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Does Green Innovation Increase Shareholder Wealth?

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Abstract

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JEL classifications: O34, Q55, G14, G23

Keywords: green innovation, patents, climate change, climate concerns, institutional investors, ESG

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1. Introduction

Green technologies are the key to decarbonizing the economy (Nordhaus, 2021) and mitigating and adapting to climate change (United Nations, 2021). Governments rely heavily on the private sector to invest and develop many of these green technologies - a key source of innovation is the private sector. For instance, for-profit companies own 85% of patents in the United States (National Science Board, 2018). Although motivated by the prospect of getting a return on their investment, green innovation can also help firms capture climate-related opportunities and lower their exposure to climate risks. Similarly, recent evidence suggests that institutional investors encourage companies to make more environmentally friendly decisions (Dyck et al., 2019). We investigate whether environmental (green) innovation by public firms increases shareholder wealth.

Innovation is considered crucial for the future success of a firm, and therefore one of the most important corporate decisions is how much to spend on innovation activities. Patents benefit firms as they can increase firms' employment growth, sales growth, chances of survival, and access to capital (Hegde et al., 2022). Hence, the market reacts positively to the announcements of new patents (Kogan et al., 2017).

Green innovation, commonly measured using the number of green patents (Aghion et al. 2016; Cohen et al., 2022), can be important to investors who care about environmental issues and want to minimize their exposure to environmental risks (Ilhan et al., 2021). Moreover, the number of green patent announcements are increasing rapidly. The annual number of green patents granted in the United States increased by 301% from 2009 to 2019, compared with a 97% increase in the annual number of non-green patents. Since developing green technologies is generally risky and expensive, green patents can be a credible signal of a firm's environmental commitment (Berrone et al., 2017; Spence, 1973). Therefore, we address the following question: Do green patents increase shareholder wealth?

Although prior research suggests that the market rewards innovation as indicated by the positive market reaction to patents in general, it is unclear whether the market rewards *green* innovation. The related findings on the market reaction to general sustainability-related news announcements are mixed.[1] We differ from this literature by focusing on the announcements of new green patents made by the United States Patent and Trademark Office (USPTO). Green patents are a reliable evidence of corporate engagement with environmental issues for multiple reasons. First, green patents can be challenging to obtain for a company because innovation is path-dependent (Aghion et al., 2014). Second, innovating in green technologies requires a firm to redirect its research and development (R&D) efforts from other (potential) projects (Stern and Valero, 2021). Third, obtaining a patent is costly. Lemley (2001) shows that firms spend $5bn every year just on the process of obtaining patents from the USPTO. Fourth, many funds have a specific focus on environmental/sustainable investments and the amount of U.S.-domiciled assets under management following sustainable investing strategies reached $17.1 trillion in 2020, a 42% increase from 2018 (U.S. SIF, 2020). Therefore, green patents can help a firm attract a larger part of these funds (Cohen et al., 2022), reduce its cost of capital (Bolton and Kacperczyk, 2021; Chava, 2014), and help investors distinguish between firms that act on environmental issues and firms that only brand themselves as such. This suggests that investors may pay attention to green patents as they provide evidence of a firm's environmental progress (Amore and Bennedsen, 2016; EPO and IEA, 2021).

We examine the impact of green patents on shareholder wealth by measuring the market reaction to patents granted to public firms in the United States during 1976-2019. When we compare the market reaction to green patents against the market reaction to non-green (grey) patents, we find that the announcements of green patents do not increase shareholder wealth.

[1] In relation to environmental, social and governance (ESG) issues, Krueger (2015) finds a negative stock market reaction to positive news, Capelle-Blancard and Petit (2019) find no reaction, and Flammer (2013) and Klassen and McLaughlin (1996) report a positive market reaction.

This finding is contrary to the positive market reaction to the announcements of non-green patents. Also, our results and interpretations hold regardless of whether a company is operating in a carbon-intensive industry, has a low environmental score, or has a high exposure to climate change. Prima facie, our results may seem surprising, but they are not. Our findings are consistent with Pástor et al. (2021) who predict that demand for green firms pushes up their prices and lowers their expected returns, ultimately leading to underperformance compared to non-green firms. Our findings are also consistent with Pedersen et al. (2021) and Bolton and Kacperczyk (2021) who show that firms with low carbon intensity have higher valuations and lower stock performance compared to firms with high carbon intensity.

We also assess whether the impact of green patents on shareholder wealth is driven by investors' environmental concerns. High levels of climate change concerns can make the climate-related risks faced by firms more important to investors and can increase investors' preference for green assets (Ardia et al., 2022). Therefore, investors may value green patents more when their climate change concerns are greater. We test if the impact of green patents on shareholder wealth depends on the amount of public attention to climate change and find no evidence that it does, even if we focus on firms in high pollution industries.

Stocks that receive low institutional investor attention are traded less frequently and less profitably (Schmidt, 2019). Also, green innovation may be particularly relevant to institutional investors, who have been putting pressure on companies to reduce their emissions (Azar et al., 2021).[2] Therefore, the market reaction to green patent announcements may depend on institutional investor ownership or whether institutional investors are paying attention to firms developing new green technologies. We find that neither the level of institutional investor ownership nor the amount of institutional investor attention is related to the impact of green

[2] As of Aug 2022, 700 institutional investors with a total of $68 trillion of assets under management have joined the Climate Action 100+ initiative, which aims to engage firms on climate change issues. One example of shareholder activism is the battle between Engine No.1 and Exxon Mobil. In June 2021, the hedge fund won a proxy battle against the oil company gaining three seats on its board (Brower and Aliaj, 2021).

patents on shareholder wealth. Also, we assess whether the market reaction to green patents changed following the 2015 Paris Agreement. Investor attention to climate change increased after the Paris Agreement (Kruse et al., 2020), and banks started charging companies a carbon risk premium (Ehlers et al., 2022). Still, we find no evidence that the green patents granted after the adoption of the 2015 Paris Agreement have increased shareholder wealth.

Given our results, we investigate whether the changes in a company's green patenting activity are related to the changes in the firm's environmental score, level of institutional investor ownership, and firm value (Tobin's Q). We find that there is no relation between these variables and green patenting activity. The results are consistent regardless of whether we measure green patenting activity using the number of green patents obtained, the amount of green patent applications filed, or the number of citations received by a company's green patents.

Lastly, our results can be driven by temporary mispricing or underreaction to the green patent announcements. Therefore, we examine the long-run stock price performance of firms that obtain new green patents. A portfolio that is long on companies with new green patent announcements generates value- and equally-weighted alphas of -0.12% and -0.09% per week, respectively, for a 4-week portfolio holding period. The results are similar across alternative portfolio horizons. Moreover, portfolio alphas are more negative for firms operating in CO_2 intensive industries and for firms with low R&D intensity.

Overall, our results suggest that green patent announcements do not increase shareholder wealth and that this cannot be explained by mispricing or by a delayed reaction to the announcements. Moreover, firms which obtain new green patents underperform in the future. Our results may seem surprising in light of previous studies which find that the stock market reacts positively to evidence of firms' environmentally-friendly actions such as implementing sustainability programs and issuing green bonds (Flammer, 2013; Flammer, 2021; Klassen and

McLaughlin, 1996). However, unlike these studies, we focus on green patents which allows us to study the market response to environmentally-friendly actions over a longer period. Moreover, our findings are consistent with the argument and empirical evidence that green stocks enjoy greater demand pushing prices up and leading to underperformance compared to non-green stocks (Bolton and Kacperczyk, 2021; Pástor et al., 2021; Pedersen et al., 2021). Our results also support IEA (2021) and Aghion et al. (2014) who argue that the returns to green technologies can be small compared to investments in polluting technologies, because green technologies may be in their infancy stages.).

Moreover, despite institutional investors' concerns about environmental risks (Ilhan et al., 2021), we find no evidence that they reward companies for obtaining green patents. This is consistent with Michaely et al. (2021), who find that institutional investors do not support environmental and social corporate proposals when their vote matters the most. Similarly, Gianfrate et al. (2021) find no evidence that institutional investors reduce the carbon emissions of an average company. Our results also complement von Schickfus (2021), who finds no evidence that firm engagement by institutional investors affects corporate green innovation.

The contribution of this paper is fourfold. First, this is the first paper to our knowledge that investigates the impact of green patents on shareholder wealth. Second, by measuring the long-run performance of firms after their green patent announcements, we contribute to the climate-related asset pricing literature (Bolton and Kacperczyk, 2021; Engle et al., 2020). Third, we contribute to an emerging literature on the effects of investor attention to climate change (Choi et al., 2020; Huynh and Xia, 2021; Ramelli et al., 2021) by examining whether the impact of green patents on shareholder wealth depends on the level of climate change concerns. Fourth, we contribute to the literature on corporate green patents (Berrone et al., 2013; Cohen et al., 2022; Kim et al., 2021) by using an objective measure of green patent value, the market reaction to green patent announcements, and investigating whether the level of institutional investor ownership and attention affects it. We show that despite investors' calls for climate action and green innovation (McCormick, 2021; U.S. Chamber of Commerce, 2019), companies do not produce green innovation that increases shareholder wealth.

2. Hypotheses development

We apply the signaling theory (Connelly et al., 2011; Spence, 1973) to corporate green patent announcements. Patents can be valuable signals to investors (Hsu and Ziedonis, 2013; Long, 2002). We argue that green patents can serve as signals that reduce the information asymmetry about a firm's environmental commitment. Also, green patents are valuable to firms due to their impact on firm risk and cost of capital. For instance, firms can be subject to physical climate risks, and developing green technologies can help them mitigate these risks (Miao and Popp, 2014). Moreover, green innovation is negatively associated with pollution (Carrion-Flores and Innes, 2010), and the cost of complying with environmental regulations (Brunnermeier and Cohen, 2003). As investors demand higher returns for exposure to environmental regulation risk (Bolton and Kacperczyk, 2021; Chava, 2014), green patents can potentially lower a firm's cost of capital. Therefore, in addition to signaling a firm's environmental commitment, green patents can also provide other benefits to a firm.[3]

A credible "signal" is costly to copy for firms that lack the sought-after characteristics (Riley, 1979; Spence, 1973). Green patents satisfy this condition (Berrone et al., 2017). To produce a new green technology, a company has to increase its innovative input, the R&D spending, or reallocate it from other projects.[4] Patents can represent the successful output of this investment (Lerner and Seru, 2022; Sunder et al., 2017). However, success is not guaranteed, because early-stage clean technologies are risky (Stern and Valero, 2021). Moreover, any green innovation has to pass examination at the patent office in order to be

[3] To reflect this, patents are sometimes referred to as 'productive' signals (Conti et al., 2013).
[4] A firm can also obtain patents by acquiring them from other innovative companies. However, this is not a concern in our study, because the market reaction to a patent announcement is measured only once; at the time when the patent is granted to its first owner.

patented. This is a costly selection process that lasts on average three years (Farre-Mensa et al., 2020; Lemley, 2001), with only 56% of patent applications being successful without the use of continuation procedures (Carley et al., 2015). If the process is successful and a patent is granted, it represents robust evidence of technical progress (EPO and IEA, 2021). This leads to the first hypothesis:

Hypothesis 1: Green patent announcements increase shareholder wealth.

We expect that there could be a differential market reaction to green patent announcements based on differing firm characteristics. Sautner et al. (2022) find a positive correlation between a firm's exposure to climate change and green patenting. Since green patents can reduce firm pollution (Carrion-Flores and Innes, 2010), the market reaction could be stronger for green patents granted to companies that are seen by investors as the highest polluters. One of the main environmental concerns is carbon dioxide emissions (Bolton and Kacperczyk, 2021). Carbon emissions are negatively related to firm value (Matsumura et al., 2014), and lenders have started charging carbon-intensive borrowers a carbon risk premium since the Paris Agreement in 2015 (Ehlers et al., 2022).

Investor preferences for green assets can impact their price (Avramov et al., 2021; Fama and French, 2007; Pedersen et al., 2021). Pástor et al. (2021) argue that green assets can earn higher returns if investors' tastes for green investments increase unexpectedly. The evidence suggests that green firms have outperformed brown companies between 2012 and 2020 because of higher levels of environmental concerns (Pástor et al., 2022). For example, climate attention increased after the release of the 2006 Stern Review (Painter, 2020), and after the first Global Climate Strike of 2019 (Ramelli et al., 2021).

The level of concerns about climate change can proxy for the risk premium that is required by investors for bearing climate risk (Ardia et al., 2022). Higher levels of climate change concerns can increase investor preference for green assets and their demand for environmentally-friendly products (Pástor et al., 2022). Therefore, firms should be more rewarded for obtaining green patents when the levels of climate change concerns are high. This leads to the second hypothesis:

Hypothesis 2: The impact of green patent announcements on shareholder wealth is positively related to the level of climate change concerns.

Institutional investor ownership is positively associated with overall firm innovation (Aghion et al., 2013). Green innovation can be even more important to institutional investors, who are becoming increasingly concerned by climate risk (Krueger et al., 2020). Successful engagements on ESG issues are positively related to firms' accounting performance and corporate governance (Dimson et al., 2015), and they are negatively associated with downside risk (Hoepner et al., 2022). Meanwhile, Dyck et al. (2019) show that the relation between institutional investor ownership and environmental performance is causal. Overall, the literature suggests that institutional investor ownership is positively associated with environmental performance. Therefore, the impact of green patent announcements on shareholder wealth can depend on the amount of attention paid by institutional investors to the announcements. However, investor attention is a limited resource. Paying more attention to one company in their portfolio leaves institutional investors with fewer resources for monitoring other firms (Kempf et al., 2017). Companies that experience lower institutional investor attention produce fewer disclosures (Abramova et al., 2020), are subject to less board oversight (Liu et al., 2020), and have a higher stock price crash risk (Ni et al., 2020). Moreover, high institutional investor attention around earnings announcements and analyst recommendation changes leads to larger short-run abnormal returns (Ben-Rephael et al., 2017). Therefore, we argue that green patent grants accompanied by high levels of institutional investor attention should have a more positive impact on shareholder wealth. This leads to the third hypothesis:

Hypothesis 3: The impact of green patent announcements on shareholder wealth is positively related to the level of institutional investor attention.

3. Data and descriptive statistics

We obtain patent data from PatentsView, which is a publicly accessible service maintained by the USPTO. We retrieved our PatentsView data in March 2021, and it includes information on over 7.6 million patents granted in the United States since 1976. We use PatentsView to obtain data on patent numbers, grant dates, citations, claims, and patent technology classes for all patents granted during 1976-2019. We do not include patents granted in 2020, because of the exceptional market circumstances created by the outbreak of COVID-19. Our initial sample includes 7,236,657 patents.

We identify green patents using the classification developed by the OECD (Haščič and Migotto, 2015)[5] that is commonly used in the literature (Cohen et al., 2022; Sautner et al., 2022). Technology classification codes are assigned during the patent application process, and they depend on the inventions' technological content. The granular nature of patent classification systems allows for accurate identification of specific technologies, including "environmental" technologies (Haščič and Migotto, 2015). The green patent classification includes technologies related to climate change mitigation and adaptation, carbon capture and storage, renewable energy generation, pollution abatement, and waste management. Based on the green patent classification, the United States Trademark and Patent Office (USPTO) granted 7,054 green patents in 2009 and 28,320 green patents in 2019. The number of all patents granted by the USPTO was 192,052 in 2009 and 392,618 in 2019. Overall, using

[5] Our results are not sensitive to this particular green patent classification. Our results remain unchanged if we classify green patents using the Climate Change Mitigation Technologies (CCMT) classification scheme developed by the European Patent Office (Angelucci et al., 2018). The CCMT classification focuses on patents related to climate change mitigation and adaptation. The OECD classification has a broader scope and also includes other environmentally friendly technologies (Haščič and Migotto, 2015).

patents' IPC and CPC codes, we identify 351,066 green patents in our sample that were granted between 1976 and 2019.

Next, we identify which patents in our sample are owned by public firms in the United States. We use a patent-CRSP link created by Stoffman et al. (2022), who match companies in CRSP to patents granted by the USPTO until 31 December 2020. We successfully match 2,578,327 patents, out of which 110,185 are classified as green patents, to publicly listed firms. Following standard practice in the patent literature (Appel et al., 2019; Lerner et al., 2011), we drop non-utility patents, which reduces the sample to 2,456,180 patents. We obtain firms' financial data from Compustat and their ESG scores from Refinitiv's Asset4. Our share price return data comes from CRSP. Our sample only includes common stocks, i.e., stocks with CRSP share code 10-12 (Cohen et al., 2013). We drop 628,102 patents with missing stock return data around the announcement date which reduces the sample to 1,828,078 patents.

For each company in our sample, we obtain earnings announcement dates from CRSP and dividend declaration dates from Compustat. To avoid contamination of the patent events by other closely occurring events (de Jong and Naumovska, 2016), we drop all patent announcements which occur within two trading days of a firm's earnings or dividend announcements (Stickel, 1986). In total we remove 192,026 patents from the sample, which reduces the sample to 1,636,052 patents. Lastly, we remove 19,118 patents owned by either financial services firms (SIC 6000-6999) or utility companies (4900-4999). Overall, our sample includes 1,616,934 patents, of which 67,310 (4.2%) are classified as green (Cohen et al. 2022 similarly report that 5.6% of the patents in their sample are green).

We obtain data on the level of climate change concerns from Ardia et al. (2022). Similar to Pástor et al. (2022), we follow Ardia et al. (2022) to construct the Unexpected Media Climate

Change Concerns index.[6] The media index captures the daily level of negative attention about climate change during 2006 to 2018. We use the average value of the UMC index over a three-day window (0,+2) following a patent announcement to measure the level of climate change concerns. Our institutional ownership data is from Ghaly et al. (2020).[7] The ownership data is obtained from Securities and Exchange Commission's Forms 13F that are filed by institutional investors every quarter. The forms contain information on all equity assets under the investors' management. Our data covers the period from 1981 to 2018.

Our measure of institutional investor attention is based on the Bloomberg Heat Scores (Ben-Rephael et al., 2017). Bloomberg Heat Scores can take on values of 0, 1, 2, 3, and 4. Similar to Chiu et al. (2021), we use the average value of the Bloomberg Heat Scores over a three-day window (0,+2) following a patent announcement to measure the level of institutional investor attention. We also measure institutional investor attention over alternative windows for robustness and our results remain unchanged. Our institutional investor attention data covers the period from 2010 to 2019.

Lastly, we obtain firm-level climate change exposure data from Sautner et al. (2022). Sautner et al. (2022) analyze the transcripts of quarterly earnings calls of over 10,000 publicly listed companies from 34 countries during 2002-2020. The authors measure firm-level exposure to climate change as the proportion of a firm's earnings call transcript that is centered around the topic of climate change. All variables are defined in Table A1 in Appendix A.

Table 1 shows the descriptive statistics. We conduct our analysis and present the descriptive statistics on a patent announcement day level. Newly granted patents are announced by the USPTO on Tuesdays. The USPTO can announce a grant of multiple patents to the same

[6] First, we compute the expected level of climate change concerns using a first-order autoregressive model calibrated on three years of the Media Climate Change Concerns (MCCC) data from Ardia et al. (2022). Then, we calculate UMC by subtracting the predicted value of MCCC from the actual value of MCCC. Due to the fact that 3-years of data is used to calculate UMC, the UMC data starts in 2006.

[7] We are grateful to Kostas Stathopoulos for providing us with an updated dataset.

company on the same day. Since we observe one market reaction per announcement day, we treat each announcement as one observation. Our sample consists of 467,502 patent announcements, which include 1,616,934 patents granted during 1976-2019 to 7,263 different public companies. Panel A presents firm characteristics. The average company has a market capitalization of $19.4 billion, while the median firm has a capitalization of $2.9 billion. With a debt to assets ratio of 0.525, the average company in our sample is more leveraged in comparison to the average nonfinancial corporation headquartered in the U.S. (Palazzo and Yang, 2019). The average firm in our sample has an R&D intensity of 8.6%. This more than double the average R&D intensity of a typical U.S. company of 4.1% (Wolfe, 2020). Moreover, 57.2% of the equity of an average company in our sample is owned by institutional investors, which is similar to Aghion et al. (2013) and von Schickfus (2021).

/Table 1 here/

The characteristics of the patents granted to the firms are shown in Panel B of Table 1. After excluding examiner and self-citations[8], an average patent in our sample has a truncation-adjusted number of citations of 1.3.[9] Moreover, the average patent contains 1.1 independent claims.[10] Panel C of Table 1 presents the characteristics of a typical patent announcement day in our sample. The average announcement includes 3.6 patents, with an average of 0.1 green patents per announcement. Lastly, panel D of Table 1 shows that green patents make up 3.7% of all patents granted to an average company in our sample every year.

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[8] We exclude citations added by patent examiners and self-citations made by patent owners to their own patents, because they are unlikely to be useful in capturing the true patent quality (Alcácer et al., 2009).

[9] To address the issue that older patents have had more time to accumulate citations than younger patents, we use the truncation-adjusted number of citations in our analysis (Lerner and Seru, 2022). We calculate the truncation-adjusted patent citations by dividing the number of citations received by a patent by the number of citations received by an average patent applied for in the same year. For example, if a patent that was applied for in 2005 has accumulated 6 citations, but the average patent applied for in 2005 has so far received only 3 citations, the truncation-adjusted number of patent citations is equal to 2.

[10] Claims define the scope of a patent owner's rights with relation to the invention. Independent claims are complete sentences that stand on their own, without referring to other claims (Marco et al. 2019). Dependent claims refer to an independent claim and add a limitation to it.

4. Event study results

We use a standard event study approach to measure the impact of patent announcements on shareholder wealth. To estimate abnormal returns, we follow Kogan et al. (2017) and use the market adjusted model, i.e. the difference between the security's return and the return on the market portfolio[11], because many companies obtain patents every month or even every week. This approach mitigates the potential measurement error that is introduced when estimating a company's stock market beta by using asset pricing models that rely on non-overlapping pre-event estimation periods (Brown and Warner, 1985; MacKinlay, 1997).

4.1 All patent announcements

We measure the cumulative abnormal returns (CAR) over a three-day event window (0,+2) (Kogan et al., 2017).[12] We do not include the abnormal returns before the event date since the patent announcements are made by the USPTO and are unlikely to be leaked (Kogan et al., 2017). Our results are similar if we use alternative event windows.[13] In Table 2, we compare patent announcements that do not include green patents (grey events) with patent announcements that do (green events). The CAR(0,+2) of grey and green events follow similar distributions, as shown in Table B1 in Appendix B.

Panel A in Table 2 shows that grey events have an average CAR(0,+2) of 0.033%, which is statistically significant at the 1% level. This is similar to the results reported in the literature (Chemmanur et al., 2021). This is an economically significant market reaction. The average market capitalisation in our sample at the time of the patent announcement is $19.4 billion (see Table 1). Given an average CAR(0,+2) of 0.033%, the average grey event is associated with an increase in market value of $6.4 million (=0.033%*$19.4 bn). This is similar to Kogan et

[11] The risk-free rate adjusted market return for North America is from Kenneth French's website.
[12] Kogan et al. (2017) show that the share turnover increases during the first three days around a patent announcement, which suggests that this is when the patent announcement is priced in by the market.
[13] We obtain similar results when we measure the CARs over the (0,+1) and (0,+3) event windows.

al. (2017), who find that a median patent owned by a publicly listed company is worth $3m, while an average patent is valued at $10.3m. Contrary to grey events, the average CAR(0,+2) associated with green events is not statistically significant.

/Table 2 here/

4.2 Single patent announcements

To alleviate concerns that our results are sensitive to how we define grey and green events, in panel B of Table 2 we restrict the sample to patent announcements that include a single patent. This should provide a clear comparison between green and grey patents, since the announcements of single patents are not confounded by the grants of other patents. An average announcement of a grey patent generates a CAR(0,+2) of 0.023% which is statistically significant at the 1% level, and there is no market reaction to an announcement of a green patent.

To further compare green and grey patent announcements, in panel C of Table 2 we limit our sample to patents granted to firms operating in polluting industries (Berrone et al., 2013).[14] Again, we find that grey patent announcements in polluting industries generate a CAR(0,+2) of 0.038% which is statistically significant at the 1% level, while there is no market reaction to green patent announcements. Next, in panel D of Table 2, we only include patent announcements that have a high technological value. We define technological value to be high when the truncation-adjusted number of citations associated with a patent announcement is in the top 33% of its distribution. Grey events with high technological value generate a CAR (0,+2) of 0.069%, significant at the 1% level. However, there is no statistically significant reaction to green events.

[14] We follow Berrone et al. (2013) and classify polluting industries as the 20 most polluting U.S. industry sectors according to the Toxic Release Inventory (TRI), which is a U.S. government program measuring the management and emissions of toxic chemicals. The SIC codes of the 20 polluting industry sectors are: 10, 12, 13, 20, 24, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 49, 50, 51.

In panel E of Table 2 we limit our sample to patent announcements on days with a high level of climate change concerns. We define climate change concerns to be high when the value of the Unexpected Media Climate Change Concerns index measured over a three-day window (0,+2) is in the top 33% of its distribution. We find that, when climate change concerns are high, there is no statistically significant market reaction to either grey or green patent announcements.

In panel F of Table 2, we restrict our sample to announcements with high institutional investor ownership. We define institutional investor ownership as high when its value is in the top tercile of its distribution. We find evidence that high institutional investor ownership is associated with a positive market reaction to grey patent announcements, as indicated by a statistically significant CAR(0,+2) of 0.093%, at the 1% level. However, we find there is no market reaction to announcements with green patents over the same event window. Finally, in panel G of Table 2, we restrict our sample to announcements with high institutional investor attention. We define institutional investor attention as high when its value is in the top tercile of its distribution. We find evidence that high institutional investor attention is associated with a positive market reaction to grey patent announcements, as indicated by a statistically significant CARs(0,+2) of 0.126%, which is significant at the 1% level. However, there is no market reaction to announcements including green patents.

Overall our results suggest that in contrast to grey patent announcements, green patent announcements do not have a positive effect on shareholder wealth. This holds regardless of the timing of the green patent announcements, and regardless of the type of technology protected by the patents.[15] To investigate this in more detail, and control for other factors that

[15] We also rerun the analysis presented in Table 2 by limiting the time period to 1976-1990, 1991-2005, 2006-2019, and 2010-2019. Regardless of the choice of the time period, we find that there is no positive effect of green events on shareholder wealth. Moreover, there is no positive effect regardless of green patents' technological classification (Haščič and Migotto, 2015). Similarly, the results remain unchanged regardless of whether we focus only on green patents covering a product or only on patents protecting a process (Ganglmair et al., 2022). We do not report these results for the sake of brevity, but they are available upon request.

can affect the relationship between shareholder wealth and green patent announcements , in the next section we turn to regression analysis.

5. Regression analysis

Next, we test the value of green patents in a multivariate OLS regression setting. We estimate the following model:

$$CAR_{i,t} = \alpha + \beta_1 * \ln(1 + green\, patent\, volume)_{\,i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \quad (1)$$

$CAR_{i,t}$ is the average cumulative abnormal return over a three-day window (0,+2) following a patent announcement.[16] *Green patent volume* is the number of green patents granted.[17] $X_{i,t-1}$ is a vector of firm specific control variables lagged by one year. In particular, we include *market capitalization*, as larger firms may produce more valuable patents (Kogan et al., 2017); *firm age,* as younger firms can produce innovation of higher technological quality (Balasubramanian and Lee, 2008), *cash*, as companies with higher cash balances can produce more competitive innovation (Atanassov and Le, 2021); *leverage*, as debt financing can influence firm innovation (Geelen et al., 2022); *R&D*, as companies that invest more in R&D can have a higher innovation capability (Chen et al., 2018), and *Tobin's Q*, as growth opportunities can influence firm innovation (Jaffe, 1986). $Z_{i,t}$ is a vector of patent-related control variables. In particular, we include *patent volume,* as the market can react more positively to announcements of multiple patents, *patent citations*, as patents with a higher technological quality can be more valuable (Hall et al., 2005), and *patent claims*, as broader patents can be more valuable (Marco et al., 2019). Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

[16] In alternative specifications we use alternative dependent variables, including CAR(0,+1) and CAR(0,+3), and our results remain similar. For brevity we do not report these results, but they are available upon request.
[17] We obtain similar results if we use a dummy variable equal to 1 when a patent announcement includes a green patent. We do not report these results for the sake of brevity, but they are available upon request.

5.1 Impact of green patents on shareholder wealth and high climate risk exposure

We expect green patents to be more valuable to firms that are more exposed to climate risks.[18] Therefore, we modify model (2) to include an interaction between *green patent volume* and a dummy variable that identifies firms with high exposure to climate risk. We estimate the following model:

$$CAR_{i,t} = \alpha + \beta_1 * \ln(1 + green\ patent\ volume)_{i,t} + \beta_2 * high\ climate\ risk_{i,t-1} + \beta_3 * high\ climate\ risk_{i,t-1}\ x \ln(1 + green\ patent\ volume)_{\ i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \quad (2)$$

We identify high climate risk firms in three different ways. First, we identify high risk firms as firms operating in industries with high CO_2 emissions. We categorise carbon intensive industries using the list of heavy-emitting industries created by the Intergovernmental Panel on Climate Change (IPCC) (Choi et al., 2020; Krey et al., 2014). We match the most carbon intensive industries identified by the IPCC to the Fama-French 48 industry classification used in our sample. We create *CO_2 intensive industry*, which is a dummy variable equal to 1 if a firm is operating in a carbon intensive industry, and 0 otherwise. Second, we identify high climate risk firms as companies with a low Asset4 environmental score. We create *low environmental score*, which is a dummy variable that is equal to 1 when the firm's environmental score is in the bottom 33% of the variable's distribution, and 0 otherwise.[19] Third, we identify high climate risk firms by creating a dummy variable *high climate exposure $_{t-1}$*, which is equal to 1 when the level of a firm's exposure to climate change (Sautner et al., 2022) is in the top 33% of the variable's distribution, and 0 otherwise.[20]

[18] Climate risk can be divided into two parts; physical risk, which refers to a firm's exposure to more extreme weather events, and transition risk that refers to the potential costs of making the company more environmentally friendly in order to comply with climate regulations (von Schickfus, 2021).
[19] We obtain similar results if we use the median or the bottom 25% of the distribution as our cut-off points. For brevity we do not report these results, but they are available upon request.
[20] We obtain similar results if we use the median or the top 25% of the distribution as our cut-off points. The firm-level measure of climate change exposure is from Sautner et al. (2022) (see: section 3). For brevity we do not report these results, but they are available upon request.

Regression results are shown in Table 3. In column (1) of Table 3, we regress CAR(0,+2) solely on *green patent volume,* and we include year, and firm fixed effects. The coefficient is not statistically significant, which suggests that the number of green patents contained in an announcement does not affect the market reaction. In columns (3), (6), and (9) of Table 3, we interact *green patent volume* with *CO_2 intensive industry*, *low environmental score,* and *high climate risk exposure $_{t-1}$*, respectively. We find that in all specifications, the interactions are not statistically significant. The results suggest that even the green patents of firms with a high exposure to climate risks do not increase shareholder wealth.

/Table 3 here/

Overall, our results suggest that green patents do not increase shareholder wealth. Therefore, we find no support for our first hypothesis (H1). This is in contrast to the positive effect on shareholder wealth of grey patent announcements shown in section (4). But our findings are consistent with Pástor et al. (2021) who argue that green assets underperform brown assets over a long period of analysis during which any changes in green preferences of investors average to zero. Moreover, since green patents are credible signals of environmental commitment (Berrone et al., 2017), our results support Avramov et al. (2021) who argue that higher ESG ratings are negatively related to returns of firms with low ESG uncertainty. Moreover, green innovation can be seen as less valuable by the market than grey innovations because innovation is path dependent and green technologies have generally fewer past innovations to build upon (Aghion et al., 2014). Nanda et al. (2015) argue that early-stage renewable energy technologies spend more time in development and require significantly more investment than grey technologies. Similarly, Gaddy et al. (2017) show that venture capital investments in clean energy technologies yield low returns compared to investments in software or medical technologies, because clean technologies require more financing, return less capital to investors, and are more likely to fail.

5.2 Impact of green patents on shareholder wealth and climate change concerns

The impact of green patents on shareholder wealth may depend on how concerned investors are about the climate change problem. Therefore, we explore the relation between the level of climate change concerns and the market reaction to green patent announcements. We estimate the following model:

$$CAR_{i,t} = \alpha + \beta_1 * climate\ concerns_{i,t} + \beta_2 * \ln(1 + green\ patent\ volume)_{i,t} + \beta_3 * climate\ concerns_{i,t}\ x\ \ln(1 + green\ patent\ volume)_{i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \quad (3)$$

$CAR_{i,t}$ is the average cumulative abnormal return over a three-day window (0,+2) following a patent announcement.[21] The independent variable of interest is *climate concerns*, which measures the average level of the Unexpected Media Climate Change Concerns (UMC) index (Ardia et al., 2022) over a three-day window (0,+2).[22] *Green patent volume* is the number of green patents granted.[23] Our firm specific control variables include *market capitalization, firm age, cash*, *leverage*, *R&D, and Tobin's Q*. Our patent-related control variables include *patent volume*, *patent citations*, and *patent claims*. Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

Regression results are shown in Table 4. First, in column 1, we regress CAR(0,+2) solely on *climate concerns*, and we include year, and firm fixed effects. We find that the level of climate change concerns is not a statistically significant predictor of the market reaction to all patent announcements. Next, in column (3), we interact *climate concerns* with the number of green patents included in the announcement. The interaction term is not statistically significant.

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[21] In alternative specifications we use alternative dependent variables, including CAR(0,+1) and CAR(0,+3), and our results remain similar. For brevity we do not report these results, but they are available upon request.

[22] We obtain similar results if we measure the average climate change concerns over alternative windows, including (0,+1) and (-1,+1). Furthermore, our results are similar if instead of using a continuous measure we use a dummy variable that is equal to 1 when the level of climate concerns is high. For brevity we do not report these results, but they are available upon request.

[23] We obtain similar results if we use a dummy variable equal to 1 when a patent announcement includes a green patent. We do not report these results for the sake of brevity, but they are available upon request.

Therefore, we find no evidence that the impact of green patents on shareholder wealth depends on the level of climate change concerns.

/Table 4 here/

Climate concerns may only impact the market reaction to green patents granted to polluting companies, which face higher regulatory and transition risks with regards to climate change. Therefore, we modify model (4) to include *CO_2 intensive industry*, which is a dummy variable equal to 1 if a firm is operating in a carbon intensive industry, and 0 otherwise. We test the effect of climate change concerns on the value of green patents in carbon intensive industries using a triple interaction term between *CO_2 intensive industry*, *climate concerns* and *green patent volume*. The results are shown in Table I.A1 in the internet appendix.[24] Initially, in column (5) of Table I.A1, the triple interaction term is positive and significant at the 5% level, but the effect disappears after we add control variables in column (6). This suggests that climate concerns do not influence the market reaction to green patents granted to carbon intensive companies.

To test the robustness of this result, we modify model (4) to include *high climate exposure $_{t-1}$*, which is a dummy variable equal to 1 when the level of a firm's exposure to climate change (Sautner et al., 2022) is in the top 33% of the variable's distribution, and 0 otherwise.[25] We test the effect of climate change concerns on the value of green patents granted to firms with high climate change exposure by using a triple interaction term between *high climate exposure $_{t-1}$*, *climate concerns* and *green patent volume*. Our results are shown in Table I.A2 in the internet appendix. The triple interaction, which we add in column (5) of Table I.A2, is not statistically significant.

[24] The internet appendix is available at https://tinyurl.com/2p8e48c3.
[25] We obtain similar results if we use the median or the top 25% of the distribution as our cut-off points. The firm-level measure of climate change exposure is from Sautner et al. (2022) (see: section 3). For brevity we do not report these results, but they are available upon request.

We obtain similar results if we identify high climate risk firms based on their Asset4 environmental scores. We modify model (4) to include *low environmental score*, which is a dummy variable that is equal to 1 when the firm's environmental score is in the bottom 33% of the variable's distribution, and 0 otherwise.[26] Our results are shown in Table I.A3 in the internet appendix. In Column (5) of Table I.A3 we interact *low environmental score* with *climate concerns*, and *green patent volume*, and we find that the triple interaction is not statistically significant.

Overall, we find that the effect of green patents on shareholder wealth does not depend on the level of climate change concerns. Therefore, we find no support for our second hypothesis (H2). Our results suggest that investors do not view green patents as effective solutions for addressing the climate-related risks faced by companies and the broader economy.

5.3 Impact of green patents on shareholder wealth, and institutional investor ownership

Next, we investigate whether institutional investors reward companies for obtaining green patents. We modify model (4) to include institutional investor ownership as our explanatory variable of interest:

$$CAR_{i,t} = \alpha + \beta_1 * IO_{i,t-1} + \beta_2 * \ln(1 + green\ patent\ volume)_{i,t} + \beta_3 * IO_{i,t-1}\ x\ \ln(1 + green\ patent\ volume)_{i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \qquad (4)$$

CAR$_{i,t}$ is the average cumulative abnormal return over a three-day window (0,+2) following a patent announcement.[27] *IO*$_{i,t-1}$ is the proportion of a company's shares owned by institutional investors measured one quarter before a patent announcement. For example, if a patent announcement occurred in Q3 2013, we use the level of institutional investor ownership as of

[26] We obtain similar results if we use the median or the bottom 25% of the distribution as our cut-off points. For brevity we do not report these results, but they are available upon request.

[27] In alternative specifications we use alternative dependent variables, including CAR(0,+1) and CAR(0,+3), and our results remain similar. For brevity we do not report these results, but they are available upon request.

Q2 2013. We do this to address potential reverse causality between institutional investor ownership and patent announcements. *Green patent volume* is the number of green patents granted.[28] Our firm specific control variables include *market capitalization, firm age, cash, leverage, R&D, and Tobin's Q*. Our patent-related control variables include *patent volume, patent citations*, and *patent claims*. Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

Regression results are shown in Table 5. First, in column (1) of Table 5, we regress CAR(0,+2) solely on institutional ownership, and we include year, and firm fixed effects. The coefficient on $IO_{i,t-1}$ is initially negative and statistically significant at the 5% level. However, the statistical significance disappears after we include control variables in column (4), which suggests that the level of institutional investor ownership does not affect the market reaction to all patent announcements. In column (3) of Table 5, we interact institutional investor ownership with the number of green patents granted. The interaction term is not statistically significant.

/Table 5 here/

Institutional investors differ in their investment horizons which can affect how important corporate innovation is to them (Aghion et al., 2013; Bushee, 1998). Green patents could be especially valuable to institutional investors with long investment horizons since climate change is a long-run risk factor (Bansal et al., 2016). We obtain information on institutional investor classification from Brian Bushee's website, and we differentiate between the proportion of the company owned by transient, quasi-indexer, and dedicated institutional investors. Transient institutional investors are characterized by a short investment horizon, and a high portfolio turnover. Quasi-indexer and dedicated institutional investors are characterized by a long-term investment horizon and a low portfolio turnover (Bushee, 1998).

[28] We obtain similar results if we use a dummy variable equal to 1 when a patent announcement includes a green patent. We do not report these results for the sake of brevity, but they are available upon request.

We use model (5) to test whether the proportion of a company's shares owned by different types of institutional investors affects the market reaction to green patents. Regression results using the ownership by transient, quasi-indexer, and dedicated institutional investors are shown in Tables I.A4, I.A5 and I.A6 in the internet appendix, respectively. The interaction between the number of green patents and the ownership level by the three different types of institutional investors are all not statistically significant. We find no evidence that the level of institutional ownership is related to the impact of green patent announcements on shareholder wealth, regardless of how the level of institutional investor ownership is classified.[29]

5.4 Impact of green patents on shareholder wealth, and institutional investor attention

Institutional investors may not always be monitoring patent announcements since the amount of their attention is limited. Therefore, we test whether the impact of green patent announcements on shareholder wealth depends on the amount of institutional investor attention. We estimate the following model:

$$CAR_{i,t} = \alpha + \beta_1 * institutional\ attention_{i,t} + \beta_2 * \ln(1 + green\ patent\ volume)_{i,t} + \beta_3 * institutional\ attention_{i,t}\ x\ \ln(1 + green\ patent\ volume)_{i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \quad (5)$$

$CAR_{i,t}$ is the average cumulative abnormal return over a three-day window (0,+2) following a patent announcement.[30] *Institutional attention*$_{i,t}$ measures the average level of institutional investor attention over a three-day window (0,+2) (Ben-Rephael et al., 2017).[31] *Green patent*

[29] Our results are similar if instead of using a continuous measure of institutional investor ownership we use a dummy variable that equal to 1 when the level of institutional investor ownership is high. For brevity we do not report these results, but they are available upon request.

[30] In alternative specifications we use alternative dependent variables, including CAR(0,+1) and CAR(0,+3), and our results remain similar. For brevity we do not report these results, but they are available upon request.

[31] We use the three-day average of the Bloomberg Heat Scores (Ben-Rephael et al., 2017, Chiu et al., 2021). Our results are similar if we measure institutional investor attention over alternative windows, or if we use a dummy variable to identify high levels of institutional investor attention. For brevity we do not report these results, but they are available upon request.

volume is the number of green patents granted.[32] Our firm specific control variables include *market capitalization, firm age, cash, leverage, R&D, and Tobin's Q*. Our patent-related control variables include *patent volume, patent citations*, and *patent claims*. Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

Regression results are shown in Table 6. First, in column 1 of Table 6, we regress CAR(0,+2) solely on *institutional attention*, and we include year, and firm fixed effects. Ceteris paribus, the positive and statistically significant coefficient (at the 1% level) on *institutional attention* indicates that the market reaction to a patent announcement increases by 0.09% when institutional investor attention increases by 1. The standard deviation of institutional investor attention is 1.0 (see Table 1). Therefore, a one-standard deviation increase in institutional investor attention increases the market reaction to a patent announcement by 0.09% (=1.0*0.09%). In column 3 of Table 6, we interact institutional investor attention with the number of green patents announced. The interaction term in column (3) is not statistically significant. This suggests that green patent announcements do not increase shareholder wealth , even when institutional investors are paying attention to the company that is obtaining the patents.

/Table 6 here/

Institutional investor attention may only affect the market reaction to green patents when the level of institutional investor ownership is high. Therefore, we modify model (6) to include *high* IO_{t-1}, which is a dummy variable equal to 1 when the level of institutional ownership of a company is in the top 33% of the variable's distribution, and 0 otherwise.[33] Our results are shown in Table I.A7 in the internet appendix. In column (5) of Table I.A7, we interact *high*

[32] We obtain similar results if we use a dummy variable equal to 1 when a patent announcement includes a green patent. We do not report these results for the sake of brevity, but they are available upon request.
[33] We obtain similar results if we use the median or the top 25% of institutional ownership's distribution as our cut-off points. For brevity we do not report these results, but they are available upon request.

IO_{t-1} with institutional investor attention and the number of green patents, and we find that the interaction term is not statistically significant. This result remains unchanged if we use a high level of transient, quasi-indexer, or dedicated level of institutional ownership instead.[34]

Institutional investor attention may affect the market reaction to green patents when the level of climate concerns is high. A high level of climate concerns can increase the perceived urgency of the climate change problem. This can make institutional investors react to green patents more positively. We test this proposition by modifying model (6) to include *high climate concerns*, which is a dummy variable equal to 1 when the level of climate concerns is in the top 33% of the variable's distribution, and 0 otherwise.[35] The results are presented in Table I.A8 in the internet appendix. The interaction between *high climate concerns*, *institutional attention*, and the *green patent volume* is added in column (5) of Table I.A8. The triple interaction term is not statistically significant.

Next, we investigate whether institutional investor attention affects the market reaction to green patents for firms with high climate exposure (Sautner et al., 2022). To test this, we modify model (6) to include *high climate exposure* $_{t-1}$, which is a dummy variable equal to 1 when the level of a firm's exposure to climate change is in the top 33% of the variable's distribution, and 0 otherwise.[36] Our results are shown in Table I.A9 in the internet appendix. In column (5) we add the triple interaction between *high climate exposure* $_{t-1}$, *institutional attention*, and *green patent volume*. The triple interaction is not statistically significant.

Overall, we find no evidence that the impact of green patents on shareholder wealth depends on the level of institutional investors' ownership or attention, even when the companies that obtain the green patents face a high exposure to climate change. Therefore, we find no support

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[34] For brevity we do not report these results, but they are available upon request.

[35] We obtain similar results if we use the median or the top 25% of institutional ownership's distribution as our cut-off points. For brevity we do not report these results, but they are available upon request.

[36] We obtain similar results if we use the median or the top 25% of institutional ownership's distribution as our cut-off points. For brevity we do not report these results, but they are available upon request.

for our third hypothesis (H3). This result is consistent with Michaely et al. (2021), who study the voting behavior of institutional investors on environmental and social (ES) corporate proposals. They find that institutional investors' ES funds tend not to support ES proposals when their vote is likely to affect a voting outcome that conflicts with the broader non-ES objectives of the institutional investors. Therefore, whilst institutional investors communicate their commitment to protecting the environment (Fink, 2020), they do not necessarily act accordingly. Moreover, our results are also consistent with von Schickfus (2021), who finds that institutional investor ownership is not related to a change in the direction of firm innovation towards green technologies.

The results so far suggest that green patent announcements do not increase shareholder wealth. However, it is possible that investors have only more recently started rewarding companies for obtaining green patents as governments have increasingly highlighted the vital importance of strategies to combat climate change. To test the robustness of our results, we exploit a major shock to the importance of green technologies caused by the adoption of the Paris Agreement during the 2015 United Nations Climate Change Conference. We present this analysis in Appendix C. Overall; we find no evidence that the impact of green patent announcements on shareholder wealth changed after the adoption of the Paris Agreement.

6. What happens after firms obtain green patents?

6.1 Green patenting activity, and environmental score

Overall, our results suggest that green patents do not increase shareholder wealth. In this section, we investigate the possible reasons for this result. We start by testing whether changes in green patenting activity of a company are related to the firm's environmental score. If green patents improve environmental performance (Amore and Bennedsen, 2016), we expect to see a positive association between the two variables. We estimate the following model:

$$Environmental\ score_{i,t} = \alpha + \beta_1 * green\ patenting\ activity_{\ i,t-1} + \ \beta_n * X_{i,t-1} + \gamma + \xi + u_{i,t} \quad (6)$$

Environmental score measures a firm's environmental performance. We measure *green patenting activity* using six different firm-level metrics that are lagged by one year: (1) *green patents ratio$_{t-1}$*, (2) *green applications ratio$_{t-1}$*, (3) *green citations ratio$_{t-1}$*, (4) *green patent stock ratio$_{t-1}$*, (5) *green applications stock ratio$_{t-1}$*, and (6) *green citations stock ratio$_{t-1}$*.[37] We describe these metrics in Appendix D. $X_{i,t-1}$ is a vector of firm specific control variables, including *market capitalization*, *firm age*, *cash*, *leverage*, *R&D, and Tobin's Q*.[38] Moreover, γ denotes firm fixed effects and ξ denotes year fixed effects.

Our regression results are shown in Table 7. In column (1) of Table 7, we regress *environmental score* solely on *green patents ratio$_{t-1}$*. We find that there is no statistically significant relation between green patenting activity and environmental scores. In the remaining columns of Table 7, we test the other measures of green patenting activity, and we find very similar results. As shown in columns (3), (5), and (11) of Table 7, the green applications- and citations-related metrics are initially statistically significant, but the effect disappears after adding control variables. Overall, we find no evidence that green patenting activity affects environmental scores. Our results are at odds with Cohen et al. (2022), who find a positive correlation between green patenting and environmental scores of firms operating outside of the energy sector. However, the difference possibly lies in the fact that Cohen et al. (2022) rely only on year fixed effects as they are interested in the cross-sectional variation. Instead, we include both firm- and year-fixed effects to examine whether new green patents obtained by firms are related to changes within firms.

/Table 7 here/

[37] For robustness, in alternative model specifications we also include the second and the third lags of the green patent activity measures, and we obtain similar results. For brevity we do not report these results, but they are available upon request.
[38] Our results are not sensitive to the choice of firm specific control variables.

6.2 Green patenting activity, and institutional investor ownership

Next, we investigate whether the level of institutional investor ownership is related to a firm's green patenting activity. Since environmental performance can be important to institutional investors (Krueger et al., 2020), we expect a positive correlation between the two variables. We use model (7) where all metrics of green patenting activity are lagged by one year. In alternative specifications we also include the second and the third lags of the green patent activity measures and our results (unreported) are similar. Our dependent variable is $IO_{i,t}$, which is the proportion of a company's shares owned by institutional investors in a given year. Our results are presented in Table 8. In column (1) of Table 8, we regress the level of institutional investor ownership on the green proportion of all patents granted to a company in a given year. We find no statistically significant relation between the two variables. Similarly, as shown in columns (3) to (12) of Table 8, when we use any of our other measures of green patenting activity, we also find that they have no effect on the level of institutional investor ownership.

/Table 8 here/

The importance of green patents to institutional investors may also differ depending on their investment horizon. Therefore, we use model (7) to test whether the proportion of a company's shares owned by different types of institutional investors is related to green patenting activity. Regression results using the ownership by transient, quasi-indexer, and dedicated institutional investors are shown in Tables I.A10, I.A11 and I.A12 in the internet appendix, respectively. We find that there is no relation between firms' green patenting activity and the level of ownership by the three different types of institutional investors. Overall, we find no evidence that institutional investors value green innovation, which is consistent with our previous results and the work of von Schickfus (2021).

6.3 Green patenting activity, and Tobin's Q

Lastly, we test whether changes in green patenting activity are related to changes in firm value, as measured by Tobin's Q. If green patents are valuable we expect to find a positive correlation between the two variables. We estimate the following model:

$$Tobin's\ Q_{i,t} = \alpha + \beta_1 * green\ patenting\ activity_{\ i,t-1} + \ \beta_n * X_{i,t-1} + \gamma + \xi + u_{i,t} \qquad (7)$$

Where *green patenting activity* is measured using six different metrics that are lagged by one year[39] : (1) *green patents ratio*$_{t-1}$, (2) *green applications ratio*$_{t-1}$, (3) *green citations ratio* $_{t-1}$, (4) *green patent stock ratio*$_{t-1}$, (5) *green applications stock ratio*$_{t-1}$, and (6) *green citations stock ratio*$_{t-1}$. $X_{i,t-1}$ is a vector of firm specific control variables, including *market capitalization*, *firm age*, *cash*, *leverage*, and *R&D*. [40] Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

Regression results are shown in Table 9. We find no statistically significant relation between any of our measures of green patenting activity and Tobin's Q.[41] Overall, we find no evidence that green patenting activity is positively associated with firm value.[42]

/Table 9 here/

6.4. Portfolio analysis

Our findings so far could be the result of the market mispricing green patents or realizing their value with a delay. We test this alternative explanation using a calendar-time portfolio approach. Every week we construct value- and equally-weighed portfolios of companies that

[39] In alternative model specifications we also include the second and the third lags of the green patent activity measures, and we obtain similar results. For brevity we do not report these results, but they are available upon request.
[40] Our results are not sensitive to the choice of firm specific control variables.
[41] Our results are similar if we use a logarithm of Tobin's Q.
[42] Our results contrast with Hao et al. (2022), who find a positive correlation between green patenting and Tobin's Q. However, their study focuses on China during 2007-2018, while our sample covers the United States during 1976-2019. The disparity in the results could be driven by the different regulatory environments of the two countries (Allen et al., 2005).

obtain new green patents. The stock selection takes place on Tuesdays.[43] We consider portfolio holding periods of 4, 12, 24, 32, 52, 104, and 156 weeks. We include a stock in a portfolio every time a new green patent is announced, and we rebalance the portfolios every week.[44] We evaluate the performance of the portfolios using the following model:

$$R_{p,t} - R_{f,t} = \alpha + \beta_{Mkt} * (R_{m,t} - R_{f,t}) + \beta_{SMB} * SMB_t + \beta_{HML} * HML_t + \beta_{RMW} * RMW_t + \beta_{CMA} * CMA_t + \beta_{MOM} * MOM_t + \varepsilon_t \quad (8)$$

Where $R_{p,t}$ is the portfolio return, $R_{f,t}$ is the risk-free rate, and $R_{m,t}$ is the market return. SMB_t, HML_t, RMW_t, and CMA_t are the size, value, profitability, and investment factors, respectively (Fama and French, 2015). MOM_t is the momentum factor (Carhart, 1997). All factor returns are from Kenneth French's website and are on a weekly frequency.

Panel A of Table 10 presents the alphas of both value- and equally-weighted portfolios of firms that had a green patent announcement. We find that green patent portfolios yield a negative alpha, with consistent results across all holding periods. For instance, the value-weighted strategy generates a negative alpha of -11 basis points per week (significant at the 1% level) over a 12-week holding period. For robustness, in Panel B of Table 10 we limit the portfolio construction to companies that had a green event which consisted of a single green patent only. Once again, the results show that across holding periods green patents yield a negative alpha. The only exception is the 4-week holding period when the alpha is not statistically significant.

We also split the portfolios into quintiles based on the initial market reaction to green patent announcements, and the results hold. The majority of alphas of green patent portfolios remain negative regardless of the initial market reaction to the announcements. For brevity we do not

[43] Our results are similar if we select the stocks every Wednesday instead. For brevity we do not report these results, but they are available upon request.
[44] Our results are similar if we buy the stock of the same company only once during the same portfolio holding period instead. For brevity we do not report these results, but they are available upon request.

report these results, but they are available upon request. In additional analysis (unreported for brevity), we find that for the 1976-1999 period the underperformance of green patenting companies was even more pronounced. In contrast, during 2000-2019 the portfolios' alphas are either negative or not statistically significant. This could be explained by the fact that green technologies have progressed significantly since the end of the 20th century (Blanco et al., 2022).

Overall, our results indicate that firms engaging in green innovation underperform the market. This is consistent with the argument that investors' green preferences, who can derive non-monetary benefits from holding green assets, put a downward pressure on the expected alphas of green stocks (Pástor et al., 2021). Similarly, Avramov et al. (2022) find that stock performance of high ESG-rated firms is negatively associated with low ESG uncertainty. This is relevant since green patents can decrease the uncertainty with regards to a firm's environmental commitment (Berrone, 2017). Moreover, the results are consistent with green technologies having low average returns (Gaddy et al., 2017), which van den Heuvel and Popp (2022) attribute to weak market demand for green technologies.

To further explore our findings, we conduct sub-sample analysis based on different firm characteristics. First, we differentiate between green patent announcements involving firms that operate in CO_2 intensive industries, as created by the IPCC (Krey et al., 2014), and firms that do not. We follow the same approach described earlier in this section to build the weekly portfolios. Second, we differentiate between firms based on their R&D intensity. Each week, we sort firms with green patent announcements into quintiles depending on their previous year's amount of R&D expenditure scaled by total assets.[45] The results for CO_2 intensity (Tables E1 and E2) and R&D intensity (Table E3) are reported in Appendix E. Portfolios consisting of firms that operate in CO_2 intensive industries have alphas that are more negative

[45] Our results are similar if we sort firms into deciles instead (unreported for brevity but available upon request).

and more statistically significant than the full-sample results presented in Table 10. In contrast, all alphas of portfolios consisting of non-CO_2 intensive firms are not statistically significant (Table E2 in Appendix E). This is consistent with Cohen et al. (2022) who find that energy companies are less rewarded for obtaining green patents than other firms, in terms of their environmental scores. Regarding R&D intensity (Table E3 in Appendix E) portfolios of firms in the bottom quintile in terms of R&D intensity consistently generate negative and statistically significant alphas at the 5% level. In contrast, the alphas of portfolios of firms in the top R&D quintile are largely not statistically significant. Our results support Cohen et al. (2013), who show that firms with low innovation 'ability' and low R&D underperform compared to firms with high innovation 'ability' and R&D. Overall, our results suggest that carbon-intensive firms and firms with a low R&D focus are penalized more for obtaining green patents.

7. Robustness: Climate Change Mitigation Technologies

To alleviate any concerns that our results are driven by how we classify patents on environmentally friendly technologies (see: section 3), in this section we focus specifically on patents covering Climate Change Mitigation Technologies (CCMTs). CCMT patents are identified by a dedicated patent classification scheme developed by the European Patent Office (Angelucci et al., 2018). CCMT patents are tagged using either an "Y02" or a "Y04" classification code. These codes are a part of the Cooperative Patent Classification (CPC) system (Grassano et al., 2020).[46]

We repeat all of our analyses using CCMT patents (Angelucci et al., 2018) instead of green patents (Haščič and Migotto, 2015) and our results remain unchanged. We find no effect of CCMT patent announcements on the shareholder wealth of firms with a high exposure to climate change risks, as shown in Table I.A13 in the internet appendix. Moreover, there is no

[46] The CCMT classification scheme includes, among others, technologies on carbon capture storage of greenhouse gases, technologies related to adaptation to climate change, and technologies that aim to reduce greenhouse gas emissions (Grassano et al., 2020).

statistically significant relation between the level of climate change concerns and the market reaction to CCMT patents (Table I.A14 in the internet appendix). Furthermore, neither the level of institutional investor ownership, nor the amount of institutional investor attention affects the market reaction to CCMT patents, as shown in Tables I.A15 and I.A16 in the internet appendix, respectively. We also find no relation between CCMT patenting activity and firm's environmental score, level of institutional investor ownership, or Tobin's Q, as shown in Tables I.A17, I.A18, and I.A19 in the internet appendix, respectively. Lastly, portfolios constructed based on announcements of new CCMT patents have alphas that are either negative or not statistically significant, as shown in Table I.A20 in the internet appendix. We conclude that it is unlikely for our results to be driven by how we identify patents on environmentally friendly technologies.

8. Conclusion

Despite the urgent calls for more green innovation to fight climate change (Climate-KIC, 2021; Nordhaus, 2021; U.S. State Department, 2021) we find no evidence that green patents increase shareholder wealth. This is true for green patents obtained by companies operating in carbon-intensive industries as well as for firms with a high exposure to climate change. We also find that the impact of green patent announcements on shareholder wealth does not depend on the level of climate concerns. Despite the increasing pressure from institutional investors on companies to reduce their carbon footprint, we find no evidence that the environment is a priority for institutional investors. The impact of green patent announcements on shareholder wealth is not related to the level of institutional investor ownership or the amount of institutional investor attention. Similarly, we find that the impact of green patent announcements on shareholder wealth has not changed after the adoption of the Paris Agreement on 12 December 2015. Moreover, we find no evidence that an increase in the number of green patents obtained by companies is related to higher environmental scores, level of institutional investor ownership, or firm value. Lastly, we show that investors respond negatively to firms obtaining new green patents. Moreover, the underperformance of firms with green patent announcements is most pronounced for firms in CO_2 intensive industries and for firms with low R&D intensity.

Overall, we find that firms are not rewarded for engaging in green innovation. At a first glance, this finding may seem surprising since green innovation is seen as the key to solving the climate change problem. However, our results are consistent with the argument that this is partially a consequence of green tastes of investors, who push up the prices of green stocks and lower their expected returns (Pástor et al., 2021). Moreover, our results are consistent with green innovation being viewed as risky (Nanda et al., 2015), and potentially less advanced than grey innovation (Acemoglu et al., 2012; IEA, 2021).

Table 1: Descriptive statistics

Panel A: Patent owner characteristics							
	Mean	Median	SD	25th	75th	Firms	Events
Market capitalization ($bn)	19.4	2.9	56.7	0.6	12.7	6,736	450,628
Firm age (years)	30.1	23.2	23.4	10.8	48.1	7,263	467,502
Cash (%)	11.9	7.6	13.7	2.3	16.3	6,608	421,283
Leverage (%)	52.5	51.8	40.0	37.8	64.9	6,751	449,700
R&D (%)	8.6	5.1	13.3	2.3	10.2	5,557	421,386
Tobin's Q	2.2	1.6	2.4	1.2	2.4	6,619	402,088
IO (%)	57.2	61.0	24.3	42.3	76.3	6,362	397,233
IO transient (%)	13.1	11.4	9.0	6.2	18.1	5,967	389,023
IO quasi-indexer (%)	41.3	43.4	18.9	28.9	55.5	6,315	396,619
IO dedicated (%)	3.6	1.7	5.2	0.3	4.7	4,773	328,921
Environmental score	38.4	37.5	29.3	9.4	63.7	1,310	143,952
Climate exposure (%)	8.1	3.1	18.6	0.0	8.2	2,591	206,389
Panel B: Patent characteristics							
Patent citations	1.3	0.5	4.0	0.1	1.2	7,101	454,741
Patent claims	1.1	1.0	0.2	1.0	1.0	7,263	467,500
Panel C: Announcement day characteristics							
Patent volume	3.6	1.0	7.9	1.0	3.0	7,263	467,502
Green patent volume	0.1	0.0	0.8	0.0	0.0	7,263	467,502
Climate concerns (0,+2) (%)	10.3	6.2	24.2	-6.9	23.4	2,979	171,026
Institutional attention (0,+2)	0.7	0.0	1.0	0.0	1.3	1,765	128,504

Table 1. Continued

Panel D: Yearly measures of green patenting activity							
Green patents ratio (%)	3.7	0.0	14.2	0.0	0.0	8,030	N/A
Green applications ratio (%)	3.7	0.0	14.3	0.0	0.0	8,052	N/A
Green citations ratio (%)	4.1	0.0	15.6	0.0	0.0	7,604	N/A
Green patent stock ratio (%)	3.9	0.0	14.7	0.0	0.0	8,217	N/A
Green applications stock ratio (%)	4.0	0.0	15.0	0.0	0.0	8,234	N/A
Green citations stock ratio (%)	4.3	0.0	15.9	0.0	0.0	7,611	N/A

This table reports the descriptive statistics. Events is the number of patent announcements. Panels A, B, and C present descriptive statistics on a patent announcement-level. Panel A reports patent owner characteristics. Panel B shows patent characteristics, Panel C shows announcement day characteristics and Panel D shows descriptive statistics of green patenting activity on a yearly level. See Table A1 in Appendix A for variable definitions.

Table 2: Event study results

	Mean AR (0), %	Mean AR (+1), %	Mean AR (+2), %	Mean AR (+3), %	Mean CAR (0,+1), %	Mean CAR (0,+2), %	Mean CAR (0,+3), %	Events
Panel A: All patent announcements								
All events	-0.015***	0.023***	0.020***	0.013***	0.008*	0.028***	0.042***	467,502
Grey events	-0.015***	0.025***	0.023***	0.016***	0.010**	0.033***	0.048***	428,026
Green events	-0.013	0.002	-0.010	-0.009	-0.011	-0.021	-0.030*	39,476
Panel B: Announcements of single patents only								
All events	-0.031***	0.019***	0.033***	0.033***	-0.012*	0.021**	0.054***	248,411
Grey events	-0.029***	0.019***	0.033***	0.033***	-0.010	0.023***	0.056***	238,412
Green events	-0.069***	0.013	0.024	0.038*	-0.056*	-0.031	0.007	9,999
Panel C: All announcements in polluting industries								
All events	-0.013***	0.029***	0.016***	0.008**	0.016***	0.032***	0.040***	323,916
Grey events	-0.013***	0.032***	0.019***	0.009**	0.019***	0.038***	0.047***	293,349
Green events	-0.011	0.001	-0.017	-0.003	-0.010	-0.026	-0.030	30,567
Panel D: All announcements with high technological value								
All events	-0.008	0.035***	0.033***	0.007	0.027***	0.060***	0.068***	149,299
Grey events	-0.009	0.038***	0.040***	0.011*	0.029***	0.069***	0.080***	136,046
Green events	0.011	0.001	-0.016	-0.028*	0.011	-0.005	-0.033	12,846

Table 2. Continued

	Mean AR (0), %	Mean AR (+1), %	Mean AR (+2), %	Mean AR (+3), %	Mean CAR (0,+1), %	Mean CAR (0,+2), %	Mean CAR (0,+3), %	Events
Panel E: All announcements with high climate change concerns								
All events	-0.029***	0.034***	-0.001	0.001	0.006	0.004	0.006	56,186
Grey events	-0.029***	0.036***	0.003	0.005	0.006	0.009	0.014	50,805
Green events	-0.020	0.019	-0.040*	-0.032	-0.001	-0.041	-0.072	5,381
Panel F: All announcements with high institutional investor ownership								
All events	0.016***	0.045***	0.026***	0.009*	0.061***	0.087***	0.096***	134,901
Grey events	0.018***	0.047***	0.028***	0.009*	0.065***	0.093***	0.102***	125,844
Green events	-0.003	0.007	0.008	0.008	0.004	0.012	0.019	9,057
Panel G: All announcements with high institutional investor attention								
All events	0.039***	0.057***	0.017*	-0.019**	0.096***	0.113***	0.095***	38,219
Grey events	0.042***	0.066***	0.017*	-0.015*	0.109***	0.126***	0.112***	31,929
Green events	0.022	0.011	0.014	-0.039**	0.033	0.047	0.008	6,290

This table presents the event study results, in %. “All events” refers to all announcements. “Green events” (“Grey events”) refers to events that do (do not) include a green patent. Panel A presents full sample results. Panel B shows events that include a single patent only. Panel C shows events in polluting industries only, as classified by Berrone (2013). Panel D presents events with high technological value; when the truncation-adjusted number of citations is in the top 33% of its distribution. Panel E shows events with a high level of climate change concerns; when the value of the UMC index measured over a three-day window (0,+2) is in the top 33% of its distribution. Panel F shows events that include firms with a high level of institutional investor ownership; when the institutional ownership variable is in the top 33% of its distribution. Panel G shows events that are accompanied by high levels of institutional investor attention; when the value of the attention variable over a three-day window (0,+2) is in the top 33% of its distribution. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 3: Market reaction (CAR 0,+2), green patents, and high climate risk firms

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ln (1+green patent volume)	0.0002 (0.0002)		0.0001 (0.0003)	0.0001 (0.0003)		0.0003 (0.0003)	0.0004 (0.0003)		0.0001 (0.0003)	0.0002 (0.0004)
CO_2 Intensive Industry		0.0006 (0.0007)	0.0006 (0.0007)	-0.0033** (0.0015)						
CO_2 Intensive Industry x Ln (1+green patent volume)			0.0001 (0.0004)	-0.0000 (0.0004)						
Low env. Score $_{t-1}$					0.0006* (0.0004)	0.0007* (0.0004)	0.0008** (0.0004)			
Low env. Score $_{t-1}$ x Ln (1+green patent volume)						-0.0008 (0.00013)	-0.0008 (0.0015)			
High climate exposure $_{t-1}$								-0.0000 (0.0002)	-0.0000 (0.0002)	-0.0000 (0.0002)
High climate exposure $_{t-1}$ x Ln (1+green patent volume)									-0.0000 (0.0004)	-0.0001 (0.0004)
Market capitalization $_{t-1}$				-0.0014** (0.0003)			-0.0031*** (0.0007)			-0.0018*** (0.0005)
Firm age $_{t-1}$				-0.0007* (0.0004)			0.0006 (0.0007)			-0.0007 (0.0006)
Cash $_{t-1}$				0.0012 (0.0011)			0.0018 (0.0020)			-0.0012 (0.0014)

Table 3. Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Leverage $_{t-1}$				-0.0013*			-0.0011			-0.00012
				(0.0007)			(0.0014)			(0.0011)
R&D $_{t-1}$				-0.0007			-0.0039			-0.0003
				(0.0026)			(0.0074)			(0.0038)
Tobin's Q $_{t-1}$				0.0000			0.0002			0.0002
				(0.0002)			(0.0002)			(0.0002)
Ln (1+patent volume)				0.0001			-0.0002			-0.0000
				(0.0001)			(0.0002)			(0.0002)
Patent citations				0.0002*			0.0000			0.0001
				(0.0001)			(0.0002)			(0.0002)
Patent claims				0.0004			0.0013			-0.0018
				(0.0009)			(0.0013)			(0.0012)
Constant	0.0003**	0.0001	0.0001	0.0145***	0.0004*	0.0004*	0.0269***	0.0005**	0.0005**	0.0193***
	(0.0001)	(0.0003)	(0.0003)	(0.0024)	(0.0002)	(0.0002)	(0.0067)	(0.0002)	(0.0002)	(0.0043)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	466,227	466,227	466,227	337,166	125,928	125,928	98,378	199,139	199,139	160,338
R-squared	0.0269	0.0269	0.0269	0.0284	0.0127	0.0127	0.0146	0.0208	0.0208	0.0226

The dependent variable is CAR (0,+2) calculated using the market-adjusted model. Standard errors are clustered at firm and grant date-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of patent announcements. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 4: Market reaction (CAR 0,+2), green patents, and climate concerns (0,+2)

	(1)	(2)	(3)	(4)
Climate concerns	-0.0013 (0.0011)		-0.0014 (0.0012)	-0.0019 (0.0013)
Ln (1+green patent volume)		0.0002 (0.0002)	-0.0001 (0.0003)	-0.0003 (0.0003)
Climate concerns x Ln (1+green patent volume)			0.0012 (0.0010)	0.0020* (0.0011)
Market capitalization $_{t-1}$				-0.0024*** (0.0006)
Firm age $_{t-1}$				-0.0015** (0.0007)
Cash $_{t-1}$				-0.0014 (0.0017)
Leverage $_{t-1}$				-0.0002 (0.0012)
R&D $_{t-1}$				-0.0053 (0.0042)
Tobin's Q $_{t-1}$				0.0004* (0.0002)
Ln (1+patent volume)				0.0001 (0.0002)
Patent citations				0.0001 (0.0002)
Patent claims				-0.0031** (0.0013)
Constant	0.0005 (0.0003)	0.0003** (0.0001)	0.0005 (0.0003)	0.0263*** (0.0058)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	170,583	466,227	170,583	131,839
R-squared	0.0297	0.0269	0.0298	0.0316

The dependent variable is CAR (0,+2) calculated using the market-adjusted model. Standard errors are clustered at firm and grant date-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of patent announcements. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 5: Market reaction (CAR 0,+2), green patents, and inst. Investor ownership

	(1)	(2)	(3)	(4)
IO $_{t-1}$	-0.0014** (0.0007)		-0.0015** (0.0007)	-0.0006 (0.0008)
Ln (1+green patent volume)		0.0002 (0.0002)	-0.0003 (0.0008)	-0.0000 (0.0010)
IO $_{t-1}$ x Ln (1+green patent volume)			0.0007 (0.0012)	0.0002 (0.0015)
Market capitalization $_{t-1}$				-0.0016*** (0.0003)
Firm age $_{t-1}$				-0.0005 (0.0004)
Cash $_{t-1}$				0.0015 (0.0012)
Leverage $_{t-1}$				-0.0015* (0.0008)
R&D $_{t-1}$				-0.0020 (0.0027)
Tobin's Q $_{t-1}$				0.0000 (0.0002)
Ln (1+patent volume)				0.0000 (0.0001)
Patent citations				0.0003** (0.0002)
Patent claims				0.0004 (0.0010)
Constant	0.0012*** (0.0004)	0.0003** (0.0001)	0.0012*** (0.0004)	0.0148*** (0.0027)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	390,611	466,227	390,611	289,776
R-squared	0.0275	0.0269	0.0275	0.0295

The dependent variable is CAR (0,+2) calculated using the market-adjusted model. Standard errors are clustered at firm and grant date-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm and year fixed effects. All firm control variables are lagged by one year. Observations is the number of patent announcements. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 6: Market reaction (CAR 0,+2), green patents, and inst. Investor attention (0,+2)

	(1)	(2)	(3)	(4)
Institutional attention	0.0009*** (0.0002)		0.0010*** (0.0002)	0.0011*** (0.0002)
Ln (1+green patent volume)		0.0002 (0.0002)	0.0003 (0.0003)	0.0001 (0.0004)
Institutional attention x Ln (1+green patent volume)			-0.0003 (0.0002)	-0.0003 (0.0002)
Market capitalization $_{t-1}$				-0.0021*** (0.0006)
Firm age $_{t-1}$				-0.0008 (0.0009)
Cash $_{t-1}$				-0.0021 (0.0020)
Leverage $_{t-1}$				0.0025* (0.0014)
R&D $_{t-1}$				0.0036 (0.0038)
Tobin's Q $_{t-1}$				0.0006*** (0.0002)
Ln (1+patent volume)				0.0002 (0.0002)
Patent citations				0.0000 (0.0002)
Patent claims				-0.0005 (0.0014)
Constant	-0.0005** (0.0003)	0.0003** (0.0001)	-0.0005** (0.0003)	0.0167** (0.0056)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	128,305	466,227	128,305	99,811
R-squared	0.0239	0.0269	0.0239	0.0257

The dependent variable is CAR (0,+2) calculated using the market-adjusted model. Standard errors are clustered at firm and grant date-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of patent announcements. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 7: Green patenting activity and environmental score

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Green patents ratio $_{t-1}$	-1.88	-1.77										
	(2.14)	(2.80)										
Green applications ratio $_{t-1}$			3.85*	4.84								
			(1.96)	(2.81)								
Green citations ratio $_{t-1}$					7.26*	2.54						
					(3.67)	(5.36)						
Green patent stock ratio $_{t-1}$							-7.51	-0.78				
							(5.31)	(6.16)				
Green applications stock ratio $_{t-1}$									-3.55	-3.85		
									(5.73)	(13.74)		
Green citations stock ratio $_{t-1}$											20.08**	16.14
											(7.67)	(12.93)
Market capitalization $_{t-1}$		4.12***		3.74***		3.63***		2.98***		2.90***		3.39***
		(0.89)		(1.05)		(1.05)		(0.95)		(0.93)		(1.03)
Firm age $_{t-1}$		0.48		0.13		-0.29		0.53		0.77		0.00
		(2.09)		(1.88)		(3.28)		(1.96)		(1.68)		(3.26)
Cash $_{t-1}$		-0.57		1.29		1.63		0.61		0.96		1.30
		(3.35)		(3.32)		(3.89)		(3.00)		(2.87)		(3.66)
Leverage $_{t-1}$		1.80		1.25		1.21		0.22		-0.45		1.22
		(3.25)		(3.20)		(3.32)		(2.98)		(2.86)		(3.25)
R&D $_{t-1}$		5.59		4.97		6.19		3.41		3.33		4.34
		(5.02)		(5.16)		(6.51)		(4.34)		(4.21)		(5.27)

Table 7. Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Tobin's Q $_{t-1}$		-0.73**		-0.66*		-0.52		-0.38		-0.42		-0.44
		(0.31)		(0.31)		(0.38)		(0.32)		(0.32)		(0.38)
Constant	29.61***	-3.47	28.75***	-2.74	29.58***	-0.51	28.16***	1.78	27.25***	1.95	28.65***	-0.23
	(0.06)	(9.88)	(0.07)	(10.79)	(0.13)	(13.62)	(0.20)	(9.80)	(0.22)	(9.22)	(0.27)	(13.46)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,714	5,773	7,911	5,813	8,426	6,005	10,273	6,885	10,873	7,136	9,110	6,240
R-squared	0.84	0.85	0.83	0.85	0.83	0.85	0.84	0.85	0.84	0.85	0.83	0.85

The dependent variable is environmental score (out of 100). Standard errors are clustered at firm and year-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of firm-year observations. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 8: Green patenting activity and institutional investor ownership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Green patents ratio $_{t-1}$	-0.01 (0.01)	-0.00 (0.01)										
Green applications ratio $_{t-1}$			-0.01 (0.01)	0.00 (0.01)								
Green citations ratio $_{t-1}$					0.01 (0.01)	0.01 (0.01)						
Green patent stock ratio $_{t-1}$							0.02 (0.02)	0.02 (0.02)				
Green applications stock ratio $_{t-1}$									0.02 (0.02)	0.01 (0.02)		
Green citations stock ratio $_{t-1}$											0.03 (0.03)	0.03 (0.03)
Market capitalization $_{t-1}$		0.07*** (0.00)		0.07*** (0.00)		0.07*** (0.00)		0.07*** (0.00)		0.07*** (0.00)		0.07*** (0.00)
Firm age $_{t-1}$		0.05*** (0.01)		0.05*** (0.00)		0.04*** (0.01)		0.04*** (0.01)		0.04*** (0.00)		0.03*** (0.01)
Cash $_{t-1}$		0.01 (0.01)		0.00 (0.01)		0.01 (0.01)		0.00 (0.01)		-0.01 (0.01)		0.01 (0.01)
Leverage $_{t-1}$		-0.04*** (0.01)		-0.04*** (0.01)		-0.04*** (0.01)		-0.03*** (0.01)		-0.03*** (0.01)		-0.03*** (0.01)
R&D $_{t-1}$		-0.05*** (0.02)		-0.05*** (0.02)		-0.04** (0.02)		-0.03* (0.02)		-0.03* (0.01)		-0.04** (0.02)

Table 8. Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Tobin's Q $_{t-1}$		-0.00***		-0.00*		-0.01***		-0.01***		-0.00***		-0.01***
		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.000)
Constant	0.45***	-0.02	0.45***	-0.02	0.44***	-0.01	0.41***	-0.04*	0.40***	-0.05**	0.43***	-0.02
	(0.00)	(0.02)	(0.00)	(0.02)	(0.00)	(0.03)	(0.00)	(0.02)	(0.00)	(0.02)	(0.00)	(0.03)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	44,960	30,799	46,746	31,715	51,377	33,310	71,674	44,128	81,597	48,624	58,214	36,333
R-squared	0.79	0.84	0.78	0.83	0.79	0.85	0.79	0.85	0.78	0.85	0.80	0.85

The dependent variable is the proportion of a company's shares owned by institutional investors. Standard errors are clustered at firm and year-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of firm-year observations. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 9: Green patenting activity and Tobin's Q

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Green patents ratio $_{t-1}$	0.00 (0.06)	0.04 (0.07)										
Green applications ratio $_{t-1}$			-0.02 (0.06)	0.02 (0.07)								
Green citations ratio $_{t-1}$					0.08 (0.08)	0.06 (0.08)						
Green patent stock ratio $_{t-1}$							0.10 (0.13)	0.11 (0.17)				
Green applications stock ratio $_{t-1}$									0.13 (0.13)	0.13 (0.18)		
Green citations stock ratio $_{t-1}$											0.00 (0.17)	-0.13 (0.15)
Market capitalization $_{t-1}$		0.33*** (0.03)		0.32*** (0.03)		0.33*** (0.03)		0.32*** (0.02)		0.30*** (0.02)		0.32*** (0.02)
Firm age $_{t-1}$		-0.43*** (0.06)		-0.45*** (0.05)		-0.54*** (0.11)		-0.44*** (0.06)		-0.47*** (0.05)		-0.55*** (0.11)
Cash $_{t-1}$		1.24*** (0.17)		1.27*** (0.16)		1.31*** (0.17)		1.26*** (0.15)		1.27*** (0.14)		1.28*** (0.17)
Leverage $_{t-1}$		0.75*** (0.12)		0.67*** (0.12)		0.67*** (0.12)		0.67*** (0.11)		0.65*** (0.11)		0.64*** (0.11)
R&D $_{t-1}$		3.18*** (0.32)		3.39*** (0.34)		3.60*** (0.35)		3.07*** (0.28)		3.20*** (0.27)		3.47*** (0.35)

Table 9. Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Constant	2.15***	0.46**	2.27***	0.63***	2.04***	0.89**	2.05***	0.78***	2.18***	0.95***	2.01***	1.03***
	(0.00)	(0.23)	(0.00)	(0.22)	(0.00)	(0.34)	(0.00)	(0.21)	(0.00)	(0.19)	(0.01)	(0.33)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	47,220	37,662	50,961	38,585	51,093	38,730	73,474	52,809	83,980	57,962	57,739	42,196
R-squared	0.57	0.60	0.55	0.59	0.57	0.60	0.56	0.59	0.54	0.58	0.56	0.60

The dependent variable is Tobin's Q. Standard errors are clustered at firm and year-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of firm-year observations. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table 10: Green events and weekly stock returns

Panel A: Portfolios based on all green events				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.12***	0.04	-0.09**	0.04
12-week	-0.11***	0.04	-0.09**	0.04
24-week	-0.10**	0.04	-0.09**	0.04
32-week	-0.10**	0.04	-0.09**	0.04
52-week	-0.10**	0.04	-0.08**	0.04
104-week	-0.09**	0.04	-0.08**	0.04
156-week	-0.09**	0.04	-0.08*	0.04
Panel B: Portfolios based on single green events				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.09	0.06	-0.06	0.05
12-week	-0.11**	0.06	-0.08*	0.04
24-week	-0.12***	0.05	-0.08**	0.04
32-week	-0.12***	0.04	-0.07*	0.04
52-week	-0.10**	0.04	-0.06	0.04
104-week	-0.08*	0.04	-0.06	0.04
156-week	-0.09**	0.04	-0.06	0.04

This table reports the weekly values and robust standard errors of the six-factor alphas of portfolios based on new green patents obtained by public U.S. companies during 1976-2019. Panel A presents alphas of portfolios constructed from all green patent announcements, while the portfolios in Panel B are constructed using announcements of single green patents only. All portfolios are constructed weekly, with stock selection on Tuesdays. A stock is added to a portfolio whenever a new green patent is announced. We rebalance the portfolios every week and evaluate portfolio performance over 4,12,24,32,52,104, and 156-week long portfolio holding periods. All factor returns are from Kenneth French's website. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Appendices

Appendix A. Variable definitions

Table A1: Variable definitions

Variable	Definition	Source
Cash	Cash is defined as cash (Compustat item: ch) divided by total assets.	Compustat
CCMT applications ratio	This variable is defined as the yearly number of patent applications covering climate change mitigation technologies divided by the yearly number of all patent applications filed during the same year.	N/A
CCMT applications stock ratio	This variable is defined as the cumulative number of patent applications covering climate change mitigation technologies divided by the cumulative number of all patent applications filed by a company. The variable has been adjusted for depreciation of applications stock at a yearly rate of 15%.	N/A
CCMT citations ratio	This variable is the yearly number of citations received by patents covering climate change mitigation technologies divided by the yearly number of citations received by all patents during the same year.	N/A
CCMT citations stock ratio	This variable is the cumulative number of citations received by patents covering climate change mitigation technologies divided by the cumulative number of citations received by all patents. The variable has been adjusted for depreciation of citations stock at a yearly rate of 15%.	N/A
CCMT patents ratio	CCMT patents ratio is the yearly number of patents covering climate change mitigation technologies divided by the yearly number of all patents obtained during the same year.	N/A
CCMT patent stock ratio	This variable is defined as the cumulative number of patents covering climate change mitigation technologies divided by the cumulative number of all patents obtained by a company. The variable has been adjusted for depreciation of patent stock at a yearly rate of 15%.	N/A
CCMT patent volume	This variable the number of patents covering climate change mitigation technologies granted to the same company on the same day. We classify CCMT patents based on the classification developed by the European Patent Office (Angelucci et al., 2018).	N/A

Table A1. Continued

Climate concerns	Climate concerns is the average level of the Unexpected Media Climate Change Concerns (UMC) index (Ardia et al., 2022) over a three-day window (0,+2).	Ardia et al. (2022)
CO_2 Intensive Industry	CO2 Intensive Industry is a dummy variable equal to 1 if a firm is operating in a carbon intensive industry, and 0 otherwise.	Krey et al. (2014)
Firm age	Firm age is the number of years since the firm first appearance in CRSP.	CRSP
Green applications ratio	Green applications ratio is defined as the yearly number of green patent applications divided by the yearly number of all patent applications filed during the same year.	N/A
Green applications stock ratio	This variable is defined as the cumulative number of green patent applications divided by the cumulative number of all patent applications filed by a company. The variable has been adjusted for depreciation of applications stock at a yearly rate of 15%.	N/A
Green citations ratio	Green citations ratio is the yearly number of citations received by green patents divided by the yearly number of citations received by all patents during the same year.	N/A
Green citations stock ratio	Green citations stock ratio is the cumulative number of citations received by green patents divided by the cumulative number of citations received by all patents. The variable has been adjusted for depreciation of citations stock at a yearly rate of 15%.	N/A
Green patent stock ratio	Green patent stock ratio is defined as the cumulative number of green patents divided by the cumulative number of all patents obtained by a company. The variable has been adjusted for depreciation of patent stock at a yearly rate of 15%.	N/A
Green patent volume	Green patent volume is the number of green patents granted to the same company on the same day. We classify green patents using the classification developed by Haščič and Migotto (2015).	N/A
Green patents ratio	Green patents ratio is defined as the yearly number of green patents divided by the yearly number of all patents obtained by a company that year.	N/A
High climate exposure	High climate exposure is a dummy variable that is equal to 1 when the level of a firm's exposure to climate change (cc_expo variable in Sautner et al., 2022) is in the top 33% of the variable's distribution, and 0 otherwise.	Sautner et al. (2022)

Table A1. Continued

Institutional attention	Institutional attention is the average level of the Bloomberg Heat Score over a three-day window (0,+2) around a patent announcement (Ben-Rephael et al., 2017; Chiu et al., 2021).	Bloomberg
IO	IO is the proportion of a company's shares owned by institutional investors.	Ghaly et al. (2020)
IO dedicated	IO dedicated is the proportion of a company's shares owned by dedicated institutional investors.	Ghaly et al. (2020)
IO quasi-indexer	IO quasi-indexer is the proportion of a company's shares owned by quasi-indexer investors.	Ghaly et al. (2020)
IO transient	IO transient is the proportion of a company's shares owned by transient institutional investors.	Ghaly et al. (2020)
Leverage	Leverage is defined as total liabilities (Compustat item: lt) divided by total assets (Fang et al., 2014).	Compustat
Low environmental score	Low environmental score is a dummy variable that is equal to 1 when the firm's Asset4 environmental score is in the bottom 33% of the variable's distribution, and 0 otherwise.	Asset4
Market capitalization	Market capitalization is the number of shares outstanding multiplied by the share price.	CRSP
Paris Agreement	Paris Agreement is a dummy variable equal to 1 if a patent announcement takes place after 12 December 2015, and 0 otherwise.	N/A
Patent citations	Patent citations is the number of citations received by a patent, excluding examiner citations and self-citations, divided by the number of citations received by an average patent granted in the same year.	PatentsView
Patent claims	Patent claims is a simple count of the number of independent claims of a patent (Marco et al., 2019).	PatentsView
Patent volume	Patent volume is the number of patents that a particular company obtained from the USPTO on the same trading day.	PatentsView
R&D	R&D is defined as research and development expense (Compustat item: xrd) divided by total assets (Hirshleifer et al., 2012).	Compustat
Tobin's Q	Tobin's Q is the ratio of market value to book value of assets (Hirshleifer et al., 2012).	Compustat and CRSP

Appendix B. Descriptive statistics of CAR (0,+2)

Table B1: Descriptive statistics of CAR (0,+2)

	Mean (%)	Median (%)	SD (%)	Min (%)	Max (%)	N
Panel A: All patent announcements						
All events	0.028	-0.060	3.745	-22.175	25.517	467,502
Grey events	0.033	-0.059	3.799	-22.175	25.517	428,026
Green events	-0.021	-0.069	3.098	-22.175	24.987	39,476
Panel B: Announcements of single patents only						
All events	0.021	-0.084	4.177	-22.175	25.517	248,411
Grey events	0.023	-0.082	4.186	-22.175	25.517	238,412
Green events	-0.031	-0.123	3.960	-22.175	24.415	9,999
Panel C: All announcements in polluting industries						
All events	0.032	-0.069	3.766	-22.175	25.517	323,916
Grey events	0.038	-0.068	3.826	-22.175	25.517	293,349
Green events	-0.026	-0.071	3.132	-22.175	23.669	30,567
Panel D: All announcements with high technological value						
All events	0.060	-0.044	3.909	-22.175	25.517	149,299
Grey events	0.069	-0.042	3.957	-22.175	25.517	136,046
Green events	-0.005	-0.040	3.220	-22.175	24.415	12,846
Panel E: All announcements with high climate change concerns						
All events	0.004	-0.041	3.278	-22.175	25.517	56,186
Grey events	0.009	-0.041	3.317	-22.175	25.517	50,805
Green events	-0.041	-0.042	2.877	-19.760	23.167	5,381
Panel F: All announcements with high institutional investor ownership						
All events	0.087	0.005	3.383	-22.175	25.517	134,901
Grey events	0.093	0.007	3.399	-22.175	25.517	125,844
Green events	0.012	-0.016	3.147	-19.760	23.167	9,057
Panel G: All announcements with high institutional investor attention						
All events	0.113	0.048	3.082	-19.892	25.517	38,219
Grey events	0.126	0.067	3.178	-19.892	25.517	31,929
Green events	0.047	-0.015	2.534	-16.256	16.204	6,290

This table reports descriptive statistics for all CARs (0,+2) presented in Table 2.

Appendix C. Paris Agreement

This appendix examines the impact of the adoption of the Paris Agreement on the market reaction to green patents. The Paris Agreement, signed on 12 December 2015, is a legally binding international treaty which aims to tackle the problem of climate change and limit global warming to 1.5°C above pre-industrial levels (Kruse et al., 2020). The scope of the agreement and its ambitious goal of limiting the temperature increase to 1.5°C was seen as unexpected (Kruse et al., 2020). Bolton and Kacperczyk (2021) argue that the Paris Agreement increased both the risk and the investor awareness of regulatory action aimed at limiting carbon emissions. Moreover, we observe that the number of green patents obtained by firms, as a proportion of all patents, increased from 3.7% to 5.1% after the adoption of Paris Agreement (see Table C1 in this appendix).[47] [48]

Since the Paris Agreement reflected a worldwide commitment to protecting the environment, we expect the agreement to have a positive effect on the market reaction to green patents. We test this using the following model:

$$CAR_{i,t} = \alpha + \beta_1 * \ln(1 + green\ patent\ volume)_{i,t} + \beta_2 * Paris\ Agreement + \beta_3 * Paris\ Agreement\ x\ \ln(1 + green\ patent\ volume)_{i,t} + \beta_n * X_{i,t-1} + \beta_n * Z_{i,t} + \gamma + \xi + u_{i,t} \quad (10)$$

$CAR_{i,t}$ is the average cumulative abnormal return over a three-day window (0,+2) following a patent announcement.[49] *Green patent volume* is the number of green patents granted.[50] *Paris Agreement* is a dummy variable equal to 1 if a patent announcement takes place after 12

[47] In our sample, 3.7% of all patents obtained by an average company every year are green patents (see: Table 1). Using the coefficient on Paris Agreement of 0.014 (column (1) of Table C1), we calculate the green proportion of all patents granted after the Paris Agreement at 5.1% (=3.7%+1.4%).
[48] We use a multivariate OLS model to test this. The dependent variable is the green proportion of all patents granted to a company in a year. Our independent variable of interest equals 1 for all patents granted after December 2015, and 0 otherwise. We include firm fixed effects and the same set of firm controls as in model (10).
[49] In alternative specifications we use alternative dependent variables, including CAR(0,+1) and CAR(0,+3), and our results remain similar. For brevity we do not report these results, but they are available upon request.
[50] We obtain similar results if we use a dummy variable equal to 1 when a patent announcement includes a green patent. We do not report these results for the sake of brevity, but they are available upon request.

December 2015, and 0 otherwise. Our firm specific control variables include *market capitalization*, *firm age*, *cash*, *leverage*, *R&D, and Tobin's Q*. Our patent-related control variables include *patent volume, patent citations*, and *patent claims*. Lastly, γ denotes firm fixed effects and ξ denotes year fixed effects.

Table C1: The Paris Agreement and the number of green patents

	(1)	(2)
Paris Agreement	0.014*** (0.003)	0.011*** (0.004)
Market capitalisation $_{t-1}$		-0.000 (0.001)
Firm age $_{t-1}$		0.004** (0.002)
Cash $_{t-1}$		-0.002 (0.005)
Leverage $_{t-1}$		-0.001 (0.004)
R&D $_{t-1}$		-0.008 (0.006)
Tobin's Q $_{t-1}$		0.000 (0.000)
Constant	0.035*** (0.001)	0.027*** (0.006)
Firm FE	YES	YES
Year FE	NO	NO
Observations	59,817	39,816
R-squared	0.507	0.541

The dependent variable is the number of green patents divided by the number of all patents obtained by a company in a year. Standard errors are clustered at firm and year-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects. We do not include year fixed effects, because they are collinear with *Paris Agreement*. All firm control variables are lagged by one year. Observations is the number of firm-year observations. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table C2: Market reaction (CAR 0,+2), green patents, and the Paris Agreement

	(1)	(2)	(3)	(4)
Ln (1+green patent volume)	0.0002 (0.0002)		0.0002 (0.0002)	0.0002 (0.0003)
Paris Agreement		0.0010 (0.0014)	0.0010 (0.0014)	0.0018 (0.0019)
Paris Agreement x Ln (1+green patent volume)			-0.0001 (0.0004)	-0.0004 (0.0004)
Market capitalization $_{t-1}$				-0.0014*** (0.0003)
Firm age $_{t-1}$				-0.0007* (0.0004)
Cash $_{t-1}$				0.0012 (0.0011)
Leverage $_{t-1}$				-0.0013* (0.0007)
R&D $_{t-1}$				-0.0007 (0.0026)
Tobin's Q $_{t-1}$				0.0000 (0.0002)
Patent volume				0.0001 (0.0001)
Patent citations				0.0002* (0.0001)
Patent claims				0.0004 (0.0009)
Constant	0.0003** (0.0001)	0.0002 (0.0002)	0.0002 (0.0002)	0.0132*** (0.0023)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	466,227	466,227	466,227	337,166
R-squared	0.0269	0.0269	0.0269	0.0284

The dependent variable is CAR (0,+2) calculated using the market-adjusted model. Standard errors are clustered at firm and grant date-level and are reported in parentheses. All control variables are winsorized at the 1% and 99% tails. All regressions include firm fixed effects and year fixed effects. All firm control variables are lagged by one year. Observations is the number of patent announcements. See Table A1 in Appendix A for variable definitions. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

The regression results are shown in Table C2. We interact *Paris Agreement* and *green patent volume* in column (3) of Table C2. The interaction term is not statistically significant, which suggests that the impact of green patents on shareholder wealth did not change after the adoption of the Paris Agreement. We add control variables in column (4) and our results remain unchanged.

Next, we test whether the relation between climate concerns and the market reaction to green patents has changed after the adoption of the Paris Agreement. The agreement is considered as a historic achievement in the fight against global warming and the promise by global leaders to address the climate change problem should have a negative effect on the level of climate change concerns. We modify model (10) to include an interaction between *Paris Agreement*, *green patent volume*, and *climate concerns*, which measures the average level of climate change concerns over a three-day window (0,+2).[51] The regression results are presented in Table I.A21 in the internet appendix. The triple interaction term is not statistically significant, which suggests that the adoption of the Paris Agreement did not affect the relation between climate concerns and the market reaction to green patents.

Arguably, the adoption of the Paris Agreement has increased the risk of environmental regulations faced by companies (Degryse et al., 2022). Since green technologies can help firms mitigate these risks, companies that obtain green patents may be seen as more valuable to institutional investors after the adoption of the agreement. We test this by modifying model (10) to include an interaction between *Paris Agreement, green patent volume* and $IO_{i,t-1}$, which is the proportion of shares owned by institutional investors. The regression results are shown in Table I.A22 in the internet appendix. The triple interaction is not statistically significant.[52]

[51] We obtain similar results if we measure the average climate change concerns over alternative windows. For brevity we do not report these results, but they are available upon request.

[52] We obtain similar results if we use the proportion of shares owned by transient, quasi-indexer, or dedicated institutional investors. For brevity we do not report these results, but they are available upon request.

Lastly, we test whether the adoption of the Paris Agreement affected the relation between institutional investor attention and the market reaction to green patents. We modify model (10) to include an interaction between *Paris Agreement, green patent volume* and $institutional\ attention_{i,t}$. Our regression results are shown in Table I.A23 in the internet appendix. The triple interaction is not statistically significant, which suggests that the adoption of the agreement did not have an effect on institutional investors' reaction to green patents.

Appendix D. Measures of green patenting activity

We use six firm-level metrics to measure *green patenting activity*. All metrics are lagged by one year. They include: (1) *green patents ratio*$_{t-1}$, which is the green proportion of all patents granted in a given year (Amore and Bennedsen, 2016; Cohen et al., 2022), (2) *green applications ratio*$_{t-1}$, which is the green proportion of all patent applications filed in a given year that are eventually granted (Hao et al., 2022), (3) *green citations ratio*$_{t-1}$, which is the number of citations received by green patents in a year as a proportion of all patent citations received in a given year (Amore and Bennedsen, 2016; Cohen et al., 2022), (4) *green patent stock ratio*$_{t-1}$, which is the green proportion of a firm's patent stock, (5) *green applications stock ratio*$_{t-1}$, which is the green proportion of a firm's patent applications stock, and (6) *green citations stock ratio*$_{t-1}$, which is the green proportion of all patent citations received by a company.

The first three measures capture a firm's green patenting behavior in a particular year. In contrast, the last three measures are calculated using a company's patent stock, which is a cumulative measure of innovation (Porter and Stern, 2000). Patent stock counts the total number of patents granted to a company until a specific point in time. It is calculated as follows:

$$patent\ stock_{i,t} = patents_{i,t} + (1-\delta) * patent\ stock_{i,t-1} \qquad (11)$$

Where $patents_{i,t}$ is the number of patents granted to a firm in a given year. δ is a depreciation rate set to 15% (Balasubramanian and Sivadasan, 2011; Hall et al., 2005), which accounts for the depreciation in the value of ideas over time (Porter and Stern, 2000). For example, if a company received its first patent two years ago, received three patents last year, and obtained four patents this year, its current patent stock equals 7.27 (=1*0.85*0.85+3*0.85+4). We calculate the green proportion of a firm's patent stock by dividing a company's green patent stock by its total patent stock. We follow the same process to calculate the green proportion of the patent applications stock and the green proportion of the patent citations stock.

Appendix E. Sub-sample portfolio analysis

Table E1: Green events in CO_2 intensive industries and weekly stock returns

Panel A: Portfolios based on all green events in CO_2 intensive industries				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.20***	0.05	-0.15***	0.04
12-week	-0.17***	0.04	-0.13***	0.04
24-week	-0.17***	0.04	-0.14***	0.04
32-week	-0.17***	0.04	-0.13***	0.04
52-week	-0.15***	0.04	-0.12***	0.04
104-week	-0.14***	0.04	-0.12***	0.04
156-week	-0.14***	0.04	-0.11***	0.04
Panel B: Portfolios based on single green events in CO_2 intensive industries				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.12*	0.06	-0.08	0.05
12-week	-0.14***	0.05	-0.12***	0.05
24-week	-0.15***	0.05	-0.14***	0.04
32-week	-0.14***	0.05	-0.12***	0.04
52-week	-0.13***	0.05	-0.10**	0.04
104-week	-0.10**	0.05	-0.10**	0.04
156-week	-0.10**	0.05	-0.10**	0.04

This table reports the weekly values and robust standard errors of the six-factor alphas of portfolios based on new green patents obtained by public U.S. companies operating in CO2 intensive industries during 1976-2019. We categorize carbon intensive industries using the list of heavy-emitting industries created by the IPCC (Krey et al., 2014). Panel A presents alphas of portfolios constructed from all green patent announcements, while the portfolios in Panel B are constructed using announcements of single green patents only. All portfolios are constructed weekly, with stock selection on Tuesdays. A stock is added to a 62ortfolio a new green patent is announced. We rebalance the portfolios every week and evaluate portfolio performance over 4,12,24,32,52,104, and 156-week long portfolio holding periods. All factor returns are from Kenneth French's website. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table E2: Green events in non-CO_2 intensive industries and weekly stock returns

Panel A: Portfolios based on all green events in non-CO_2 intensive industries				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.04	0.05	-0.00	0.05
12-week	-0.06	0.05	-0.02	0.04
24-week	-0.06	0.05	-0.02	0.04
32-week	-0.05	0.05	-0.01	0.04
52-week	-0.05	0.05	-0.01	0.04
104-week	-0.05	0.05	-0.02	0.04
156-week	-0.05	0.05	-0.02	0.04
Panel B: Portfolios based on single green events in non-CO_2 intensive industries				
	Value-weighted		Equally-weighted	
Horizon	Alpha	Robust std. error	Alpha	Robust std. error
4-week	-0.03	0.09	-0.04	0.08
12-week	-0.08	0.06	-0.01	0.06
24-week	-0.03	0.05	-0.02	0.05
32-week	-0.05	0.05	-0.02	0.05
52-week	-0.06	0.05	0.03	0.05
104-week	-0.03	0.05	0.02	0.05
156-week	-0.05	0.04	0.02	0.04

This table reports the weekly values and robust standard errors of the six-factor alphas of portfolios based on new green patents obtained by public U.S. companies operating in non-CO2 intensive industries during 1976-2019. We categorize carbon intensive industries using the list of heavy-emitting industries created by the IPCC (Krey et al., 2014). Panel A presents alphas of portfolios constructed from all green patent announcements, while the portfolios in Panel B are constructed using announcements of single green patents only. All portfolios are constructed weekly, with stock selection on Tuesdays. A stock is added to a portfolio whenever a new green patent is announced. We rebalance the portfolios every week and evaluate portfolio performance over 4,12,24,32,52,104, and 156-week long portfolio holding periods. All factor returns are from Kenneth French's website. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

Table E3: Green events, weekly stock returns, and R&D intensity

Panel A: Portfolios based on all green events

	Value-weighted					Equally-weighted				
	$R\&D_{low}$	2	3	4	$R\&D_{high}$	$R\&D_{low}$	2	3	4	$R\&D_{high}$
	4-week horizon									
α	-0.13**	-0.13**	-0.14**	-0.07	-0.00	-0.13***	-0.08	-0.12**	-0.05	-0.03
	12-week horizon									
α	-0.13**	-0.15***	-0.13**	-0.04	-0.04	-0.15***	-0.10**	-0.10**	-0.05	-0.03
	24-week horizon									
α	-0.13**	-0.16***	-0.12**	-0.03	-0.03	-0.14***	-0.13***	-0.10**	-0.05	-0.01
	32-week horizon									
α	-0.13***	-0.15***	-0.11**	-0.05	-0.03	-0.14***	-0.12***	-0.09**	-0.04	-0.01
	52-week horizon									
α	-0.13**	-0.14***	-0.10**	0.05	-0.03	-0.13***	-0.11**	-0.08*	-0.03	-0.02
	104-week horizon									
α	-0.13**	-0.13***	-0.10**	-0.06	-0.05	-0.12***	-0.11**	-0.08*	-0.04	-0.02
	156-week horizon									
α	-0.11**	-0.13***	-0.09*	-0.06	-0.05	-0.12***	-0.10**	-0.08*	-0.04	-0.02

Panel B: Portfolios based on single green events

	Value-weighted					Equally-weighted				
	$R\&D_{low}$	2	3	4	$R\&D_{high}$	$R\&D_{low}$	2	3	4	$R\&D_{high}$
	4-week horizon									
α	-0.03	-0.20**	-0.01	0.14	-0.25	-0.02	-0.18**	0.04	0.12	-0.33*
	12-week horizon									
α	-0.14**	-0.09	-0.07	-0.05	-0.21*	-0.12**	-0.13**	-0.03	0.06	-0.27**
	24-week horizon									
α	-0.16***	-0.08	-0.06	0.02	-0.03	-0.12***	-0.11**	-0.03	-0.03	-0.13
	32-week horizon									
α	-0.15***	-0.11*	-0.06	-0.03	-0.00	-0.09**	-0.11**	-0.05	-0.01	-0.08
	52-week horizon									
α	-0.14***	-0.06	-0.04	0.01	-0.03	-0.08*	-0.08*	0.01	0.02	-0.12*
	104-week horizon									
α	-0.09*	-0.07	-0.04	-0.01	-0.01	-0.07*	-0.08*	-0.02	-0.02	-0.09
	156-week horizon									
α	-0.10**	-0.05	-0.05	-0.01	0.01	-0.08*	-0.08*	-0.03	-0.02	-0.05

This table reports the weekly values of the six-factor alphas of portfolios based on new green patent announcements that are sorted on R&D intensity. Every week, stocks with non-missing one-year lag of R&D scaled by total assets are sorted into quintiles. $R\&D_{low}$ ($R\&D_{high}$) contain stocks with lowest (highest) lag of R&D intensity. Panel A presents alphas of portfolios constructed from all green patent announcements, while the portfolios in Panel B are constructed using announcements of single green patents only. All portfolios are constructed weekly, with stock selection on Tuesdays. A stock is added to a portfolio whenever a new green patent is announced. We rebalance the portfolios every week and evaluate portfolio performance over 4,12,24,32,52,104, and 156-week long portfolio holding periods. All factor returns are from Kenneth French's website. Significance at 10%, 5%, and 1% level is represented by *, **, and ***, respectively.

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