) | | (-12.99) |
| Constant | 0.0570*** | 0.1261*** | 0.0625*** | 0.1354*** | 0.0816*** | 0.1670*** |
| | (396.75) | (25.90) | (359.08) | (24.90) | (319.24) | (26.20) |
| Observations | 1,559,987 | 1,559,987 | 1,402,834 | 1,402,834 | 1,050,842 | 1,050,842 |
| R-squared | 0.004 | 0.009 | 0.008 | 0.013 | 0.009 | 0.016 |
| Year FE | YES | YES | YES | YES | YES | YES |