The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0307-4358.htm

Green innovation and environmental misconduct

Blake Rayfield
W.A.Franke College of Business, Northern Arizona University, Flagstaff, Arizona, USA, and
Omer Unsal
Department of Finance, Girard School of Business and International Commerce, Merrimack College, North Andover, Massachusetts, USA

Received 28 September 2021
Revised 1 December 2021
24 February 2022
Accepted 26 February 2022

Abstract

Purpose – The aim of this study is to discuss the idea that the legal cost of environmental violations, along with reputational concerns, may persuade firms to generate more green patents.

Design/methodology/approach – This study examines the relationship between firms generating green patents and environmental violations. The authors show the green innovation trend over the past two decades and explore the potential motivations behind it. In addition, the authors investigate the impact of regulatory actions, such as governmental finds, on green innovation.

Findings – The authors find that firms that commit environmental violations switch to producing green patents in the long-run. The authors also document that market reaction following environmental offenses is negative for firms with a high ratio of green patents in their portfolio.

Originality/value – This study explores innovation. The authors investigate the literature and trends of green innovation over the past 20 years. The authors also find that green innovation is growing at a relatively slow rate. Overall, this study highlights the importance of green innovation and firms' response to corporate wrongdoing.

Keywords Innovation, Legal matters, Environment

Paper type Research paper

1. Introduction

The next generation will be defined by green innovation. Many countries, governments (both local and national) and companies are making the push to be seen as "greener" by investors and customers alike. This trend has extended not only to the day-to-day business of firms, but also to their patentable innovations. The change in preferences has sparked interest in the motivations behind green innovation. In this study, we investigate green innovation in the United States by corporations. We show the green innovation trend over the past two decades and explore potential motivations behind it. In addition, we investigate the impact of regulatory actions, such as governmental finds, on green innovation.

For many firms, green innovation is one way to satisfy a customer base that increasingly demands green products. Recently, there has been additional ways for corporations to label themselves as green. For example, the firm can and has announced operational improvements geared towards reducing carbon emissions Zhu *et al.* (2012). Firms have announced reducing carbon emissions in their supply chain and delivery methods. Some firms have even pledged to be net-zero carbon, a term meaning they will offset any carbon emissions with carbon capture or a similar manner in the future.

Similar improvements and announcements can be made for project-specific financing in the form of green bonds. A green bond is a specific type of bond covenant that promises investors that monies raised from the issuance of a green bond will go to a project that meets specific environmental goals. A non-governmental entity or self-labeled can label green

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare no conflicts of interest.

Managerial Finance

0307-4358
DOI 10.1108/MF-09-2021-0458

bonds. In addition, green bonds must provide a level of transparency regarding the use of funds generated by the issuance. Much research has been done surrounding green bonds regarding premiums. Hong *et al.* (2020) provide a complete review of issues regarding climate finance.

This study explores innovation. We investigate the literature and trends of green innovation over the past 20 years. We find that green innovation is growing at a relatively slow rate. In an investigation of potential barriers to green innovation, we investigate environmental violations' impact on green innovation. We find that the market reacts in predictable ways, small firms have a large and significant negative market reaction, and we fail to find a market reaction in large firms. Furthermore, firms with many green patents relative to total patents also experience a significant adverse market reaction.

In the following sections, we review the literature surrounding green innovation and consider its ethical implications for future generations. In section 2, we discuss the methodology used in this study as well as data collection efforts. In section 4, we present the results of this study, and in section 5, we show the results.

2. Literature review and ethical debate

The ethical motivation for firms to peruse more green innovation is debated widely. The business roundtable is one organization that has identified environmental, social, and governance as valuable for companies to consider [1]. Environmental risk can span from several locations, and two sources are social pressure and climate risk. In the past, most of the discussion surrounded social pressure on a firm for adopting green innovation. By producing green innovation, firms can better relate to a group of customers that emphases the environment and gain a comparative advantage over their competitors Cheng (2011). Markets are growing increasingly hostile towards firms that produce non-green innovation or actively produce excess greenhouse gases. Firms can experience pressure to produce a more equitable environment from several stakeholders, including state and local governments, consumers, employees (Rayfield and Unsal, 2021) and institutional investors (Cheng *et al.*, 2020).

In addition to social pressure, firms can experience climate-related pressures as well. Changing climate has affected the way chief executive officer (CEO) and corporations think. Choi *et al.* (2020) show how local changes to climate can influence how CEOs perceive climate risk. In addition, Alok *et al.* (2020) show that the local climate events also impact professional money managers. Sometimes, the risk goes beyond perception, a large set of literature studies, Maio and Popp (2014) and Elnahas *et al.* (2018), show that firms change in response to abnormal climate events.

The literature discusses several motivations for green innovation. Innovation itself is necessary for a firm, and motivations for green innovation can be broad. Motivation can come from internal stakeholders as well as external stakeholders. Flammer and Kacperczyk (2016) show how stakeholder orientation can lead to more and better-cited innovation. The authors use variation in state-level labor laws to show how changing orientation can affect innovation. Miao and Popp (2014) discuss how environmental disasters can motivate a firm to generate more green innovation. The authors find that natural disasters such as floods, earthquakes, among others, cause firms to innovate for risk mitigation.

Motivations for a firm to respond to climate action do not have to come from natural disasters. Cadez *et al.* (2019) discuss the ability of shareholders to motivate managers for green innovation. Corporate governance has also been connected to green innovation; for example, Amore and Bennedsen (2016) find that firms with poor corporate governance practices have worse green innovation outcomes.

In summary, firms tend to be motivated by outside pressures, from natural disasters, shareholders, other uncontrollable events, or inward pressures, employees, managers, or even their own ethics. In the following sections, we discuss how another external factor, environmental violations, can motivate and cause green innovation. We find that environmental violations cause an outside impact on a firm's market value when most of the firm has green patents. Therefore, we discuss green violations as a motivating factor for green innovation.

3. Methodology and data

3.1 Green patents

In this study, we collected data from several sources. To investigate the role of green patents in the marketplace, we collected data on green patents. For data on green patents, we collect data from the USTPO. We carefully match patent data to firms in Compustat and consult prior patent databases such as Kogan *et al.* (2017). Each patent can have multiple assignees meaning that multiple parties can own patents. After ensuring the patent match is complete and substantial, we classify patents as green.

The World International Patent Organization (WIPO) has created a green patent classification scheme based on the International Patent Classification (IPC) system. The classification system was developed by the IPC committee of experts and classified specific patent categories as "green." IPC patent classification is not available in the Kogan *et al.* (2017) dataset, so we collect the information directly from the USTPO.

The IPC system has broad categories related to green innovation such as alternative energy production, transportation, energy conservation, agriculture, administrative/regulatory aspects and nuclear power generation. Each board categories have a subset of the classification, which has been classified as green; patents that do not have a classification that falls into one of the IPC categories are not classified as green. We match these classifications to the patents in our dataset to organize each patent as green or not. The remaining sample provides green patent counts for Compustat firms from 2000 to 2016. Figure 1 shows the percent of green patents in the sample over time.

The percentage of green patents remains relatively stable over time, from 10% in 2000, increasing to nearly 12% by 2015. Several policy changes and social changes may have led to increased green patent activity during our sample period. For example, on December 9th, 2009, the USTPO launched a pilot program to accelerate the review of green patents. This

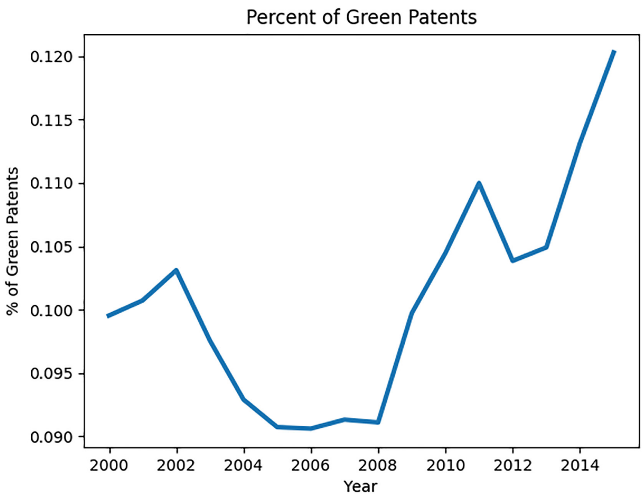

Figure 1.
Ratio of green patents to total patents

program was set to end after either 3,000 patents were granted or the end of 2011. There is not enough evidence from Figure 1 to say whether this program led to any substantial green innovation increase.

In panel D of Figure 1, we conduct logit analysis where the dependent variable is one if the firm has ever issued a green patent and zero otherwise. We find several variables to be significant, including the firm being subject to a violation. Firms subject to violations are more likely to issue a green patent. In addition to violations, larger firms (as measured by total assets), firms with higher return on assets (ROA), higher sales growth, more capital expenditure and older firms are also associated with green patent issuance.

However, Figure 2 shows that the count of green patents approved by the USTPO increased following 2009.

Figure 2 shows the total number of unique (one count per patent number, rather than assignee) green patents approved by the USTPO each year. Similar to Figure 1, there was variance in the number of green patents approved year over year, ranging from 7,000–9,500 patents per year. Over the sample period, the raw number of green patents increase over time. Inferring from Figure 1, this represents 10–12% of all patents approved each year from the USTPO. Figure 3 shows green patents relative to all USPTO patents.

While green patents make up a small portion of total patents (nearly 12% according to the results in Figure 1), we can see that their increase cannot be entirely attributed to a rise in all patents. However, the total number of green patents produced by firms has remained relatively stable.

Several firms in several different sectors produce green patents. Figure 4a shows the total number of green patents produced on a log scale. We can see from Figure 4a that many green patents are produced near coasts, with states such as California, Texas and New York leading the way in a green patent generation. However, as seen in Figure 4 many other states also contribute green patents.

More informative than simple patent counts would be the percentage of green patents produced on a state level. We also display the percent of green patents relative to total patents on a state level; this analysis is displayed in Figure 4b. Similar to Figure 4a, green patents make up a considerable portion of patents issued to California, Texas, Illinois and New York. Many inland states produce fewer green patents relative to their total patents.

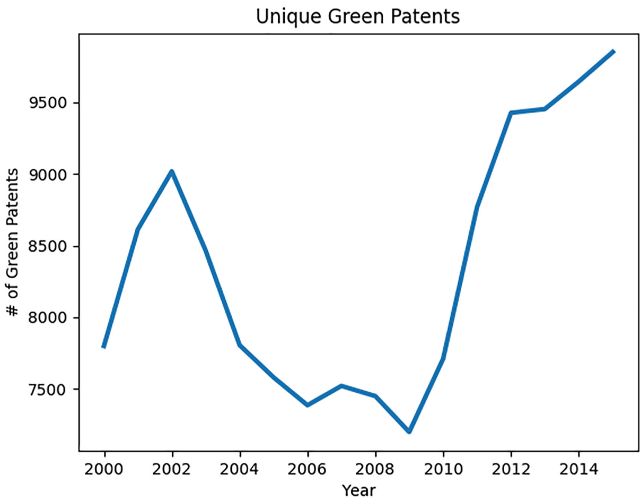

Figure 2.
Total number of green patents

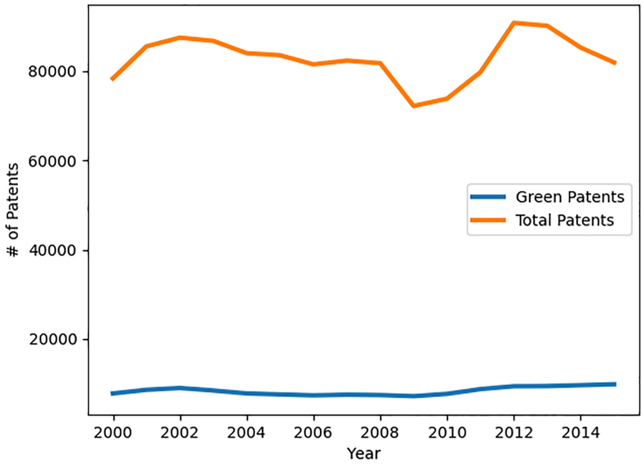

Figure 3.
Green patents relative to all patents

The data show that many firms can produce green patents; however, many are located in coastal states. The next section will describe additional data sources, including data on green patents and firm-level environmental fines.

3.2 Environmental violations

We collect environmental violations and other regulatory actions from the Good Jobs First database. Our violations include environmental wrongdoings, toxic release actions, energy conservation-related violations, maritime violations, nuclear safety, offshore drilling and zoning violations. A map of environmental violations by state is displayed in Figure 5.

3.3 Firm data

We use Compustat data to collect our publicly traded firms. We drop firms with less than \$5m in total assets and are not located in the USA. Our results for initial data are presented in Table 1.

In panel A, we find that the number of green patents to overall patents is 10% on average. We also find that 28% of our sample firms have at least one green patent in a given year. In addition, 80% of the firms have at least one green patent over the sample span for those who produced patents. In panel B, we show that 10% of the firms have environmental violations in a given year, while 40% have at least one violation during a sample span. In panel C, we document the control variables used in the study.

4. Empirical results

4.1 Univariate tests

Our results from panel B of Table 1 show the univariate tests in our sample. In panel B, we only work with the firms that have produced at least one green patent over the span. Among those firms, we divide the sample based on environmental violation status. We find that those firms produce substantially more patents and green patents compared to non-violator firms. The violator firms also tend to be larger; however, they tend to have less profitability, more leverage, less growth, fewer sales and less capital expenditure, as well as less research and development (R&D).

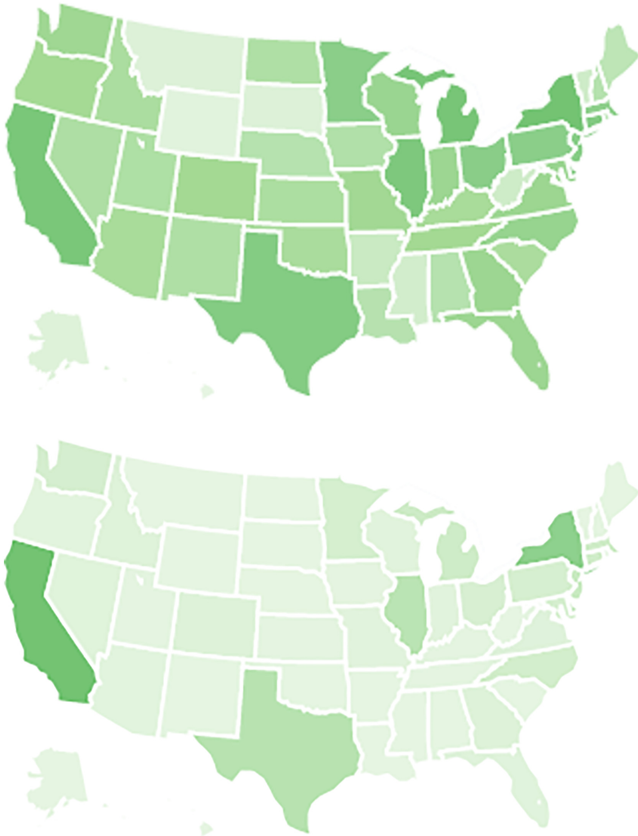

Figure 4.
Heat map – green patents

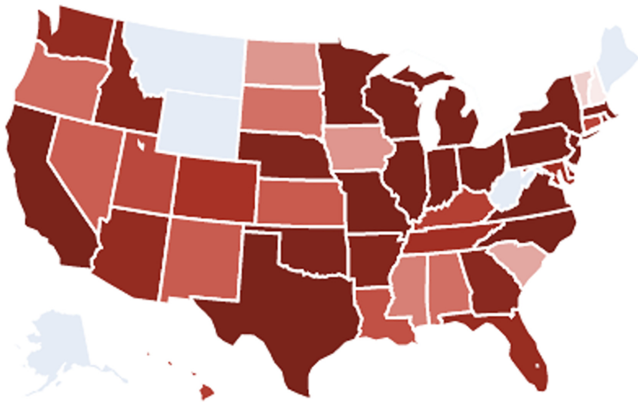

Figure 5.
Heat map – violations

Variables	Mean	Std. Dev	Min	Max
Section A: patent variables				
Total patents	30.66	203.68	0.00	8,870.00
Green patents	3.75	27.24	0.00	911.00
Ratio% (green pat./tot. pat.)	0.10	0.23	0.00	1.00
Green patent firm%	0.28	0.45	0.00	1.00
Ever green patent%	0.80	0.40	0.00	1.00
Section B: violation variables				
Cumulative penalty	$11,200,000.00	$140,000,000.00	0.0	$ 5,380,000,000.00
Total penalty	$ 1,303,807.00	$ 49,400,000.00	0.0	$ 5,150,000,000.00
Cumulative violation	6.7	72.1	0.0	3,155.00
Total violation	0.8	7.7	0.0	287.0
Violation%	0.1	0.3	0.0	1.0
Ever violation%	0.4	0.5	0.0	1.0
Section C: firm variables				
Log (size)	6.95	2.01	3.28	10.51
Log (asset)	6.88	2.07	3.23	10.54
Book leverage	0.21	0.18	0.00	0.58
Tobin's *Q*	2.03	1.18	0.88	5.31
ROA	−0.02	0.17	−0.52	0.15
R&D	0.33	0.78	0.00	3.22
Sales growth	0.08	0.23	−0.34	0.66
Capital expenditure	4.34	3.59	0.38	13.83
Herfindahl index	0.07	0.04	0.02	0.16
Firm age	26.65	17.78	1.00	68.00

Panel B. Green patent firms

	Violation Firms $N = 5{,}630$	Never violation Firms $N = 14{,}516$	Diff	*t*-stat
Total patents	79.18	22.44	56.74	16.05***
Green patents	10.98	2.24	8.74	18.52***
Ratio% (green pat./tot. pat.)	0.15	0.11	0.04	9.55***
Green patent firm%	0.47	0.31	0.17	22.33***
Cumulative penalty	$37,800,000.00	0.00	$37,800,000.00	16.23***
Cumulative violation	19.49	0.00	19.49	22.60***
Total penalty	$ 4,343,511.00	0.00	$ 4,343,511.00	5.21***
Total violation	2.17	0.00	2.17	21.64***
Log (size)	8.40	6.20	2.20	68.42***
Log (asset)	8.47	5.98	2.49	77.19***
Book leverage	0.26	0.20	0.07	10.03***
Tobin's *Q*	1.88	2.46	−0.58	−15.28***
ROA	−0.11	0.05	−0.16	−12.26***
R&D	0.05	9.55	−9.50	−2.06**
Sales growth	0.06	0.51	−0.45	−2.18**
Capital expenditure	4.00	4.83	−0.83	−12.06**
Herfindahl index	0.08	0.06	0.02	4.16***
Firm age	39.82	22.11	17.71	25.55***

(*continued*)

Table 1.
Summary statistics

Panel C. Violation firms only

	Green patent Firms N = 5,650	Never produced Green patent N = 4,986	Diff	t-stat
Cumulative penalty	$37,700,000.00	$ 14,000,000.00	$23,700,000.00	5.66***
Cumulative violation	19.45	12.01	7.44	3.46***
Total penalty	$ 4,331,217.00	$ 1,693,647.00	$ 2,637,570.00	1.78*
Total violation	2.16	1.35	0.81	3.54***
Log (size)	8.40	7.48	0.925	21.57***
Log (asset)	8.47	7.73	0.741	22.54***
Book leverage	0.26	0.29	−0.028	−6.93***
Tobin's Q	1.88	1.78	0.1	2.08**
ROA	0.05	0.03	0.018	3.47***
R&D	0.19	0.05	0.14	−4.44***
Sales growth	0.06	0.12	−0.059	−6.59***
Capital expenditure	4.83	6.79	−1.962	−15.56***
Herfindahl index	0.08	0.06	0.015	11.02***
Firm age	39.81	25.00	14.807	42.45***

Panel D. Logit analysis

Variables	(1) Logit (Prob = 1) ever green patent
Post Violation	0.339 (0.001)***
Log (size)	0.776 (0.001)***
Book Leverage	−0.119 (0.442)
Tobin's Q	−0.221 (0.335)
ROA	0.887 (0.001)***
R&D	0.551 (0.337)
Sales growth	0.001 (0.001)***
Capital expenditure	0.445 (0.056)*
Herfindahl index	−0.449 (0.001)***
Log (firm age)	0.556 (0.001)***
Firm and year FEs	YES
Observations	20,146
R-squared	5%

Note(s): Table 1 shows the variables used in the study. Section A represents the innovation variables. Section B represents the corporate misconduct data. Section C represents the firm-level control variables. In panel B, we perform a t-test by comparing sample means of violator firms and non-violator firms. In panel C, we compare sample means between firms with green patents and firms that have never produced green patents. In panel D, we run logistic regression where our dependent variable is green patent and is equal to one if a firm has ever produced a green patent, or zero otherwise. We run industry and year fixed effects. In all tables, *, ** and *** indicate significance at the 10%, 5% and 1% levels

Table 1.

In panel C, we only work with firms that have committed environmental violations. Among those firms, we split our sample based on their green patent status. We show that firms with green patents commit more violations and more cumulative violations over time, and they are charged significantly more for penalties and other monetary sanctions. In panel D, we run logistic regression where the dependent variable is green patent and is equal to one if a firm has ever produced a green patent, zero otherwise. We regress the green patent binary variable on Post Violation years and other firm-level control variables. Post Violation is the diff-in-diff variable equal to one for all the years after the corporate misconduct and zeroes otherwise.

We find that the odds of a firm producing green patents increase by 39% following the years after the violation.

4.2 Event study

Table 2 reports the market reaction to environmental violations for our sample firms. We divide our firms based on median size. We find that markets significantly react to environmental violations for small firms compared to large firms. We may find a significantly negative reaction because smaller firms have fewer green patents than larger firms. Furthermore, if small firms have green patents, they are likely to be the majority of the firms' patents.

In Table 3, we repeat our tests for firms with green patent portfolios. We find that market reaction is negative and significant for firms if their green patent ratio to overall patents is higher. Again, we expect to find this reaction because green patents make up a larger portion of the overall portfolio.

Using the data collected on environmental violations, we conduct an event study to investigate environmental violations' impact on firm value. Total patent violations vary over time; however, green patent violation remains relatively constant. We report all patent violations in Figure 6.

Figure 6 shows that in the sample period, a patent violation has increased over time. However, environmental violation (denoted by the orange line) remains relatively constant over time. The first event study investigates the impact of firm violations and firm *e*. We believe that smaller firms will be more affected by environmental violations. First, smaller

	Large firms				Small firms		
Panel A Event time	CARs	T-value	Prob	Panel B Event time	CARs	T-value	Prob
−10	−0.84%	−0.45	0.445	−10	−0.04%	−0.32	0.221
−9	0.68%	0.33	0.567	−9	−0.07%	−0.22	0.667
−8	0.17%	0.78	0.312	−8	0.07%	0.34	0.788
−7	0.89%	0.67	0.332	−7	0.11%	1.01	0.452
−6	0.40%	0.12	0.122	−6	−0.12%	−0.89	0.558
−5	0.07%	0.01	0.878	−5	−0.17%	−0.99	0.889
−4	1.44%	1.67	0.198	−4	−0.33%	−1.03	0.743
−3	0.09%	0.33	0.779	−3	0.12%	1.04	0.912
−2	−0.50%	−0.66	0.687	−2	−0.21%	−0.81	0.691
−1	0.09%	0.78	0.298	−1	−0.09%	−1.33	0.411
0	−0.07%	−0.33	0.331	0	−5.07%	−6.77***	0.001
1	−0.24%	−0.31	0.445	1	−6.24%	−6.98***	0.001
2	−0.39%	−0.44	0.478	2	−5.79%	−6.01***	0.001
3	0.71%	0.78	0.832	3	−4.11%	−5.53***	0.001
4	0.76%	0.33	0.339	4	−3.76%	−6.99***	0.001
5	0.26%	0.19	0.228	5	−1.26%	−3.22**	0.021
6	0.94%	0.33	0.227	6	−2.94%	−4.32**	0.032
7	−0.83%	−0.23	0.789	7	−2.83%	−3.89**	0.044
8	0.40%	0.76	0.655	8	−1.40%	1.33	0.112
9	0.36%	1.11	0.445	9	−1.36%	−1.11	0.449
10	0.24%	0.33	0.432	10	−1.24%	−0.45	0.444

Note(s): Table 2 displays aggregated cumulative abnormal returns for large (panel A) and small (panel B) firms. Each panel reports the event date – where date zero is the date of an environmental violation – the CAR, the t-value testing if the CAR is different than zero, and the associated *p*-value. In all panels, *, ** and *** indicate significance at the 10%, 5% and 1% levels

Table 2. Market reaction to violations

Table 3.
Market reaction to violations: green patent ratio%

Panel A. (Green patent/total patent)%							
Event time	10–20%	30%	40%	50%	70–60%	90–80%	100%
−10	−0.32%	0.02%	−0.90%	−0.04%	−0.57%	−0.87%	0.05%
−9	−0.10%	0.29%	−1.72%	0.07%	−0.43%	1.54%	−0.32%
−8	−0.01%	0.31%	−1.19%	−0.29%	−1.25%	1.57%	0.94%
−7	0.12%	0.42%	0.30%	−0.48%	−1.10%	0.09%	1.27%
−6	0.34%	0.35%	0.31%	−0.54%	−1.14%	0.68%	0.81%
−5	0.31%	0.59%	0.30%	−0.07%	−0.90%	0.28%	1.46%
−4	0.19%	0.67%	0.36%	−0.15%	−0.72%	0.79%	1.39%
−3	0.19%	0.55%	0.70%	−0.18%	−0.85%	−0.06%	1.10%
−2	0.14%	0.74%	0.60%	−0.44%	−0.31%	0.72%	1.47%
−1	0.18%	0.66%	0.60%	−0.44%	−0.95%	−0.07%	1.65%
0	0.01%	0.64%	0.51%	−1.65%***	−1.95%***	−0.26%	−1.31%
1	0.09%	0.51%	0.70%	−1.99%***	−2.94%***	−3.10%***	−1.41%***
2	0.18%	0.89%	0.66%	−1.78%***	−2.35%***	−0.88%***	−1.23%***
3	0.22%	0.62%	0.48%	−1.54%***	−2.55%***	−0.63%**	−1.44%***
4	0.93%	0.52%	0.57%	−2.20%***	−2.83%***	−0.23%**	−1.59%***
5	0.07%	−0.14%	0.64%	−2.00%***	−3.01%***	−0.10%*	−1.02%***
6	1.30%	−0.15%	0.78%	−2.20%***	−2.71%***	−0.89%***	−0.72%***
7	1.20%	−0.32%	1.13%	−2.36%***	−2.24%***	1.18%	−0.78%***
8	1.09%	−0.40%	1.08%	−2.15%***	−2.60%***	1.61%	−0.23%*
9	0.98%	−0.59%	1.43%	−1.82%***	−2.16%***	0.81%	−0.27%
10	1.08%	−0.53%	1.25%	−1.33%***	−1.89%**	1.47%	−0.30%*

Note(s): Table 3 displays aggregated cumulative abnormal returns for firms based on green patent deciles. Each column is defined as firms in a decile based on the number of green patents divided by total patents. In all columns, *, ** and *** indicate significance at the 10%, 5% and 1% levels

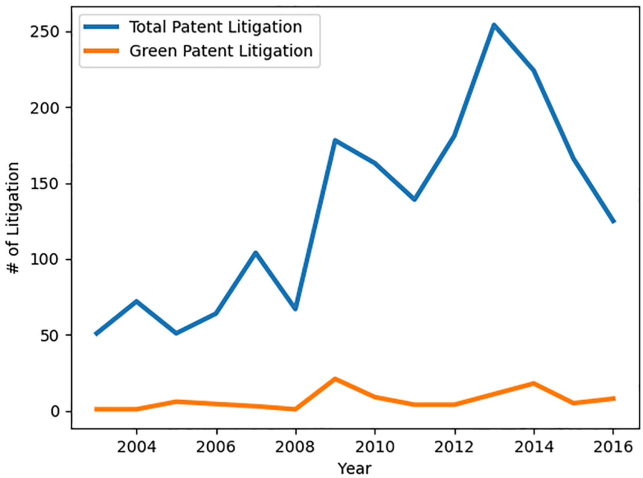

Figure 6.
Green violations relative to all

firms have fewer resources at their disposal to fight environmental violations. Second, smaller firms depend on their patents more because they are less likely to have several patents outside of being sued. The results of an event study using large firms are found in Figure 7.

As seen from Figure 7, there is no significant effect of the announcement of environmental violations on firms. We attribute this to the size effect. Larger firms have the resources to fight any pending environmental violations. Furthermore, environmental violations will make up a smaller portion of the firm's overall patent portfolio. The following study, shown in Figure 8, shows the results of green environmental violations on small firms.

Figure 8 shows a significantly negative effect related to green patent ligation and firm market value. We see that when environmental violations are announced, markets react in a significantly negative manner. This leads to small firms losing firm value due to green patent ligation. For the same reasons, we believe we do not detect an effect for large firms, and we observe small firms' effect.

Because small firms may have fewer green patents, in the next section, we investigate the impact of environmental violations on firms that invest a large portion of their patent

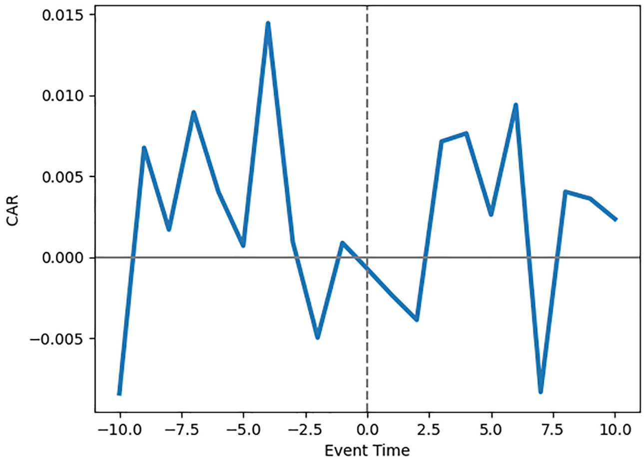

Figure 7.
Event study: market reaction to violations for large firms

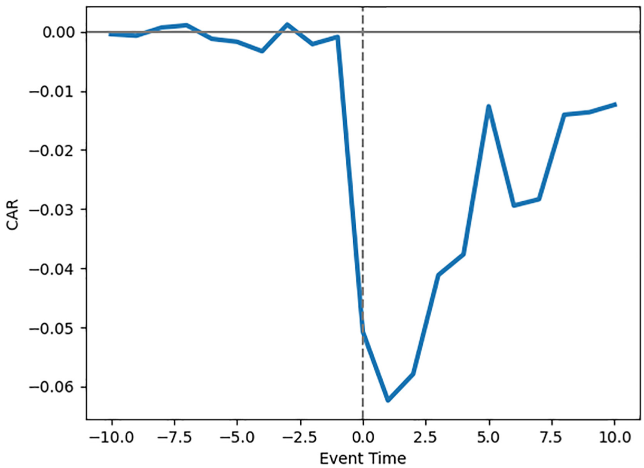

Figure 8.
Event study: market reaction to violations for small firms

portfolio in green technology. This will allow us to show that the more a green patent portfolio, the more market reaction to a green environmental violation. This analysis is shown in Figure 9.

Figure 9 shows the effect of green environmental violations on firms with 50–59, 60–69, 70–79, 80–89 and 90 + green patents. We compute the percentage of green patents per firm by dividing the total number of green patents by the total number of patents per firm. We can see that firms with 50% or more green patents have a significant negative market reaction. These results are consistent with the prior results based on size. Continuing the investigation, we show firms with less than 50% of green patents; these results are shown in Figure 10.

Figure 10 shows that we do not find a significant positive or negative reaction for firms with less than 50% of green patents. This may be because firms with a smaller number of green patents have many other patents. This section's results are consistent with our hypothesis, as smaller firms and those with more green patents are a portion of their portfolio experience a significant negative market reaction. We fail to find any significant effect for

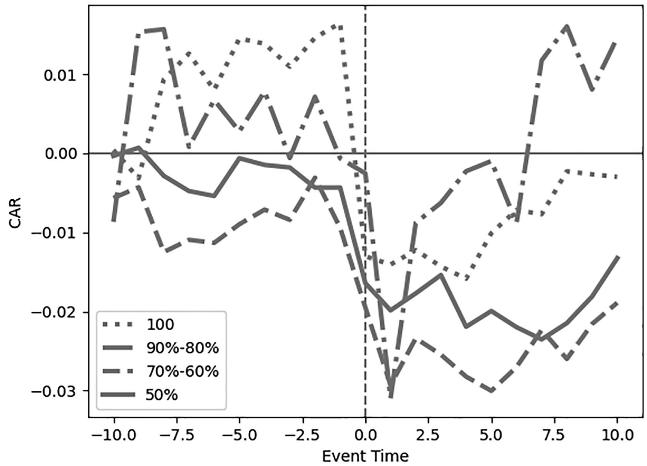

Figure 9.
Event study: market reaction to violations for green patent ratio 50–100%

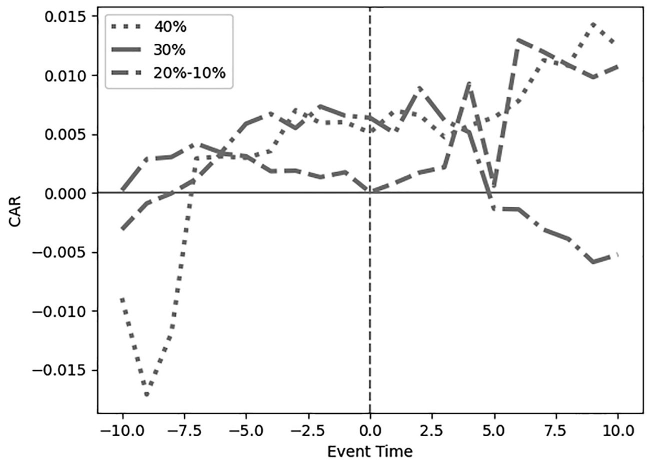

Figure 10.
Event study: market reaction to violations for green patent ratio 0–40%

larger firms and those with fewer green patents as a percentage of their portfolio. In the following sections, we investigate the impact of environmental violations on creating future green patents.

In Table 4, we conduct additional analysis investigating the impact of environmental violations on green patents at time t+2. For violations, we include available (1/0) that captures post-violation years compared to pre-violation years, the log of total violations and the log total dollar amount in penalties from environmental violations. The results reported in Table 4, columns (1), (2), and (3) show that all violation proxies have a positive and significant effect on green patents in the future. In column (1), we document that firms obtain more green patents following the violation compared to pre misconduct years. In addition, we find that increase in the total number of environmental misconducts leads to a higher number of green patents. Finally, we also show that dollar penalties resulting from environmental violations increase the long-run green patents. Overall, our results from Table 4 document the firms' response to environmental misconduct with their green patent performance changes.

4.3 Regression discontinuity results

This session tests how companies adopt green patents following the violations. We calculate environmental penalties in dollars and set the two million dollars as a breakpoint in our sample, close to the overall mean score (see panel B of Table 1). Our results are presented in Table 5.

In panels A, B and C, we work with firms with green patents only, firms involved in environmental violations only, and firms with green patents or are engaged in green violations. We conduct a regression discontinuity design (RDD) analysis and find that firms gradually increase their green patents once they pass the average penalties for violations.

Figures 11–13 show the firms' response to environmental violations. Year zero is when firms reach the average dollar cost of violations for our sample. In the long run, we document that firms switch to green patents. This effect is consistent for 10 to 20 years after the

Variables	(1) Log (green patent) t+2	(2) Log (green patent) t+2	(3) Log (green patent) t+2
Post Violation	0.443 (0.001)***		
Log (total violation)		0.221 (0.001)***	
Log (total $$ penalty)			0.665 (0.001)***
Log (size)	0.111 (0.001)***	0.112 (0.001)***	0.114 (0.001)***
Book leverage	−0.556 (0.337)	−0.677 (0.556)	−0.557 (0.778)
Tobin's Q	0.673 (0.221)	0.668 (0.445)	0.778 (0.556)
ROA	0.439 (0.001)***	0.442 (0.001)***	0.509 (0.001)***
R&D	0.445 (0.331)	0.409 (0.376)	0.391 (0.339)
Sales growth	0.002 (0.043)**	0.002 (0.049)**	0.002 (0.039)**
Capital expenditure	0.034 (0.027)**	0.034 (0.035)**	0.037 (0.035)**
Herfindahl index	−0.022 (0.078)*	−0.024 (0.071)*	−0.021 (0.067)*
Log (firm age)	0.776 (0.001)***	0.775 (0.001)***	0.779 (0.001)***
Firm and year FEs	YES	YES	YES
Observations	20,146	20,146	20,146
R-squared	5%	5%	4%

Note(s): Table 4 documents the relationship between green patents and environmental violations. Our dependent variable is the log transformation of the total number of green patents. Firm and year-fixed effects are included in each regression but omitted for brevity. In all columns, *, ** and *** indicate significance at the 10%, 5% and 1% levels

Table 4. Violations and green patents at time t+2

Panel A. Only green patent firms	Conventional	p-value
Polynomial regression (1)	4.45	0.001
Polynomial regression (2)	5.45	0.001
Polynomial regression (3)	4.02	0.001
Panel B. Only violation firms		
Polynomial regression (1)	3.33	0.001
Polynomial regression (2)	3.92	0.001
Polynomial regression (3)	2.97	0.001
Panel C. Violation firms or green patent firms		
Polynomial regression (1)	2.44	0.001
Polynomial regression (2)	3.73	0.001
Polynomial regression (3)	2.89	0.001

Note(s): Table 5 documents green patent performance following the environmental misconduct. We conduct regression discontinuity design analysis (RDD), where the cutoff point in the year $t = 0$ is the penalty year from environmental misconduct. We run RDD with different polynomial degrees and report coefficients and P-values. In panel A, the sample consists of firms that have only produced green patents. In panel B, the sample is firms with at least one environmental violation. In panel C, our sample is firms with at least one green patent, environmental violation or both

Table 5.
Regression discontinuity design

violations. This effect could be because firms gradually adopt newer technologies better for the environment and reduce future environmental wrongdoings' potential costs.

5. Limitation, future research and conclusion

This study examines how firms respond to environmental violations by analyzing their green patent production. There are limitations to this study. For example, the tests included only include publicly traded US firms. To investigate the market reaction from green patents, we must utilize the stock price information and basic financial data. In addition, another limitation can be the extension of environmental violations. Multinational US firms may also commit costly environmental violations outside the USA, but this information, verdicts or settlements are not available at the firm level.

Extensions of this work may include analyzing other types of violations, including patent lawsuits, environmental accidents, and changes in state or federal level regulations and how they affect firms' green patent performance. Location-based characteristics may also persuade firms to produce more green patents (e.g. tax breaks), which may be supported by additional state or federal level law changes.

In this paper, we examine the impact of environmental violations on green innovation. We find that firms that commit environmental violations switch to green innovation in the long run. We also document that the market reaction to costly environmental violations is more severe for firms with more green innovation agenda. We discuss that adjustments to green portfolios, in the long run, could be due to two reasons. First, the legal cost associated with environmental wrongdoings can persuade firms to adopt more green innovation. Second, the reputational damage associated with environmental violations can harm stakeholders and shareholders, forcing firms to adopt more green technologies. Overall, our results are important to understand how corporates respond to climate-related violations in their patent portfolio.

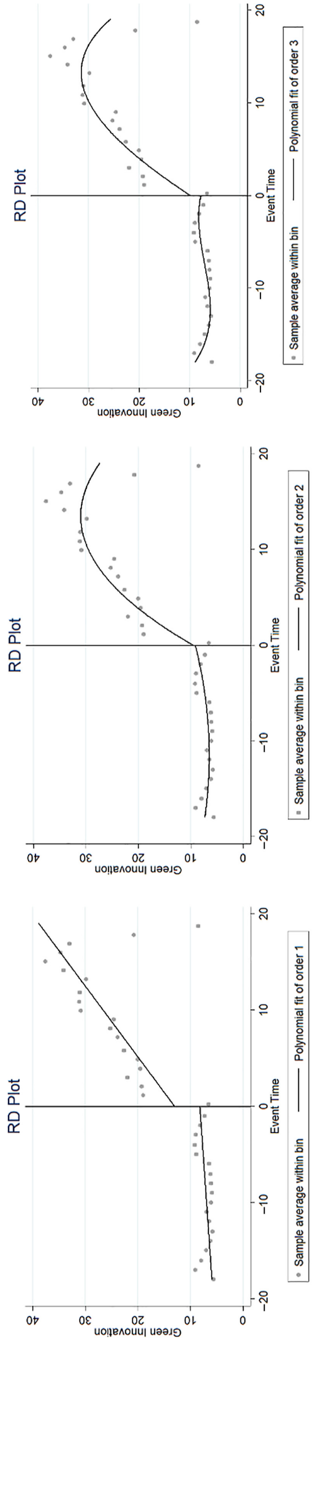

Figure 11.
Regression discontinuity design for penalties: only green patent firms

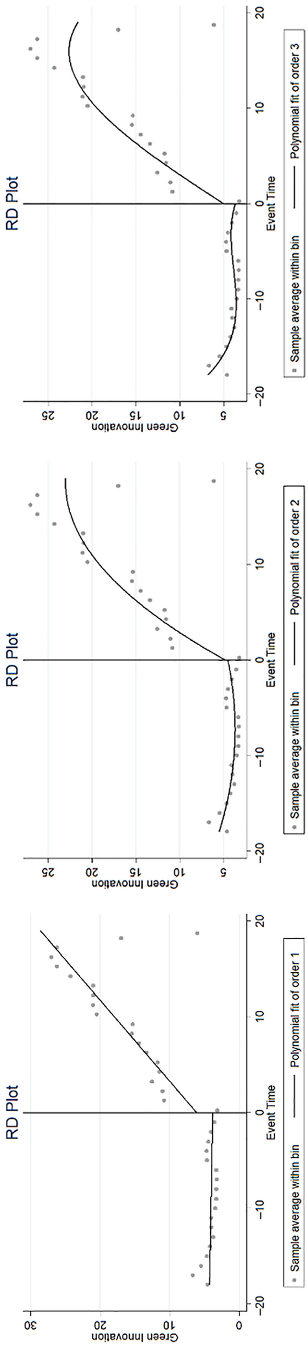

Figure 12.
Regression discontinuity design for penalties: only violation firms

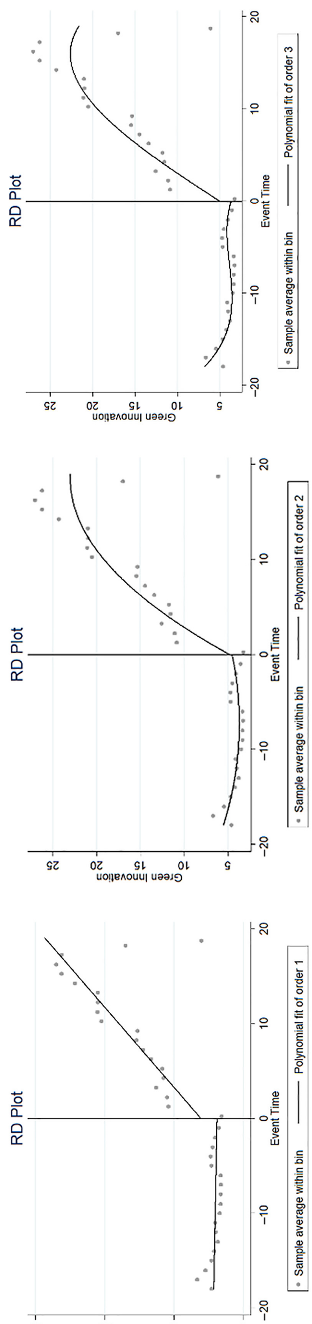

Figure 13.
Regression discontinuity design for penalties: violation firms or green patent firms

Note

1. https://www.businessroundtable.org/business-roundtable-redefines-the-purpose-of-a-corporation-to-promote-an-economy-that-serves-all-americans

References

Alok, S., Kumar, N. and Wermers, R. (2020), "Do fund managers misestimate climatic disaster risk", *The Review of Financial Studies*, Vol. 33, pp. 1146-1183.

Amore, M.D. and Bennedsen, M. (2016), "Corporate governance and green innovation", *Journal of Environmental Economics and Management*, Vol. 75, pp. 54-72.

Cadez, S., Czerny, A. and Letmathe, P. (2019), "Stakeholder pressures and corporate climate change mitigation strategies", *Business Strategy and the Environment*, Vol. 28, pp. 1-14.

Chang, C.-H. (2011), "The influence of corporate environmental ethics on competitive advantage: the mediation role of green innovation", *Journal of Business Ethics*, Vol. 104, pp. 361-370.

Cheng, M., Lin, B., Lu, R. and Wei, M. (2020), "Non-controlling large shareholders in emerging markets: evidence from China", *Journal of Corporate Finance*, Vol. 63, 101259.

Choi, D., Gao, Z. and Jiang, W. (2020), "Attention to global warming", *The Review of Financial Studies*, Vol. 33, pp. 1112-1145.

Elnahas, A., Kim, D. and Kim, I. (2018), "Natural disaster risk and corporate leverage", Available at: SSRN 3123468.

Flammer, C. and Kacperczyk, A. (2016), "The impact of stakeholder orientation on innovation: evidence from a natural experiment", *Management Science*, Vol. 62, pp. 1982-2001.

Hong, H., Karolyi, G.A. and Scheinkman, J.A. (2020), "Climate finance", *The Review of Financial Studies*, Vol. 33, pp. 1011-1023.

Kogan, L., Papanikolaou, D., Seru, A. and Stoffman, N. (2017), "Technological innovation, resource allocation, and growth", *The Quarterly Journal of Economics*, Vol. 132, pp. 665-712.

Miao, Q. and Popp, D. (2014), "Necessity as the mother of invention: innovative responses to natural disasters", *Journal of Environmental Economics and Management*, Vol. 68, pp. 280-295.

Rayfield, B. and Unsal, O. (2021), "Institutional monitoring and litigation risk: evidence from employee disputes", *Journal of Financial Research*, Vol. 44 No. 1, pp. 81-119.

Zhu, Q., Sarkis, J. and Lai, K.-h. (2012), "Examining the effects of green supply chain management practices and their mediations on performance improvements", *International Journal of Production Research*, Vol. 50, pp. 1377-1394.

Corresponding author
Blake Rayfield can be contacted at: blake.rayfield@nau.edu