Corporate governance and green innovation

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Abstract

We present evidence of corporate governance effects on firms' environmental innovation. Exploiting changes in antitakeover legislation in the US, we show that worse governed firms generate fewer green patents relative to all their innovations. This negative effect is greater for firms with a smaller share of institutional ownership, with a smaller stock of green patents, and with more binding financial constraints. Investigating regulatory and industry variations, we also find more pronounced effects for firms operating in states with lower pollution abatement costs, and in sectors less dependent on energy inputs. Overall, our results suggest that a shift in corporate governance toward more managerial entrenchment will weaken the incentives and resources necessary to devise and sustain green innovation strategies.

Keywords: corporate governance, environment, green innovation, patents

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1. Introduction

Global climate change is one of the greatest economic and social challenge that humanity faces in the foreseeable future. Although researchers have identified some important determinants of environmental efficiency—including public policies (e.g. Jaffe et al. 2002; Johnstone et al. 2010; Martin et al. 2014; Nesta et al. 2014), energy prices and technology (e.g. Popp 2002; Martin 2010)—there is still much variation across firms that remains unexplained. To fill this gap, scholars have recently begun paying attention to the role played by organizational structures (e.g. De Canio 1998; De Canio and Watkins 1998; Cole et al. 2007).

Previous works in this area have explored the effect of management (Bloom et al. 2010; Martin et al. 2012) and governance systems (Aggarwal and Dow 2012; Kock et al. 2012) on energy efficiency and pollution emissions. The prevailing view of extant research is that good governance and management are positively correlated with firms' environmental efficiency. Yet, as some have acknowledged (Bloom et al. 2010), it has been difficult to tease out the causal direction in the relationship between organizational structures and environmental activities. We contribute to this literature by empirically showing that worse corporate governance, as proxied by the enactment of antitakeover laws in the US, reduces firms' environmental innovations, a category of innovation activities that is currently receiving great attention from both policy-makers and academic scholars due to its potential to reduce greenhouse gas emissions (e.g. Aghion et al. 2015; Veugelers 2012).

Following a common approach in innovation economics (e.g. Griliches 1990), we use patent data to measure innovation output. The use of patents to measure innovation is subject to well-known limitations, the most prominent being that patents only cover *patentable* and *patented* inventions. However, there are several important advantages of using patent data, such as the fact that patents are clearly measurable and widespread across industries and time (Hall et al. 2005). Moreover, contrary to standard accounting items on R&D, patent applications provide detailed information on key features of the underlying invention useful to classify innovations according to their technological content.

Linking US Compustat firms with the patent dataset provided by the National Bureau of Economic Research (NBER), we exploit information on the technological class of patents to identify environment-related (green) innovations (e.g. Jaffe and Palmer 1997; Brunnermeier and Cohen 2003; Carrion-Flores and Innes 2010; Dechezlepretre et al. 2013a, 2013b). There are several reasons that make green patents an interesting research domain. First, green patents represent a central aspect of organizational knowledge in the area of environmental technologies; as such, they not only reduce pollution outcomes (Carrion-Flores and Innes 2010) but also have a potential to affect the entire trajectory of corporate innovation (Aghion et al. 2015). Second, green patents can potentially generate positive externalities in the form of knowledge spillovers and thus facilitate the adoption and diffusion of environmental technologies at the industry and country level. Third, green patents have distinctive features, e.g. they have more general applications, are cited more frequently than non-green patents (Dechezlepretre et al. 2013b) and receive citations from a wider array of technological classes (Popp and Newell 2012). Fourth, companies are subject to growing stakeholder and institutional pressures towards responsible environmental behavior (e.g. Kock et al. 2012; Sharma and Henriques 2005) that may have distinct impacts on green innovation activities (Berrone et al. 2013).

Despite these important features, the effect of corporate governance on green patenting activities remains unexplored. A few studies have analyzed the effect of takeover pressures on general innovation reaching mixed conclusions. For instance, it has been shown that weaker takeover pressures can (1) decrease innovation due to moral hazard (Atanassov 2013), (2) increase innovation by insulating managers from short-term pressure (Chemmanur and Tian 2013), that (3) the governance-innovation relationship is U-shaped (Sapra et al. 2014), or that (3) it differs by firm and state-level provisions (Becker-Blease 2011). These empirical ambiguities (also due to methodological complications with the use of antitakeover laws in causality tests, which we fully address following Karpoff and Wittry 2014) preclude us from drawing conclusions on the potential effect of takeover pressures on green patenting. Moreover, the above-discussed uniqueness of green patents in terms of technological novelty and complexity further hinders the ability to generalize to green patenting the previous results obtained on the general population of patents.

We fill this research gap by adopting a generalized difference-in-differences model based on the passage of business combination (BC) laws in US states during the second half of the 1980s (e.g. Atanassov 2013; Bertrand and Mullainathan 2003; Karpoff and Malatesta 1989; Giroud and Mueller 2010). This approach rests on the long-running argument that an effective market for corporate control mitigates agency conflicts between managers and shareholders (Manne 1965; Shleifer and Vishny 1997). This is due to the fact that, by lowering a firm’s market value, managerial actions that generate private benefits at the expenses of shareholder returns would invite hostile takeovers (after which the manager of the inefficient firm is usually fired); by increasing the threat of hostile takeovers targeted to badly managed firms, an efficient market for corporate control can effectively align shareholder and managers’ interests. Introducing obstacles to the transfer of assets from target firms to acquirers, BC laws hampered the effectiveness of this mechanism and thus made firms incorporated in the legislating states less subject to the disciplining threat of hostile takeovers.

Empirically, the staggered passage of BC laws across US states provides geographic and time variation that helps us mitigate endogeneity concerns.[1] Moreover, given that BC laws affected firms in their state of incorporation, we can exploit the discrepancy between state of headquarters and state of incorporation to control for geographic effects.

Our main finding is that, following the passage of BC laws, firms experienced on average a 13% reduction of green patents in their patent portfolio (i.e. after explicitly taking into account the generalized effect of BC laws on *all* patents documented in Atanassov 2013). We validate this finding using several tests to reduce concerns of confounding factors, endogeneity, outliers and sample selection.

According to the “quiet life” argument proposed in Bertrand and Mullainathan (2003), when managers are not exposed to the disciplining role of takeovers—as occurs in the wake of BC legislation—they will extract personal rent by engaging less in initiatives that require major effort and organizational changes. This argument helps interpret our findings. Indeed, a significant shift in the firm’s current pattern of research and development (R&D) could well demand such changes, since “going green” is a relatively new and complex activity that requires changes in the R&D division, novel methods and research questions. Along this line, Kock et al. (2012) argue that: “successfully reducing and preventing waste emissions necessitates a great deal of extra managerial effort because it requires a complex redesign of a firm’s internal processes and the development of green competencies”. Similarly, an OECD

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[1] Due to these advantages, several works have exploited the passage of BC laws to establish changes in corporate governance (e.g. Atanassov 2013; Amore and Zaldokas 2015; Bertrand and Mullainathan 2003; Francis et al. 2010; Giroud and Mueller 2010).

study on green management strategies writes that: "the most important factor in preventing firms from taking a more radical approach to eco-innovation and aiming for systemic shifts would be that even more progressive businesses remain unconsciously aligned to and locked into conventional business models. Many companies are comfortable with their existing business models and not ready to leverage the crucial systemic changes that are needed for radical innovation".[2] We empirically validate these arguments by showing that innovators in the area of environmental technologies engage more intensively in R&D spending, and that green patents entail superior technological complexity.

Next, we derive various results showing the heterogeneity behind the average impact of BC laws on green patenting. First, consistent with the argument of technological lock-in put forward by Aghion et al. (2015), we find that a larger stock of green innovations reduces the drop in green patents induced by the BC laws. Second, in line with the presence of important opportunity costs of reducing green innovation, we find that the effect of BC laws is more pronounced in sectors characterized by less energy dependence, and in states with lower pollution abatement costs. Third, pointing to a mitigating role of internal governance mechanisms, we find that the stake of institutional ownership within the firm mitigates the negative effect of BC laws on green patents. Fourth, highlighting financing needs as a possible channel at play, we find that firms that experienced the larger drop in green patenting following the passage of BC laws were those with more binding financial constraints, as well as those operating in industries relying on external capital and with high R&D spending requirements.

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[2] "The future of eco-innovation: The role of business models in green transformation", OECD Background Papers (2012).

Our work relates to a strand of research on the nexus between corporate governance and innovation (Atanassov 2013; Becker-Blease 2011; Chemmanur and Tian 2013; Sapra et al. 2014). While these works have explored how takeover pressures affect the *level* of innovation activities, we focus on the *composition* of a firm's patent portfolio and argue that the effect of corporate governance on innovation varies significantly depending on the project type. By suggesting a "pecking-order" of innovation whereby worse corporate governance reduces green projects the most, our results highlight novel heterogeneity of how different innovation types respond to managerial incentives. Moreover, we explore the interaction between corporate governance, firm-specific and external factors showing that the effect of managerial entrenchment on green innovation is contingent upon financing conditions as well as industry and regulatory pressures towards environmental sustainability. Finally, we expand the empirical identification used in the related literature in order to ameliorate concerns of confounding events and endogeneity in the law passages and thus deliver sharper causal evidence.

Our work also expands a growing literature on the organizational determinants of energy efficiency. While works in this area have looked extensively into managerial practices (Bloom et al. 2010; Martin et al. 2012), the role of corporate governance has received relatively little attention. Yet, we know from several corporate finance studies that governance mechanisms significantly shape firm outcomes, not just strictly financial ones but also related to corporate social responsibility (Cespa and Cestone 2007). We contribute to this research in two ways. First, by investigating the effect of corporate governance on green patents, we document a specific mechanism through which good governance may effectively reduce pollution outcomes (Kock et al. 2012). Second, we use changes in antitakeover regulation in an attempt to establish the directional effects in the nexus between firms' environmental activities and corporate governance.

The rest of the paper proceeds as follows. Section 2 describes the data and provides summary statistics. Section 3 illustrates the empirical strategy. Section 4 presents the empirical findings and a number of robustness checks. Section 5 illustrates our analysis on heterogeneous effects, and Section 6 concludes.

2. Data and summary statistics

2.1. Financial data

We use firm-level data from the Compustat dataset, which contains comprehensive financial information on US publicly traded firms. Consistent with Bertrand and Mullainathan (2003), the time period considered is 1976–1995, which covers a number of "pre" and "post-event" years. We restrict the sample to US-headquartered and incorporated firms with positive sales and positive book value of assets.

We construct a set of firm-level variables such as the logarithm of firm sales, of the capital/labor ratio, of R&D stock, and of firm age, as well as an industry-level control, the Herfindahl–Hirschman index (HHI) to account for the potential effect of market structures on environmental activities (Fernandez-Kranz and Santalò 2010). We compute the HHI using the distribution of firms' revenues in a particular 3-digit SIC (Standard Industrial Classification) industry.

We drop observations with missing values in each of these variables. Table A2 describes how each variable was constructed.

2.2. Antitakeover legislation

Our main proxy for the quality of corporate governance is provided by the passage of second-generation antitakeover laws, in particular the BC laws, by US states during the late 1980s. BC laws reduced the threat of hostile takeovers by imposing a 3 to 5-year moratorium on the transfer of assets from the target to the acquiring company, thus limiting the latter's ability to pay down acquisition debt. By making it harder to realize the benefits of takeovers, BC laws drastically weakened the market for corporate control and its ability to discipline managers.

[[INSERT Table 1 about Here]]

Table 1 shows the staggered passage of BC laws during the period 1985–1991. Thus our own time window, the period 1976–1995, includes a few years before and after the passage of BC laws. Table 2 shows the number of states and firm-year observations subject to BC laws in our sample. Thirty US states (59% of states in the sample, accounting for 85% of firm-year observations) passed BC laws; twenty-one states (41% of states in the sample, 15% of firm-year observations) never passed a BC law.

[[INSERT Table 2 about Here]]

2.3. Environmental innovation

We measure firms' environmental innovation in terms of successful patent applications in environment-related technologies. Patent data come from a dataset assembled at the NBER that contains information on more than 3 million patents granted by the US Patent and Trademark Office (USPTO) and all citations made to these patents starting from 1976 (Hall et al. 2001; Bessen 2009). Given the well-documented average lag between application and granting date, we follow the literature and date granted patents at the time of the patent application, which better reflects the actual time of innovation.

Our main classification of green patents follows closely that of Carrion-Flores and Innes (2010) and is based on the primary 3-digit patent classification provided by the USPTO. The main technological categories considered are broadly related to air or water pollution, hazardous waste prevention, disposal and control, recycling, and alternative energy. A detailed description of the technology classes used to identify green patents is provided in Table A1.

Table 3 gives summary statistics for the main variables used in the empirical analysis.

[[INSERT Table 3 about Here]]

One concern with the primary classification we adopt is that it may be too broad. To mitigate this concern, in a robustness test we of adopt a finer classification based on both the main classification and the subclassification of patents (i.e. the definition of energy patents provided by Popp 2002 and Popp and Newell 2012). This definition is able to identify renewable technologies as well as new energy sources based on fossil fuels (e.g., fuel cells and coal liquefaction); hence it captures technological efforts both to improve the use of current energy supplies and to develop entirely new sources. In our sample, firms have on average 6.6% of energy patents to the total number of patents.

2.4. The characteristics of green innovators

In this section, we illustrate the differences between firms with and without green patents. Panel A shows that green innovators are usually larger (in terms of net revenues), older, and significantly more engaged in R&D spending. This latter difference suggests that green patenting firms may be characterized by more organizational complexity, stemming e.g.

from multiple innovation labs and more explorative projects. As such, this evidence is consistent with existing works, which have described "going green" as an activity characterized by substantial effort and keen managerial focus (e.g. Kock et al. 2012).

Second, we check whether green innovators are involved in more complex patenting activity from a technological standpoint as proxied by the distribution of patent citations across technological fields. To this end, we employ the "originality" index originally developed by Trajtenberg et al. (1997) and computed by Hall et al. (2001), which captures the fundamental nature of the research being patented. The originality index is equal to $1-\sum_{j}^{n_j} s_{ij}^2$, where s_{ij}^2 denotes the percentage of patent references by a patent *i* that belong to the patent technology class *j* out of n_i patent classes. The index takes high values (high originality) if a patent cites patents that belong to many different technological fields. We also use an index of patent generality, which is constructed in a similar way but it relies on the citations made rather than citations received; it takes a high value if a patent receives citations from other patents that belong to many different fields (high generality). Using the logarithm of one plus the originality and generality indexes as dependent variables, we find that green innovators are engaged in more complex patenting activity.

[[INSERT Table 4 about Here]]

In Panel B of Table 4, we compare the originality and generality of green and environment-unrelated patents. In line with the notion of superior complexity discussed above, results indicate that green patents made and receive citations across a wider array of technological classes. This evidence parallels results in Dechezlepretre et al. (2013b) who also find that, besides receiving more citations, green patents have more general technological applications than non-green patents.

3. Empirical strategy

Our main goal is to establish how corporate governance affects firms' environmental innovation. One common approach to address this question is to compare the environmental innovation of firms with different corporate governance quality. Yet even if we thereby establish a positive association, interpreting it causally—as in saying that better corporate governance causes better environmental innovation—is complicated by at least two problems. First, the association may be driven by some *third* (and perhaps unobserved) factor; a leading candidate would be the demands of stakeholders for both good governance and environmental practices. Second, reverse causality may be at play; for instance, it could be that improved environmental innovation increases a firm's visibility in the marketplace and this in turn renders managers more accountable (i.e. environmental outcomes cause corporate governance quality rather than the other way around).

In order to address these complications, we rely on the passage of BC laws, commonly used in the finance literature as shocks to the threat of hostile takeovers useful to mitigate endogeneity concerns. Although BC laws provides only binary variations in the quality of state-level corporate governance, the advantage of our identification is that such variations were imposed by state regulations and are therefore less likely to reflect firms' equilibrium choices.

However, there are two potential concerns. The first is that the adoption of BC laws may reflect lobbying by troubled firms seeking protection from takeovers. If that is the case, then the effect we identify in association with the implementation of BC laws may simply reflect past firm conditions and not a causal effect. To deal with this concern, we draw on existing evidence from legal studies. Romano (1987) finds that most of the lobbying that occurred was on behalf of single firms and that large coalitions of firms played only a minor role in the political processes leading to the adoption of BC laws. Also, the one-on-one nature of lobbying activity reduces the chances that legislation was driven by average corporate outcomes in the legislating states. However, in robustness checks we explicitly address the concern that the law passages may have been endogenous for some firms.

The second concern is that a firm's decision about where to incorporate is itself affected by BC laws: a firm seeking protection from hostile takeovers but incorporated in a state without BC laws may decide to re-incorporate in a state that has such laws. Because Compustat reports only the last state of incorporation, we cannot tackle this issue directly. However, the literature indicates that changes of incorporation during the period we consider were rare (Romano 1993).[3]

The advantages of our approach are that (1) BC laws were passed at different points in time and (2) affected firms in their state of incorporation, which often differs from their state of headquarter.[4] These features allow us to compare, within a given headquarter state and industry, the environmental activities of firms that were affected by worse governance (i.e. were incorporated in a BC state) while using as a control group those firms that were not exposed to governance changes (i.e. were incorporated in a state that passed BC laws either later or never). In other words, we are able to establish the effect of interest after controlling for geographic and industry trends in green patenting. Moreover, exploiting the discrepancy between headquarter and incorporation states helps us minimize the concern that the passage of BC laws may correlate with a state's environmental policy less favorable to green innovation:

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[3] Bertrand and Mullainathan (2003) validated this point by randomly sampling 200 firms from their dataset and manually checking how many of them had changed their state of incorporation; only three changes were found—all to Delaware and all several years prior to passage of their respective states' BC laws.

[4] In our sample, 64.5% of firms are incorporated outside their state of headquarter.

because state-level environmental policies are likely to affect firms depending on their states of headquarter (which, again, often differs from incorporation states), we can control for such potential confounding effects by including headquarter states' trends in our regressions.

[[INSERT Figure 1 about Here]]

An illustration of our methodology is presented in Figure 1, which compares the average green patenting activity of firms incorporated in Massachusetts and California. Whereas the former (treatment group) experienced a worsening in corporate governance due to passage of a BC law in 1989, the latter (control group) experienced no such change because California did not pass any BC legislation. If we focus on the pre-BC years it is clear that, though Massachusetts-incorporated firms had more green patents on average, the slightly upward trend did not differ much from California-incorporated firms. Yet focusing on post-BC years reveals a sharp decline in the green patenting activity of Massachusetts firms, whereas California firms follow the existing trends.[5]

We generalize this example to all states and law passages over the years by estimating the following model:

$$Y_{ikt} = \alpha_i + \alpha_t + \beta \mathrm{BC}_{kt} + \gamma' X_{ikt-1} + e_{ikt} . \qquad (\dagger)$$

Here Y_{ikt} measures, at time t, the green patenting activity of firm i incorporated in state k; BC_{kt} is a dummy variable set equal to 1 if a firm is incorporated in a state that has passed a BC law

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[5] To establish the statistical significance of this change around 1989, we estimate a simple difference-in-differences model: the dependent variable is the state-year average of the logarithm of one plus green patent cites; and the explanatory variables are dummies for Massachusetts and post-BC law passage as well as their interaction. The coefficient of the interaction term indicates that, relative to California, Massachusetts experienced a 1% significant drop in green patenting following the passage of BC laws.

by time t (treatment group) and to 0 otherwise (control group). Hence the coefficient β measures the effect of BC law passage on firms' green patenting activity relative to firms incorporated in states that passed BC laws later in time (or that never passed a BC law).

Given that firms incorporated in BC states may differ from those incorporated in states without BC laws, it is important to include a comprehensive set of controls. In particular, α_i and α_t represent (respectively) firm and year fixed effects, which are used to account for common shocks (e.g., the energy crises of the 1970s) that might affect green activities, and for unobserved heterogeneity across firms that is invariant over time. The term X_{ikt-1} is a vector of controls that includes (depending on the specification) the logarithm of firm sales, of the capital/labor ratio, of R&D stock, and of firm age, in addition to the HHI. Controls are lagged by one year to preclude confounding by potentially simultaneous effects of BC laws. Further, we include as controls the headquarters state and the 3-digit industry linear trends, computed as annual averages of the dependent variable excluding the firm in question.

e_{ikt} denotes the residuals, which we estimate clustering by the state of incorporation. This procedure accounts for arbitrary correlations of residuals across different firms in a given year and state of incorporation, across different firms in a given state of incorporation over time, and over different years for a given firm (Giroud and Mueller 2010). In robustness checks, we verify that our main findings hold clustering standard errors by firm.

4. Results

4.1. Main finding

This section presents our main OLS results obtained using different measures of green patenting activity as dependent variable. In column [1] of Table 5, we use the logarithm of one plus green patent cites. In column [2], we use an indicator equal to 1 if a firm reports (in a given year) at least one environment-related patent; column [3] uses the same indicator as column [2] but restricts the analysis to patenting firms.[6]

Results indicate that exposure to BC laws has a negative effect on green patenting, which is both statistically and economically relevant. For instance, the coefficient in column [3] indicates that, holding everything constant, patenting firms subject to BC laws are 6% less likely to file any green patent.

[[INSERT Table 5 about Here]]

As Atanassov (2013) shows, BC laws have a negative effect on firms' overall patenting activity. It is therefore possible that our results are driven by a generic reduction in corporate patents. We explicitly take this effect into account by using as dependent variable the ratio of green patents to the total number of patents (column [4] of Table 5). The reported values indicate the presence of a compositional change in patent portfolios above and beyond the generalized drop in patents. We find that firms subject to BC laws filed fewer green patents relative to their overall innovation effort: the coefficient of interest, which is equal to -0.033 and is statistically significant at the 5% level, indicates a drop of around 13% from the average green patent ratio.

We confirm this finding using the ratio of green patent cites to total patent cites (column [5]), which will be adopted as main dependent variable throughout our empirical analysis. Using the ratio of patent cites rather than the patent counts is useful to account not only for the difference in number of patents but also for their technological importance (as reflected by the future citations received). Following the passage of BC laws, firms

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[6] While we use linear probability models for columns [2] and [3], in which the dependent variable is binary, in untabulated tests we have checked the robustness to the use of Logit regressions.

incorporated in legislating states reduced their green patenting activity by 3.9 percentage points (statistically significant at the 5% level). Given that the average ratio of green patent cites to total cites is 25%, the reduction amounts to approximately 15% of the average green innovation and is therefore economically relevant.

4.2. Robustness

In this section, we address a number of empirical issues related to our estimation strategy. We start by taking into account that OLS may be inappropriate because our dependent variable in column [5] of Table 5 is a proportion that involves zeros (corresponding to firms that do not patent any green innovation). Column [1] of Table 6 reports the results obtained using a pooled fractional nonlinear procedure estimated via quasi–maximum likelihood technique (as proposed by Papke and Wooldridge 1996), including state and industry dummies.[7] In Column [2], we also check that our findings are robust to using the logarithm of one plus the green patent ratio.

[[INSERT Table 6 about Here]]

Green patents can be defined in several ways; yet we show that our results do not depend on the particular categorization used. To this end, in column [3] of Table 6 we employ as dependent variable the ratio of patents for new energy technologies (Popp 2002; Popp and Newell 2012) to a firm’s total patents. This alternative specification yields a significant and negative effect of BC laws on the ratio of green projects—just as in the original specification.

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[7] We also extend this model to a panel setting by using a fractional probit model with heteroskedasticity-robust standard errors, as in Papke and Wooldridge (2008). Our results are largely robust to adopting this alternative procedure, but the model has some difficulties with unbalanced data.

Some of the controls included in Table 5, for instance firm sales or capital intensity, could be considered as outcome variables themselves affected by the BC laws. In Column [4] of Table 6, we show that our main finding holds if we estimate a model that only controls for fixed effects and trends.

We are concerned that the results may be driven by a few specific states. To ensure that our findings are not driven by influential states that report the highest innovation activity, we run the regression while excluding firms headquartered in California (column [5] of Table 6). Because most firms are incorporated in Delaware, we also ensure—via an analogous exclusion in column [6]—that our results are not driven by Delaware incorporations. Finally, in column [7] we exclude states that never passed BC legislation and thus use only the staggered passage of BC laws when constructing the control group.

Next, we show that our results are robust also to restricting the analysis to manufacturing (column [8])—the sector that is viewed as the main source of toxic emissions[8] and that also accounts for the majority of patenting activity (Scherer 1983; Balasubramanian and Sivadasan 2011)—or to extending the sample to the year 2000 (column [9]).

We further verify that our results are robust to alternative procedures of estimating the standard errors—for example, clustering at the firm level (column [10]), or using block-bootstrap methods (untabulated).

Gormley and Matsa (2014) show that controlling for industry effects by the use of industry averages or industry-adjusted dependent variables can bias the inference. To mitigate

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[8] Actually, manufacturing activities are extremely heterogeneous in terms of pollution emissions, and they occur in sectors with relatively high (e.g., chemicals) and low (e.g., apparel) emission levels. In unreported analyses, our findings are substantially unchanged when restricted to either the subsample of the most pollution-intensive industries or all other industries. We follow existing studies (e.g., Keller and Levinson 2002) in classifying, as pollution-intensive industries: pulp and paper (SIC 26), chemicals (SIC 28), petroleum (SIC 29), stone clay and glass (SIC 32), primary metals (SIC 33), fabricated metals (SIC 34), and transportation equipment (SIC 37).

this concern, we check that our results are robust to excluding group averages from the controls (column [11]), and to control for state and industry trends by including the interaction between year and state or SIC dummies (columns [12] and [13]). In untabulated regressions, we also obtain results after including both sets of dummy interactions (main coefficient equal to 0.026 and significant at the 8% level).

Next, we restrict the analysis to BC-affected firms that entered the sample prior to the law passage and that remained in the sample for at least 3 years after the law passage, in order to mitigate the effects of entry and exit (column [14]). Another concern is that we cannot identify the month in which a BC law was passed; it may therefore be inappropriate to consider as "post-BC period" the observations for states that passed the law at the end of the year. To address this possibility, we drop those firm-year observations corresponding to the year of BC law passage (column [15]).

We also allow for heterogeneous time and state effects by interacting all the covariates with year and treatment-state dummies (column [16]), or we include as additional controls in column [17] the ratio of operating returns to total assets (ROA) and the ratio of liquid holdings to total assets (as well as their interactions with the BC law dummy, in column [18]) in order to absorb differences in the availability of financial resources.

Using data and procedures from Karpoff and Wittry (2014), we address a number of empirical challenges with the use of BC laws in causality tests. First, we deal with the concern that the empirical effect of BC laws may be biased by: (1) the presence of first-generation antitakeover laws, enacted by a number of US states since 1968 and valid until 1982 (when the US Supreme Court invalidated them); (2) the passage of other second-generation antitakeover provisions (i.e. fair price, control share acquisition and poison pill laws) which were adopted during the same period of the BC laws; and (3) court decisions over the same period that altered the scope of legal takeover protection. In column [19] we restrict the analysis to the period after 1982 in order to exclude the time period covered by first-generation antitakeover laws. Alternatively, in column [20] we ameliorate the same concern explicitly controlling for the presence of first-generation antitakeover laws. In column [21] we control for the other second-generation antitakeover provisions adopted by US states. In column [22] we control for the main court decisions regarding BC laws.

As argued in Section 3, the lobbying activities regarding BC legislation was on behalf of single firms and large coalitions of firms played only a minor role. This feature alleviates the concern that the political economy process leading to BC laws was endogenous to corporate activities in a way that may systematically bias our findings. However, Karpoff and Wittry (2014) identify a number of firms that conducted intense lobbying towards BC legislation (for which the BC laws cannot be considered exogenous). In column [23] we exclude these "motivating firms", for which BC laws cannot be considered exogenous.

In columns [24] and [25] we deal with concerns of influential observations by dropping, respectively, 1% or 5% of observations in the right tail of the citation distribution. Finally, in column [26] we limit the analysis to firms with a high patenting intensity (to identify the effect on companies for which patenting is strictly part of their innovation policy), and in column [27] we exclude self-citations from the computation of patent cites.

4.3. Dynamics

We test for dynamic effects by replacing the binary indicator variable for the passage (or not) of BC laws with a set of lags and leads around BC law passage. The omitted group then consists of observations from the fourth year or earlier prior to BC law passage and from never-BC states.

Results in Table 7 show that BC laws did not affect green patenting *before* the actual year of BC law passage; the pre-BC dummy has a positive sign for the third year prior to the law passage, and then the sign becomes negative but economically very small and statistically not different from zero. This finding is of special importance because it shows that our finding is not driven by the pre-treatment innovation characteristics of firms (as might occur, e.g., if struggling firms that sought protection in BC laws were also less successful in green innovation).

However, the BC law coefficient becomes much larger economically in the year of the BC law passage (it jumps from -0.015 to -0.044) and it keeps on increasing in the post-BC law period. The largest effect (-0.085) is obtained three years after the law passage, and then it flattens around -0.06 from the fourth year onwards.

[[INSERT Table 7 about Here]]

5. Heterogeneity

In this section, we present a number of tests to explore heterogeneous effects and delineate some of the mechanisms that may drive our main finding. Although we find weak statistical significance that the effect of BC laws differed across the various configurations analyzed, the coefficients display economic variations that are consistent with some specific mechanisms that we discuss in detail.

5.1. Internal governance mechanisms

We have so far established the main finding using a shock to corporate governance at the state level. Yet, we know from finance works that firms are endowed with internal governance mechanisms that may interact with external governance regimes (Brickley and James 1987; Durnev and Kim 2005) ameliorating the weakness of the institutional context where they operate. Building on the idea that sound firm-specific governance mechanisms can substitute for weaker state-level takeover pressures, we explore how the reduction in green patenting following the passage of antitakeover laws is shaped by the presence of alternative governance mechanisms within the firm. Specifically, we expect that, by counteracting the worse governance at the state level, better firm-specific governance reduces the drop in green patents induced by the BC laws.

To test this hypothesis, we use the equity shares held by institutional investors as a proxy for firm-level shareholders' power and ability to govern managers. We draw annual data on institutional investor holdings from SEC 13 filings recorded in the Thompson Financial CDA/Spectrum database, and then we construct an indicator variable set equal to 1 or 0 according as whether the firm has a large (above-median) or small (below-median) fraction of institutional ownership; this variable is then interacted with the dummy for BC law passages.

Column [1] of Table 8 reports the results of this exercise. We observe that the negative effect of BC laws is present both for firms with a high and for firms with a low level of institutional ownership. That being said, the coefficient for low level of institutional ownership is nearly 25% larger and is statistically significant at the 5% level. This finding is consistent with the argument that, by effectively monitoring managers, large institutional owners mitigated the negative effect of BC laws on green innovation activities.

5.2 Technological lock-in

Recent influential works (e.g. Acemoglu et al. 2012) have argued that innovation activities often exhibit path dependency. This is due to the fact that when firms have a large stock of innovation in a given technological field, using the knowledge from such lasting resources reduces the marginal cost of developing new products in that field, and this in turn generates a technological lock-in effect. In the context of environmental innovation, this mechanism suggests that firms with a larger stock of innovation in the field of green technologies will tend to keep innovating in this field, whereas firms with cumulated innovative experience in dirty technologies will stick to these technological fields without easily switching to the green field (see Aghion et al. 2015 for the case of the auto industry).[9]

Drawing on these arguments, we posit that it is relatively easier for firms hit by the BC shock to reduce green innovations if their innovation trajectory is not technologically constrained by past innovation decisions within the green innovation path. In other words, we expect that the negative effect of BC laws on green patenting should be larger for firms with a smaller stock of existing green patents.

To test this hypothesis, we construct the stock of green patents using the perpetual inventory method (Cockburn and Griliches 1988; Peri 2005) and a 15% depreciation rate. We then interact the indicator of worse governance with a dummy set equal to 1 if the firm has a large (above-median) stock or to 0 if it has a small (below-median) stock of green patents.

As expected, the values reported in column [2] of Table 8 indicate that firms with a small stock of green patents experience a dramatic decrease in green patenting following the BC law passage; by contrast, firms with a large stock of green patents are almost unaffected by

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[9] Another argument is that firms with a larger stock of green patents are those that may care more about being green, because of organizational commitment or managerial preferences.

the BC laws. The considerable difference between the two coefficients is in line with the idea that firms are partly locked into past technological trajectories and that this effect influences the response of environmental innovation efforts to corporate governance changes.

5.3. Energy dependence and pollution abatement costs

Focusing now on sectoral differences, we argue that the opportunity cost of reducing green innovation activities is expected to be higher for firms that operate in industries highly dependent on energy resources – a context in which green patents can induce more significant cost reductions in firms' production methods.

To test this hypothesis, we compute an industry-level measure of energy dependence using data from the NBER manufacturing dataset. In particular, we take the ratio of energy expenses (cost of electrics and fuels) to the total value added. Then we classify industries as being strongly (above-median) or weakly (below-median) dependent on energy, and interact the resulting indicator with the BC law dummy.

Results reported in column [3] of Table 8 show that BC law passages reduce the proportion of green patents more intensively in industries with low energy dependence.[10] Although insignificant statistically, the difference in coefficients suggests that BC laws did have some stronger impact on corporate green innovation activities within industries characterized by less energy dependence.

Another variation in the opportunity costs of dropping green projects stems from the stringency of environmental regulations in the state where the firm is headquartered; the cost of

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[10] This analysis is limited to firms in the SIC codes 2000–4000 because these are the only ones covered by the NBER manufacturing dataset.

lowering environmental innovation should be higher in states with more stringent pollution regulations.

To test this argument, we adopt the index computed by Levinson (2001) and Keller and Levinson (2002) who use data from the Pollution Abatement Costs and Expenditures (PACE) survey to quantify industry-adjusted pollution abatement costs in 48 US states.[11] A higher value of this index corresponds to a higher cost of compliance with a state's environmental policy. We interact the BC law dummy with an indicator set equal to 1 or 0 according as whether the firm's state of headquarters has a high (above-median) or low (below-median) pollution abatement cost index.[12]

As shown in column [4] of Table 8, the negative effect of worse governance is significant and economically greater when the firm operates in a state in which pollution abatement costs are low. In other words, in line with our hypothesis, a higher cost of complying with state-level pollution regulations lessens the drop in environmental innovation caused by the managerial slack after passage of BC laws.

[[INSERT Table 8 about Here]]

5.4. Financial constraints and R&D spending requirements

It has been shown that the availability of financial resources is a critical determinant of socially responsible corporate activities (Hong et al. 2012). At the same time, we know that good corporate governance generally improves firms' financing conditions, and that, by worsening the quality of corporate governance, BC laws made financial constraints more binding (see e.g. Qui and Yu 2009 on debt costs). Financial constraints can thus play a crucial

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[11] See http://www.census.gov/econ/overview/mu1100.html for more details on the PACE survey.

[12] We also exclude 1987 because of missing data for that year in the original survey.

role in our analysis because green technologies, by being newer and more radical, may demand more resources to satisfy larger funding requirements or to hedge greater technological risk.

In this section, we thus explore how financial constraints shape the above-documented relationship between corporate governance and green patenting. Specifically, we posit that firms with good access to capital should experience a relatively smaller drop in green patents following the passage of BC laws.

To test this hypothesis, we start by constructing an industry-based measure of dependence from external capital similar to Rajan and Zingales (1998). In particular, we classify industries depending on whether they are above or below the median dollar amount of external financial capital, and then we interact the resulting dummy with our BC variable. Results, reported in Column (1) of Table 9, indicate that BC laws are inducing the biggest drop in green patents for firms operating in industries that rely intensively on external finance.

We confirm this finding by employing a firm-specific proxy for financial constraints. Finance works (e.g. Faulkender and Petersen 2005) have argued that credit rating coverage lowers informational asymmetries and thus improves a firm's access to credit. We thus check the variations of our results depending on whether the firm has received or not a rating from Standard&Poors.

Results in Column (2) of Table 9 lend support to the idea that BC laws had a negative effect on green patents primarily among financially constrained firms.[13] Taken together, the heterogeneity documented so far suggest that financial constraints were an important channel through which worse corporate governance may have translated into weaker green patenting activities.

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[13] In untabulated tests, we have verified that this result holds if financial constraints are measured using the index recently proposed by Hadlock and Pierce (2010).

Finally, we investigate the effect of R&D spending requirements. Our hypothesis is that, if financial constraints are a channel underlying the effect of BC laws on green patenting, then such effect should be stronger for firms operating in sectors where R&D spending requirements (and thereby financing capital needs) are more prevalent. To this end, we construct a dummy that distinguishes between industries with high or low R&D expenditures (scaled by total sales).

Results in Column (3) of Table 9 confirm the importance of financial constraints by showing that the negative effect of BC laws on green patents is mostly present in industries characterized by high R&D spending requirements.

[[INSERT Table 9 about Here]]

5.5. General effects depending on patent types

Our interpretation for the drop in green patents following the passage of BC laws is that a weaker threat of hostile takeovers makes managers more prone to extract private benefits by enjoying the quiet life, i.e. by avoiding technologically complex projects. A parallel channel, also validated by the evidence in the previous section, is that worse governance, by making firms less able to access external capital, reduces the investment in radically new (and thus plausibly more expensive) innovative projects such as green technologies.

Conceptually, these interpretations are valid not just for green patents but, more generally, for all new and radical patents. To check whether antitakeover laws affected the composition of patent portfolios along this line, we conduct a separate investigation of the effect of BC laws on radical vs. non-radical patents. To proxy for these patent characteristics, we used information on citations and technological classes. Specifically, we distinguish between patents that lie in the top or bottom tertiles, within its technological class, of the distribution of both generality and originality indexes, as well as in terms of overall citations obtained. Then we establish the effect of BC laws on these two different patent types.

In line with our previous arguments, results in Table 10 indicate the negative effect of BC laws is primarily present for patents that are more complex and novel from a technological standpoint.

[[INSERT Table 10 about Here]]

6. Concluding remarks

A recent literature suggests that organizational characteristics can play an important role in determining firms' energy efficiency. We have contributed to this research by investigating the impact of corporate governance on firms' environmental innovation. Our results indicated that worse governance leads to significantly lower innovation in the area of green technologies: US firms exposed to the passage of business combination laws, which weakened the disciplinary role of the market for corporate control, experienced a 13% drop of green patents relative to their entire patent portfolio.

This finding is consistent with a "quiet life" explanation, according to which the managers of worse governed firms extract private benefits by avoiding activities that are cognitively challenging or systemically disruptive. Our results are also consistent with a financial constraints explanation, whereby badly governed firms have more difficulties raising capital needed to invest in potentially expensive projects such as green technologies. Both managerial preference and financial constraint channels support the notion that corporate governance has strong implications on corporate environmental decisions.

We dug deeper into these interpretations by investigating how the magnitude of the corporate governance effect is shaped by economic, technological and financial factors. We found that the drop in green patenting induced by worse governance is greater for firms with a smaller share of institutional ownership, with a smaller stock of green patents, and with more binding financial constraints. Investigating the role of external factors, we also found greater negative effects for firms operating in states with lower pollution abatement costs and in industries less dependent on energy inputs.

What are the welfare implications of our results? Popp and Newell (2012) offer two arguments suggesting that alternative energy innovations are among the projects with highest social return. First, there is comparatively less amount of research available on alternative energy than in other fields, which increases the potential for knowledge spillovers. Second, alternative energy innovations may affect a broader array of industries than do traditional innovations; hence, they have more potential to constitute general-purpose technologies (GPTs). These arguments suggest that bad corporate governance—by reducing incentives to environmental innovation—may be detrimental not just for shareholders but also for the society at large.

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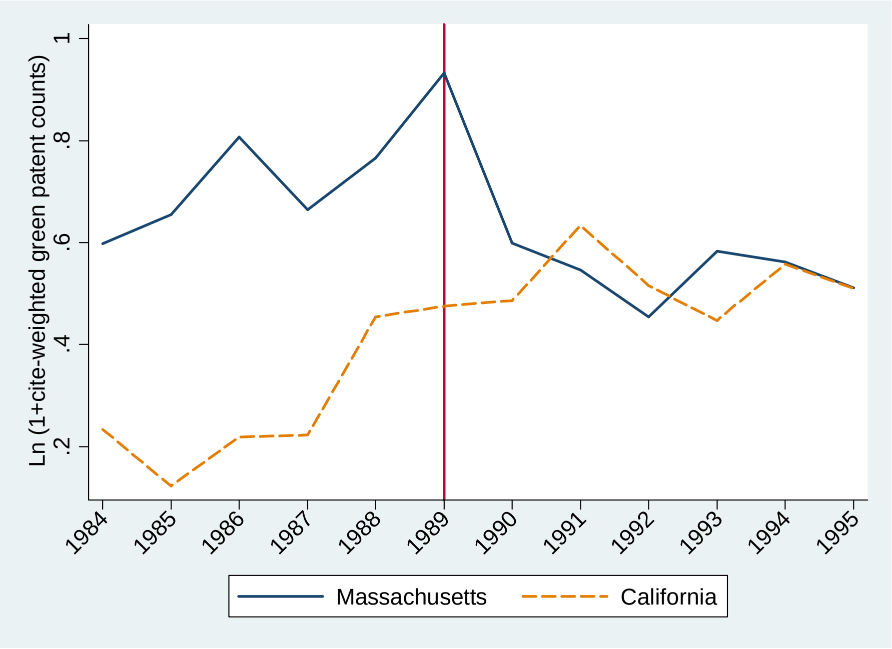
Figure 1.
Green patenting and BC laws: An example



This graph plots the average logarithm of one plus green patent cites for firms incorporated in California and Massachusetts in the years before and after 1989. Massachusetts passed BC legislation in 1989; California never passed BC legislation.

Table 1.
Business combination laws by state

State	Law passage
New York	1985
Indiana, Missouri, New Jersey	1986
Arizona, Kentucky, Minnesota, Washington, Wisconsin	1987
Delaware, Georgia, Idaho, Maine, Nebraska, South Carolina, Tennessee, Virginia	1988
Connecticut, Illinois, Kansas, Maryland, Massachusetts, Michigan, Pennsylvania, Wyoming	1989
Ohio, Rhode Island, South Dakota	1990
Nevada, Oklahoma	1991
Alabama, Alaska, Arkansas, California, Colorado, District of Columbia, Florida, Hawaii, Iowa, Louisiana, Mississippi, Montana, New Hampshire, New Mexico, North Carolina North Dakota, Oregon, Texas, Utah, Vermont, West Virginia	#

This table illustrates the passage of business combination (BC) laws in the US states during the sample period. Those states that did not pass BC legislation by 1995 are listed at the bottom of the table and marked with #.

Table 2.
Distribution of states and firms

	With BC laws	Without BC laws
	[1]	[2]
Number of states (%)	30 (59%)	21 (41%)
Number of firms (%)	4,847 (85%)	878 (15%)

This table reports the distribution of states that did and did not pass BC legislation by 1995, as well as the number of firms incorporated in these states.

Table 3.

Summary statistics

	Number of observations	Average	Standard deviation	Median
	[1]	[2]	[3]	[4]
Ln(Sales)	43,570	3.938	2.469	3.938
Ln(K/L)	42,948	2.840	1.132	2.776
Ln(Age)	43,774	2.345	0.793	2.302
HHI	43,651	0.174	0.115	0.141
Patent counts	31,684	8.471	39.112	0
Patent cites	31,684	130.359	786.739	0
Green patents ratio	13,429	0.254	0.324	0.082
Green cites ratio	13,388	0.246	0.338	0.038

This table provides summary statistics for main variables used in the empirical analysis. A complete description of each variable is provided in Table A2.

Table 4.

Differences in firm and patent characteristics

Panel A. Firm-level evidence

	Green innovators	Environment-unrelated innovators	Difference [1] - [2]
	[1]	[2]	[3]
Ln(Sale)	6.0726	3.6097	2.4629***
	(0.0271)	(0.0142)	(0.0298)
Ln(K/L)	3.2436	2.7482	0.4954***
	(0.0110)	(0.0006)	(0.0005)
Ln(Age)	2.9258	2.2790	0.6468***
	(0.0089)	(0.0049)	(0.0102)
Ln(R&D)	2.5403	0.3084	2.2319***
	(0.0135)	(0.0238)	(0.0267)
Ln(1+R&D)	2.7873	1.0407	1.7466***
	(0.0197)	(0.0073)	(0.0171)

Panel B. Patent-level evidence

	Green patents	Environment-unrelated patents	Difference [1] - [2]
	[1]	[2]	[3]
Originality	0.3708	0.3472	0.0234***
	(0.0004)	(0.0002)	(0.0005)
Generality	0.3345	0.3156	0.0189***
	(0.0005)	(0.0003)	(0.0005)

This table presents results obtained from t-tests. Panel A compares firm characteristics depending on green innovation status: green innovators are companies that have filed at least one green patent, whereas environment-unrelated innovators are companies without green patents. Panel B presents results from t-tests conducted at the patent level in the NBER patent dataset using the time period of 1976-1995. Green patents are defined in Table A2. Originality is equal to $1 - \sum_{j}^{n_j} s_{ij}^2$, where s_{ij}^2 denotes the percentage of patent references by a patent *i* that belong to the patent technology class *j* out of n_i patent classes (the index takes high values, i.e. high originality, if a patent cites patents that belong to many different technological fields. Generality is constructed in a similar way but it relies on the citations made rather than citations received. Green innovator is an indicator set equal to 1 if the firm reports at least one green patent in a given year (and to 0 otherwise). *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 5.
Main findings

Dependent variable:	Ln (1+green patent counts)	At least one green patent	At least one green patent| patents>0	Green patents ratio	Green cites ratio
	[1]	[2]	[3]	[4]	[5]
BC	-0.0477*	-0.0181**	-0.0601**	-0.0327**	-0.0385**
	(0.0276)	(0.0082)	(0.0248)	(0.0153)	(0.0164)
Ln(Sale)	0.0739***	0.0216***	0.0398***	-0.0014	-0.0022
	(0.0166)	(0.0038)	(0.0084)	(0.0055)	(0.0050)
Ln(K/L)	0.0065	0.0019	0.0043	0.0099*	0.0159***
	(0.0065)	(0.0022)	(0.0099)	(0.0052)	(0.0057)
HHI	0.6561***	0.0893	0.0792	-0.1930**	-0.2132*
	(0.1966)	(0.0644)	(0.1952)	(0.0824)	(0.1111)
HHI^2	-0.5910*	-0.0436	0.0748	0.1587	0.1379
	(0.3182)	(0.1016)	(0.3606)	(0.1769)	(0.1957)
Ln(Age)	-0.0820***	-0.0065	-0.0092	-0.0083	-0.0069
	(0.0267)	(0.0071)	(0.0132)	(0.0090)	(0.0098)
Ln(R&D stock)	0.2787***	0.0641***	0.0689***	-0.0052	-0.0064
	(0.0209)	(0.0043)	(0.0078)	(0.0068)	(0.0069)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
State and industry trends	Yes	Yes	Yes	Yes	Yes
Number of observations	31,659	31,195	13,268	13,425	13,292

This table presents results obtained from OLS regressions. The dependent variable in column [1] is the logarithm of one plus green patent cites; in column [2], an indicator set equal to 1 if the firm reports at least one green patent in a given year (and to 0 otherwise); in column [3], an indicator set equal to 1 if the firm reports at least one green patent in a given year (and to 0 otherwise) conditional on being a patenting firm; in column [4], the ratio of green to total patent counts; in column [5], the ratio of green patent cites to total patent cites. Each regression includes firm fixed effects, year dummies, and headquarters' state in addition to industry linear trends computed as annual averages of the dependent variable (after excluding the firm in question). Each regression also controls for the logarithm of sales, of the capital/labor ratio, of the R&D stock, and of firm age as well as the HHI and its square. Each control is lagged by one year. The construction of each variable is described in Table A2. Standard errors (in parentheses) are clustered by state of incorporation. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 6.
Robustness

	Pooled fractional logit	Ln(1+green patent ratio)	Energy patents to all patents	Excluding controls	Excluding California	Excluding Delaware	Excluding never-BC states	Manufact-uring industries	Time period until 2000
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
BC	−0.2121**	−0.0273**	−0.0122*	−0.0368**	−0.0263**	−0.0335*	−0.0229**	−0.0425**	−0.0328*
	(0.0895)	(0.0116)	(0.0062)	(0.0160)	(0.0122)	(0.0178)	(0.0137)	(0.0166)	(0.0178)
Year and firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State and industry trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Number of observations	13,292	13,292	13,235	13,292	11,131	6,060	12,282	12,226	18,677

	Firm clustered s.e.	Excluding trends	SIC×year dummies	State×year dummies	Stable sample	Excluding BC years	Hetero-geneous effects	Controls for cash I	Controls for cash II
	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
BC	−0.0385**	−0.0384**	−0.0299**	−0.0384***	−0.0366**	−0.0389*	−0.1016**	−0.3373**	−0.3374**
	(0.0148)	(0.0162)	(0.0115)	(0.0119)	(0.0171)	(0.0200)	(0.0453)	(0.0168)	(0.0167)
Year and firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State and industry trends	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	13,292	13,292	13,292	13,292	10,014	12,617	13,292	13,270	13,278

	Time period post-1982	First generation laws	Other takeover laws	Court decisions	No moti-vating firms	Extreme outcomes I	Extreme outcomes II	High patenting intensity	No self-citations
	[19]	[21]	[22]	[23]	[23]	[24]	[25]	[26]	[27]
BC	−0.0334*	−0.0387**	−0.0355**	−0.0289*	−0.0289**	−0.0404**	−0.0455**	−0.0315***	−0.0386**
	(0.0188)	(0.0168)	(0.0170)	(0.0147)	(0.0147)	(0.0164)	(0.0183)	(0.0093)	(0.0165)
Year and firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State and industry trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	9,647	13,292	13,292	13,292	13,145	12,976	11,707	7,911	13,272

This table presents results from various specifications. In column [1] we estimate the model in column [5] of Table 5 using a pooled fractional logit model that includes state and industry dummies rather than firm fixed effects. In Column [2] we adopt the logarithm of 1 plus the green patent ratio as dependent variable to estimate the OLS model as in column [5] of Table 5. Column [3] reports OLS estimates using the ratio of energy patent counts to total patent counts. In Column [4] we estimate the model in column [5] of Table 5 without any control besides fixed effects and trends. In column [5] we exclude firms headquartered in California, and in column [6] we exclude firms incorporated in Delaware. Column [7] excludes firms incorporated in states that never passed a BC law; column [8] includes only those firms operating in the manufacturing sector (SIC from 2000 to 4000), and column [9] extends the sample period through 2000. Column [10] provides results obtained clustering residuals by firm. Column [11] provides results after excluding trend variables, whereas Column [12] includes industry times year dummies. Column [14] shows results obtained on the subsample of firms that are in the sample prior to the BC passage and that stay in the sample for at least 3 years after the BC law passage, together with firms in non-BC states. Column [15] shows results obtained excluding the years that correspond to the passage of BC laws. Column [16] augments our specification with a set of interactions between BC law dummy and each of the time-varying firm level controls. Column [17] includes operating returns to total assets and cash holdings to total assets as additional control to the ones in Column [5] of Table 5, and Column [18] further includes the interactions between BC law dummy and these variables. Column [19] includes only years after 1982, Column [20] removes from the sample the lobbying or motivating firms indicated by Karpoff and Wittry (2014), Column [21] includes an indicator variable for the presence of first-generation antitakeover laws in the US states, Column [22] includes dummies for poison pill, control share acquisition and fair price laws in the Us states, and Column [23] control for the interaction between these latter variables and dummies indicating US major court decisions as reported in Karpoff and Wittry (2014). Columns [24] and [25] show results obtained excluding, respectively, 1% and 5% of observations on the right tail of the citations distribution. Column [26] presents estimates obtained using firms with at least 3 patents. Finally, Column [27] shows results obtained excluding self-citations before computing the dependent variable. Unless otherwise indicated, each regression includes the controls used in column [5] of Table 5. The construction of each variable is described in Table A2. Standard errors (in parentheses) are clustered by state of incorporation unless differently specified. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 7.
Dynamics

Dependent variable: Green patents ratio	
$BC_{t=-3}$	0.0010
	(0.0129)
$BC_{t=-2}$	−0.0067
	(0.0218)
$BC_{t=-1}$	−0.0154
	(0.0243)
$BC_{t=0}$	−0.0438
	(0.0278)
$BC_{t=1}$	−0.0510*
	(0.0300)
$BC_{t=2}$	−0.0489*
	(0.0278)
$BC_{t=3}$	−0.0845***
	(0.0244)
$BC_{t=4}$	−0.0610**
	(0.0279)
$BC_{t=5+}$	−0.0646**
	(0.0267)
Year fixed effects	Yes
Firm fixed effects	Yes
State and industry trends	Yes
Controls	Yes
Number of observations	13,292

This table presents results obtained from OLS regressions. The dependent variable is the ratio of green patent cites to total patent cites. The BC dummy treatment used in previous tables is replaced with dummies for the years around passage of the BC legislation. The regression includes the controls used in column [5] of Table 5. Standard errors (in parentheses) are clustered by state of incorporation. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 8.

Variations in internal governance, green policies and energy dependence

Dependent variable: Green patents ratio				
	[1]	[2]	[3]	[4]
BC × Low institutional ownership	−0.0443**			
	(0.0167)			
BC × High institutional ownership	−0.0334*			
	(0.0181)			
BC × Small stock of green patents		−0.0867***		
		(0.0173)		
BC × Large stock of green patents		−0.0068		
		(0.0200)		
BC × Low energy dependence			−0.0506***	
			(0.0164)	
BC × High energy dependence			−0.0357*	
			(0.0183)	
BC × Small pollution abatement costs				−0.0459*
				(0.0260)
BC × High pollution abatement costs				−0.0318
				(0.0258)
High institutional ownership	0.0070			
	(0.0103)			
Large stock of green patents		0.1561***		
		(0.0163)		
High energy dependence			−0.0064	
			(0.0056)	
High pollution abatement cost				−0.0096
				(0.0140)
Year fixed effects	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
State and industry trends	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Number of observations	13,291	9,569	11,761	9,953

This table presents results obtained from OLS regressions. The dependent variable is the ratio of green patent cites to total patent cites. High (resp. low) institutional ownership is a dummy set equal to 1 (resp. 0) if the firm has a share of institutional ownership above (resp. below) the median value. Small (large) stock of green patents is a dummy set equal to 1 (0) if the firm has a stock of green patent cites above (below) the median value. High (low) pollution abatement costs is a dummy set equal to 1 (0) if the firm operates in a state that is above (below) the median abatement cost index constructed by Levinson (2001) and Keller and Levinson (2002). High (low) energy dependence is a dummy set equal to 1 (0) if the firm operates in an industry above (below) the median threshold of an energy dependence index, for which we use the NBER manufacturing dataset to compute the ratio of energy expenses (cost of electric and fuels) to total value added. Each regression includes the controls used in column [5] of Table 5. Standard errors (in parentheses) are clustered by state of incorporation. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 9.

Variations in financial constraints and R&D spending requirements

Dependent variable: Green patents ratio

	[1]	[2]	[3]
BC × Low dependence from external capital	-0.0347*		
	(0.0189)		
BC × High dependence from external capital	-0.0475***		
	(0.0164)		
BC × Without S&P rating		-0.0403**	
		(0.0186)	
BC × With S&P rating		-0.0175	
		(0.0175)	
BC × Low R&D requirement			-0.0286
			(0.0206)
BC × High R&D requirement			-0.0465***
			(0.0162)
High dependence from external capital	0.0216***		
	(0.0060)		
High R&D spending			0.0260***
			(0.0118)
Year fixed effects	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
State and industry trends	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Number of observations	11,984	10,434	13,286

This table presents results obtained from OLS regressions. The dependent variable is the ratio of green patent cites to total patent cites. High (resp. low) dependence from external capital is a dummy set equal to 1 (resp. 0) if the firm operates in an industry above (resp. below) the median value of net changes in capital. Without (with) S&P rating is a dummy set equal to 1 (0) if the firm has received or not a S&P credit rating. High (low) R&D spending is a dummy set equal to 1 (0) if the firm operates in an industry above (below) the median value of R&D expenditures scaled by total revenues. Each regression includes the controls used in column [5] of Table 5. Standard errors (in parentheses) are clustered by state of incorporation. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table 10.

Variations by patent type

Dependent variable:	Complex patents ratio	Non-complex patents ratio
	[1]	[2]
BC	-0.0292**	0.0002
	(0.0124)	(0.0031)
Year fixed effects	Yes	Yes
Firm fixed effects	Yes	Yes
State and industry trends	Yes	Yes
Controls	Yes	Yes
Number of observations	13,261	13,261

This table presents results obtained from OLS regressions. The dependent variable in column [1] is the ratio of complex patents to all patents, where complex patents are those in the top tertile in terms of originality, generality and citations received; in column [2], is the ratio of non-complex patents to all patents, where non-complex patents are those in the bottom tertile in terms of originality, generality and citations received. Each regression includes firm fixed effects, year dummies, and headquarters' state in addition to industry linear trends computed as annual averages of the dependent variable (after excluding the firm in question). Each regression also controls for the logarithm of sales, of the capital/labor ratio, of the R&D stock, and of firm age as well as the HHI and its square. Each control is lagged by one year. The construction of each variable is described in Table A2. Standard errors (in parentheses) are clustered by state of incorporation. *, **, and *** denote (respectively) significance at the 10%, 5%, and 1% level.

Table A1.
Green patents

Air pollution control	015, 044, 060, 110, 123, 422, 423
Alternative energy	049, 062, 204, 222, 228, 242, 248, 425, 428, 708, 976
Alternative energy sources	062, 222, 425
Geothermal energy	060, 436
Recycling	060, 075, 099, 100, 106, 162, 164, 198, 201, 205, 210, 216, 229, 264, 266, 422, 425, 431, 432, 460, 502, 523, 525, 536, 902
Solid waste control	034, 060, 065, 075, 099, 106, 118, 119, 122, 137, 162, 165, 203, 205, 209, 210, 239, 241, 266, 405, 422, 423, 431, 435, 976
Solid waste disposal	122, 137, 239, 241, 405, 523, 588, 976
Solid waste prevention	065, 119, 137, 165, 205, 210, 405, 435
Water pollution	203, 210, 405
Wind energy	073, 104, 180, 242, 280, 340, 343, 374, 422, 440

This table illustrates the patent utility codes (provided by the USPTO) used to classify green patents, which we adopt as main dependent variable. The grouping and definition of each class follows Carrion-Flores and Innes (2010).

Table A2.
List of variables

Name	Description	Source
Innovation variables		
Patent counts	Count of a firm's number of patents	NBER
Patent cites	Count a firm's number of patent cites adjusted for truncation (as described in Hall et al. 2001; Hall et al. 2005)	NBER
Green patent counts	Count of a firm's number of green patents	NBER
Green patent cites	Count a firm's number of green patent cites adjusted for truncation (as described in Hall et al. 2001; Hall et al. 2005)	NBER
Large (small) stock of green patents	Dummy set equal to 1 (0) if the firm has a stock of green patents above (below) the median value; the stock of green patents is computed using the green patent cites and a perpetual inventory method assuming a 15% annual depreciation rate	NBER
Green patents to all patent counts	Ratio of a firm's green patent count to its total patent count (for the definition of "green" patents, see Table A1)	NBER
Energy patents to all patent counts	Ratio of a firm's energy patent count to its total patent count (for the definition of "energy" patents, see Popp and Newell 2012)	NBER
Complex patents ratio	Ratio of complex patents to all patents, where complex patents are those in the top tertile in terms of originality, generality and citations received	NBER
Non-complex patents ratio	Ratio of non-complex patents to all patents, where noncomplex patents are those in the bottom tertile in terms of originality, generality and citations received	NBER
Ln(R&D stock)	Logarithm of (1 + cumulative R&D expenditures), computed assuming a 15% annual depreciation rate and using linear interpolation to replace missing values of R&D	Compustat
Firm characteristics		
Ln(Sales)	Logarithm of a firm's sales	Compustat
Ln(K/L)	Logarithm of the ratio of capital (property, plants, and equipment) to labor (employees)	Compustat
Ln(Age)	Logarithm of 1 plus age, where "age" is the number of years the firm has been listed in Compustat	Compustat
With S&P rating	Without (with) S&P rating is a dummy set equal to 1 (0) if the firm has received or not a S&P credit rating	Compustat
Industry and state characteristics		
HHI	Herfindahl–Hirschman index, computed as the sum of squared market shares of all firms (by sales) in a given 3-digit SIC industry in each year; we drop 2.5% of the observations in the right tail of the distribution in order to minimize potential misclassification (cf. Giroud and Mueller 2010)	Compustat

Industry trends	Average of the dependent variable across all firms in the same 3-digit SIC industry, where averages are computed excluding the firm in question	Compustat
State trends	Average of the dependent variable across all firms in the same state of location of the firm, where averages are computed excluding the firm in question	Compustat
High (low) pollution abatement costs	Dummy set equal to 1 (0) if the firm operates in a state with pollution abatement costs above (below) the median value; "pollution abatement costs" are computed by Levinson (2001) and Keller and Levinson (2002) using data from the Pollution Abatement Costs and Expenditures Survey taken by the US Census Bureau, and the index is computed at the state level after adjusting for industrial composition at the 2-digit SIC level (20–39)	Levinson (2001), Keller and Levinson (2002)
High (low) energy dependence	Dummy set equal to 1 (0) if the firm operates in a 3-digit SIC industry whose energy dependence is above (below) the median value; we use the NBER manufacturing dataset to compute "energy dependence" as the ratio of energy expenses (cost of electric and fuels) to total value added	NBER
High (low) dependence from external capital	Dummy set equal to 1 (resp. 0) if the firm operates in a 3-digit SIC industry above (resp. below) the median value of net changes in equity capital	Compustat
High (low) R&D requirement	Dummy set equal to 1 (0) if the firm operates in a 3-digit SIC industry above (below) the median value of R&D expenditures scaled by total revenues	Compustat
<u>Governance characteristics</u>		
BC	Dummy set equal to 1 starting in the year that a business combination law was passed by the state where the firm is incorporated and to 0 otherwise—that is, for the years prior to BC law passage and for all years in states that never passed a BC law (see Table 1 for a listing of the dates of passage)	
High (low) institutional ownership	Dummy set equal to 1 (0) if the firm has a fraction of equity held by institutional investors above (below) the median value	Thompson Financial CDA/ Spectrum