# Carbon liability risk, corporate governance, and corporate green policies: Evidence from China's ETS program

**Chuyuan Liu**
*Southwestern University of Finance and Economics*

**Siyang Tian**
*Southwestern University of Finance and Economics*

**Valeriya Vitkova**
*Bayes Business School, City, University of London*

# Carbon liability risk, corporate governance, and corporate green policies: Evidence from China's National ETS program

**Abstract**

We investigate whether firms with larger exposure to the carbon liability risk adjust their green policies regarding investment and financing. We exploit the launch of the national carbon trading market in 2017 in China as an exogenous shock to carbon liability risk and employ the difference-in-differences (DiD) design. Following an increase in carbon liability risk, firms in ex ante highly carbon-intensive industries engage in more green innovations and are more likely to issue green bonds. Such responses appear to be primarily motivated by corporate governance schemes in that these policies could be value-enhancing. Overall, our results suggest that carbon liability risk is critical in corporate decision-making.

This version: August 2022

## 1 Introduction

Increased human emissions of heat-trapping greenhouse gases are causing climate change, contributing to the global burden of diseases and premature deaths. Climate change requires international cooperation, and governments throughout the world and regional alliances have put forward a series of environmental regulations and will continue to do so. For instance, in 2005, the European Union implemented the EU Emissions Trading System (EU ETS) to regulate carbon emissions in a variety of industries. To manifest the effort in reducing carbon emissions, 196 Parties adopted the Paris Agreement at COP 21 in 2015. Carbon emission control regulations are likely to impose substantial costs and compliance payments on firms (Böhringer, Koschel, and Moslener, 2008), and the increasingly tightening regulations could increase the risk associated with carbon liability. Prior scholars studied the physical risk of climate change such as hurricanes (Dessaint and Matray, 2017; Massa and Zhang, 2021) and the policy risk of pollution regulation or climate change (Seltzer, Starks, and Zhu., 2022; Bartram, Hou, and Kim, 2021; Dang, Gao, and Yu, 2022) on the corporate capital structure and general financing decisions. In this paper, we focus on the carbon liability risk and examine how firms adjust their green policies in terms of investment and financing choices in response to the risk exposure.

It is empirically challenging to establish the causal relationship between business risk and firm behavior. As argued by Gormley and Matsa (2011), the setting examining the real effects of business risk should serve as an exogenous shock to expected future cash flows but have minimal impact on firms' current resources. In this paper, we use China's recent national ETS program as an exogenous shock to corporate carbon liability risk. The national ETS was announced in December 2017 and its preparation took three years before it entered into force. Firms trading in the national ETS have to pay for excessive carbon emissions in the future and this shock presents a significant increase in the risk of future compliance payment and possible financial distress. At the same time, the national ETS rules are unlikely to have much of an effect on firms' cash flows which could influence corporate investment during the preparation period. In this vein, we can distinguish the exogenous increase in firms' exposure to the carbon liability risk. In addition, the launch of this program could have a differential effect on firms in industries with ex-ante different levels of carbon emission intensity. As a result, to gauge the real effects of carbon liability risk, we can test whether the green policies of firms in ex-ante carbon-intensive industries are adjusted after the announcement of the national ETS.

To construct the sample, we keep all listed manufacturing, utilities, mining, and construction firms in the Shanghai and Shenzhen stock exchanges as they are the key emitters in China. We then remove firms located in China's ETS pilot regions as they have been affected by the regional carbon market rules and may confound our estimations. We focus on three green policies: green innovation, green investment in construction work-in-progress (machines and buildings), and green bond issuance. In recent literature, it has been demonstrated that these policies represent a vital component of corporate strategies for sustainable development (Aghion, Bénabou, Martin, and Roulet, 2020; Cohen, Gurun, and Nguyen, 2020; Tang and Zhang, 2020; Flammer, 2021; Kim, Pantzalis, and Zhang, 2021). The national ETS was announced in December 2017 and its preparation period ends in January 2021. Our sample period therefore spans from 2013 to 2020 and we end up with a firm-year panel of 10,256 observations. In spirit of Bertrand, Schoar, and Thesmar (2007), we employ the difference-in-differences (DiD) research design and examine treatment differences across sectors depend upon their ex-ante carbon emission intensity. We measure firms' exposure to the ex-ante carbon-intensive environment using the average of total $CO_2$ emissions of firms in an industry during 2013-2017 (scaled between zero and one)[1].

We find that firms tend to engage in more green innovation which is measured as the ratio of green patents to total patents and the number of green patents when facing higher carbon liability risk. Innovations in green technology may help to reduce carbon emissions, thereby lowering compliance payments and future carbon obligations (Ambec, Cohen, Elgie, and Lanoie, 2013). It could also help to achieve long term environmental goals and maintain corporate competitiveness (Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen, 2016). However, these are generally costly to the firm since they require organizational changes that are complex in nature (Amore and Bennedsen, 2016). We also document that the exposed firms are more likely to issue green bonds, a new practice in finance of which proceeds are committed to finance environmental and climate-friendly investments. It may serve as a credible indication of the firm's commitment to the environmental goals (Flammer, 2021) and are issued at a premium to otherwise similar ordinary bonds (Baker, Bergstresser, Serafeim, and Wurgler, 2018). On the other hand, such adjustment in green financing policies could lead to an increase in leverage ratios and a worsening of firm liability risks. The evidence so far reveals that a firm's exposure to carbon liability risk induces the managers to undertake costly actions and exert more effort to achieve carbon emission reduction and lower future compliance payments

[1] In our robustness test, we also use the average of total $CO_2$ emissions scaled by the total assets of firms in a particular industry between 2013 and 2017 as a proxy for carbon intensity. Due to the fact that the total production information is not available in CSMAR after 2011, we do not use total production output as the scaling factor.

and carbon liability.

Next, we explore how firms' responses to increased carbon liability risk are related to corporate governance. The classic principal-agency models posit that exposing a firm's managers to business risks could induce them to work hard and exert greater efforts (Holmström, 1979; Grossman and Hart, 1983). On one hand, the managerial efforts are increased to improve overall firm value and efficiency and then benefit shareholders. In order for the adjustment in green policies to benefit shareholders, the avoided compliance cost should be larger than the potential costs of innovation and green bonds. On the other hand, large future cash outflows and poor performance could threaten the manager's employment and reputation as an environmental steward. Consequently, managerial efforts are increased to avoid the personal costs associated with carbon liability. We find that announcement returns associated with green bonds are positive and that green policies add value to shareholders. The results of further analysis reveal that firms with lower manager ownership, higher institutional investor ownership, and a more independent board are more likely to respond to carbon liability risk by engaging in green innovation and issuing green bonds. There is evidence that such responses are motivated by the goal of maximizing shareholder value, and that corporate governance schemes instruct managers in addressing long-term environmental problems and mitigating the risk of carbon liability.

Furthermore, we conduct a cross-sectional analysis to investigate whether there is heterogeneity in the effect of carbon liability risk on corporate green policies. Our first point of focus is on ownership structure, and we argue that government control of SOEs entitles them to inherent political connections. As a result of these connections, SOEs have easier access to resources (Allen, Qian, and Qian, 2005; Scott, 2005; Li, Cui, and Lu, 2014), less severe consequences of failure (Faccio, Masulis, and McConnell, 2006), and greater opportunities to communicate with regulators. SOEs exposed to higher carbon liability risks are more likely to engage in green innovation and issue corporate green bonds. In addition, we investigate whether greater public exposure exacerbates the effect of carbon liability risks. Increasing public attention intensifies external scrutiny and exacerbates the consequences of firms not exerting themselves (Dyreng, Hoopes, and Wilde, 2016). When facing more public attention, companies with carbon liability risks are more likely to modify their green policies to reduce carbon footprints. Additionally, we present evidence that young lifecycle firms that are more susceptible to uncertainties and adverse consequences (Allen, Lewis-Western, and Valentine, 2022) suppress green innovation and green bond issuance under carbon liability risks.

When conducting robustness tests, we take into account regional differences in corporate carbon-emitting behavior and find that the baseline results are generally robust to a more granular measure of carbon liability risks. Our baseline results remain robust when we use the asset-scaled measure of corporate carbon emissions intensity to proxy firms' exposure to carbon liability risks. Additionally, we examine whether electricity firms behave differently from others due to less policy uncertainty regarding the timing of inclusion. Electricity companies perceive greater carbon liability risks than other prospective firms and make greater efforts to promote green innovation and green bond issuance.

Our study contributes to the growing literature on how firms manage business risks or, more specifically, business risks related to climate change. In previous studies, it has been demonstrated that companies adjust their capital structure, investment decisions, and financing decisions in response to firm idiosyncratic risk (Panousi and Papanikolaou, 2012; Jagannathan, Matsa, Meier, and Tarhan, 2016), takeover pressure (Servaes and Tamayo, 2014; Gormley and Matsa, 2016), and financial burden (Gormley and Matsa, 2011). The threat of climate change is becoming an increasingly significant business risk in recent years since it can negatively impact corporations, clients, suppliers, and institutional investors (Daniel, Litterman, Wagner, 2016; Baker et al., 2018; Ilhan, Krueger, Sautner, and Starks, 2021). A number of scholars have examined the impact of physical climate risk (Dessaint and Matray, 2017; Massa and Zhang, 2021) on firm decisions, while a few papers address the regulatory risks associated with climate change and pollution (Delis, de Greiff, and Ongena, 2019; Dang et al., 2022). Our study adds to the literature on the policy risk associated with climate change by focusing on the carbon liability risk as a result of increasingly strict regulations. Our experiment, which affects future corporate carbon obligations but not current cash flows, allows us to isolate the effects of carbon liability risk on firm decisions. We show that companies will respond to increased carbon liability risks by investing in green innovation and issuing green bonds to finance green investments.

Additionally, we contribute to the literature by providing new evidence on corporate governance schemes and firm value in an era of frequent extreme weather events and volatile natural environments. The results demonstrate that green policies are generally beneficial to firms and that treatment effects are more pronounced when the firm has smaller management ownership, an increased involvement of professional investors, and a board with more independent directors. Based on our results, it is unlikely that such climate risk responses are a result of risk-related agency conflicts (Gormley and Matsa, 2011). In order to address long-term climate issues troubling the firm, corporate governance regimes instruct managers to prioritize shareholder value over their own interests.

Our paper is also related to the debate regarding the effectiveness of China's ETS. Cao, Ho, Ma, and Teng (2020) argue that China's ETS pilot programs failed to induce regulated power plants to improve their coal efficiency. The significant reduction in coal consumption is achieved by reducing the electricity generated by the plant. However, Cui, Zhang, and Zheng (2021) find that the Regional ETS Program induces firms to adopt climate-friendly technologies. The carbon market rules differ significantly between pilot programs, and the pilot program provides valuable experience into the design and implementation of a national ETS. In this paper, we examine the effectiveness of national ETSs and the differential changes among firms in industries with ex ante different levels of carbon intensity. We show that the announcement of the national ETS encourages managers to make efforts to reduce carbon emissions and provide new evidence regarding the effectiveness of the ETS in China.

The remainder of the paper proceeds as follows. Section 2 introduce the institutional background and Section 3 shows the research design and descriptive statistics. Section 4 presents the empirical results and Section 5 contains robustness tests. Section 6 concludes the paper.

## 2 Institutional Background

The frequent occurrence of extreme weather events like droughts and floods causes economic loss, and regulations aimed at reducing carbon emissions become increasingly important to economic stability and growth (Bank of England, 2019). As a result of its rapid development, China became the world's second largest economy[2] and the world's largest emitter of carbon dioxide ($CO_2$). In response to the threat of climate change, China demonstrated its determination to cut carbon emissions at the 2009 United Nations Climate Change Conference in Copenhagen and implemented a series of environmental regulations since then. The China's Emission Trading System (ETS) program was firstly introduced in 2011. Unlike the EU ETS which is the cap and trade (C&T) program, China's ETS is the tradeable performance standard (TPS) approach (Goulder, Long, Lu, and Morgenstern, 2019; Cui et al., 2021). While a C&T program sets a cap on total emissions, a TPS is a market-based instrument that sets benchmarks for emitters' carbon intensity and allows them to trade allowances.

The development of China's ETS can be divided into two phases. China's ETS pilot program was announced by the National Development and Reform Commission (NDRC) in 2011 and gradually came into force across eight regions including Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei, Shenzhen, and Fujian between 2013 and 2016. Each pilot can customize its carbon market rules, including covered sectors, emission targets, regulatory status, allowance allocation, monitoring, reporting, and compliance (Zhang, Karplus, Cassisa, and Zhang, 2014). For example, steel (cement) firms were not included in two (three) out of seven ETS pilots (Cui et al., 2021), and these steel firms account for only 15% of the national output (Caixin Weekly, 2021). In terms of the regulatory status of an entity, Shanghai, Tianjin, and Chongqing set the threshold of annual emissions at 20kt carbon emission while Shenzhen adopts a lower bar of 3kt. The effectiveness of the ETS pilot program has been questioned by

---

[2] Source: World Bank 2018 data.

some studies, along with the notion that it is market-driven. According to Cao et al. (2021), firms reduce their carbon emissions by reducing production instead of improving efficiency, and the effects of the ETS are in fact influenced by the actions of local governments. Throughout all pilots, the majority of firms are in compliance with the carbon market rules, and noncompliance may result in financial penalties, the deduction of allocated emission allowances, and a record on the business credit report. A pilot program could serve as an experiment to test the effectiveness of ETSs and establish the foundation for a national ETS system.

The national ETS was announced in December 2017 and goes into effect in January 2021 over a three-year preparation period. It was announced that the national ETS would initially include companies in the electricity industry and then, despite no explicit inclusion arrangement regarding industries or timing, gradually expand to include firms in other heavy carbon-emitting industries. National ETSs offer carbon market rules that apply to all firms in the country, as well as providing a large market for carbon allowance trading. The cumulative amount of carbon allowances traded in the seven pilot projects between 2013 and November 2017 is approximately 200 million tons of $CO_2$, whereas electricity firms, as the first batch to be included in the national ETS, have emitted approximately 4.1 billion tons in 2017 (Caixin Weekly, 2021). In addition, the national ETS shifts responsibility for reducing carbon emissions from the government to firms, resulting in a decreased need for the government to balance economic growth and carbon reduction.

With the development of the national ETS over a three-year period, the expected compliance payments related to carbon emissions have increased, raising the risk of a carbon liability for the firm in the future. While in preparation, the national ETS has a negligible impact on firms' current cash flows and resources. Our empirical strategy can therefore take advantage of the announcement of the national ETS in 2017 as an exogenous shock that increases a firm's exposure to carbon liability risk. We expect firms in ex ante more carbon-intensive industries to be affected by the shock to a greater extent. Therefore, we are able to analyze how a firm's carbon liability risk affects its green policies regarding investment and financing decisions.

## 3 Empirical Setting

### 3.1 The difference-in-differences estimation methodology

Despite the fact that the national ETS represents an economy-wide shock, we anticipate that it will have a greater impact on firms in industries that are more carbon-intensive ex ante. In order to isolate the impact of the carbon liability risk on firms' green policies, we examine the differential changes across industries based on the degree of carbon intensity. Our approach follows the one of Bertrand, Schoar, and Thesmar (2007) who study the effects of bank deregulation in France and examine post-treatment differences across sectors depending on their reliance on bank finance. Specifically, we use the following equation for baseline analyses:

$$Green\,policy_{it} = \alpha + \beta CO2(ind)_i \times ETS_t + \gamma Controls_{it} + \delta_i + \theta_j + \lambda_t + \varepsilon_{it}$$

where $i$, $t$, and $j$ denote firms, years, and provinces, respectively. To identify firms with higher carbon liability risk arising from the exposure to the national ETS, we construct the variable $CO2(ind)$ to measure the extent to which the firm is exposed to the ex-ante carbon-intensive environment[3]. $CO2(ind)$ is defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017 and then scaled between zero and one. The dummy variable, $ETS$, takes the value of one if the year is equal to or greater than 2018, and zero otherwise. We also control a battery of firm characteristics including size, leverage, age, profitability, intangible assets, and sales. These control variables are measured in the year *t-1* and winsorized at the 1% and 99% levels. The regression model also includes firm fixed effects $\delta_i$, province fixed effects $\theta_j$, and year fixed effects $\lambda_t$. The firm fixed effects could control for any time-invariant heterogeneity across firms that may affect green policies. The province fixed effects control for any time-invariant province-level features. The year fixed effects $\lambda_t$ account for national economic conditions. Standard errors are clustered at the industry level.

As for our dependent variables, we consider three corporate green policies with respect to investment and financing choices.

***Green Innovation***. It is an important component of corporate green investment policies, and is usually measured by green patents (Popp, 2002; Calel and Dechezleprêtre, 2016). The green patent can be identified by matching the International Patent Classification (IPC) code of the patent with the IPC Green Inventory code of the World Intellectual Property Organization. Thus, a green patent can be classified as either a green invention patent or a green utility model patent. It has been suggested that green technology can reduce carbon emissions, reduce compliance costs due to fewer allowances being required, and increase revenue through the sale of excess emission allowances (Ambec et al., 2013). In addition, it is imperative that

---

[3] We use the total $CO_2$ emissions to proxy for the exposure to carbon liability risk. In our robustness test, we also use the $CO_2$ emissions divided by total assets as the alternative measure.

technological innovation be used to address long-term environmental problems, create a sustainable environment, as well as increase productivity and competitiveness because they could have a profound impact on the entire corporate innovation trajectory (Aghion et al., 2016). Furthermore, green patents may generate positive externalities at the national and industry levels through technological spillovers (Amore and Bennedsen, 2016). Green innovation, however, typically requires changes in the research department, the introduction of new methods, and an increase in managerial efforts. If a company is comfortable with its current business model, it may be reluctant to leverage such changes. We employ two measures of green innovation in this paper. $Green\ Innovation\ Ratio$ is defined as the number of green invention patent applications in the company divided by its total patent applications, a measure of the extent to which a company has focused on high-quality green innovation. We also use $Green\ Innovation\ Quantity$, which is defined as the natural logarithm of one plus the number of green invention patent applications to measure a firm's general efforts in green innovation.

***Green Investment*** in construction work-in-progress. In response to the risk of carbon liability, the company could also invest in equipment and buildings for emission control and monitoring and adjust their production processes. Adopting such policies may have immediate effects and reduce emissions in the near term. This type of investment may lower the incentive for innovation, which is inherently uncertain (Rogge, Schneider, and Hoffmann, 2011), as well as sacrifice the opportunity and capital required for firms to address the long-term climate change challenge in a radical way. We define $Green\ Investment$ as the natural logarithm of one plus the firm's green investment in construction work-in-progress.

***Green Bonds***. A green bond is a fixed income security whose proceeds are used to fund environmental and climate-friendly projects. Apple, for example, issued a $4.7 billion green bond on March 29, 2022, in order to support green technologies that reduce Apple's carbon footprint. Green bonds, however, can also be used in the practice of "greenwashing", which occurs when firms issue green bonds in order to portray an image of environmental responsibility without actually fulfilling their commitments. Also, the study by Flammer (2021) shows that corporate green bond issuers actually deliver on what they promise and green bonds could be value-enhancing. In this paper, we define $Green\ Bond$ as a dummy variable equal to one if the firm has issued green bonds this year, and zero otherwise.

### 3.2 The sample

First, we examine all public companies listed on the Shanghai and Shenzhen stock exchanges in the CNRDS database. The screening procedure follows. Since the preparation period for the national ETS lasts for three years, we set the pre-treatment period as 2013-2017 and the post-treatment period as 2018-2020. We also exclude all firms located in the pilot regions since they were affected by the ETS pilot program before 2017. These pilot regions include Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei, Shenzhen, and Fujian. In addition to the electricity sector, the national ETS has not explicitly announced the next sectors to be covered, and therefore our attention is drawn to the manufacturing, utilities, mining, and construction sectors based on their role as key carbon emitters in China (Shao, Liu, Geng, Miao, and Yang, 2016; Lu, Feng, Liu, Wang, Lu, and Wang, 2020; Cui et al., 2021;). These covered sectors are represented by 41 2-digit industry codes in the 2012 CSRC industry classification system. We keep observations with positive total assets and sales and exclude observations with missing information on key variables. We also supplement the firm characteristics data with the CSMAR database. We extract carbon emissions data from the CEADs database, green innovation and green bonds data from the CNRDS database, and green investment data from the CSMAR database. The final sample for baseline analyses consists of 10,256 firm-year observations.

### 3.3 Descriptive statistics

Table 1 illustrates the descriptive statistics of the key variables. The mean values of $Green\ Innovation\ Ratio$, $Green\ Innovation\ Quantity$, $Green\ Bond$, and $Green\ Investment$ are 0.0359, 0.5790, 0.0028, and 11.4599, respectively, suggesting that green innovation and corporate green bonds are relatively emerging. There is a 0.0598 mean value of $CO2(ind)$ and a 0.1837 standard deviation, indicating that firms in certain industries are much more exposed to an ex-ante carbon-intensive environment and therefore have a greater carbon liability risk. The mean value of $Size$ is 22.0630 and $Leverage$ has an average value of 0.4186, which is similar to prior literature (e.g., Chang, Pan, Wang, and Zhou, 2021). On average, firms are 17.7207 years old and have a return on equity of 4.93%.

[Insert Table 1 here]

## 4 Empirical Results

### 4.1 Baseline regressions

In this section, we analyze how firms respond to the increase in carbon liability risk by studying the impact on corporate green policies. Innovations in green technology, investments in green equipment and buildings, and the issuance of green bonds to finance these green investments are possibilities for managers to reduce compliance payments in the future and the likelihood of financial distress.

We illustrate the results in Table 2. Our study shows that firms put more effort into green innovation when they face increased carbon liability risks. The estimates for *Green Innovation Ratio*, reported in column (1), indicate that the redirection to high-quality green innovation occurs more, following increase in carbon liability risk for firms in industries that were ex ante more carbon intensive. The effect is both statistically and economically significant. For example, following the start of the national ETS, a one-standard-deviation increase in $CO_2(ind)$ is associated with 0.24% increase in a typical firm's green innovation ratio, which is amount to a 6.80% increase in ratio for the sample average. Importantly, our results are robust to the interaction of province and year fixed effects (reported in column (2)). The high-dimensional fixed effects could help us to control for unobserved, time-varying differences across provinces and ensure that out difference-in-differences estimates are robust to various types of unobservable omitted variables that might bias our estimation. We also find that, in columns (3) and (4), the number of patent applications at these firms also increases. However, we find that the green investment in equipment and buildings at these firms change insignificantly, suggesting that these firms are not strictly making capital investment to reduce the carbon liability risk but sparing no efforts in technological innovation which is instrumental to address long-term climate-change problems.

To shed some light on how companies fund the green innovation activities, we study the effect of increase in carbon liability risk on the issuance of green bonds. As for regressions with fixed effects and binary outcome variables, we adopt the linear probability models instead of non-linear models such as Logit models because they only produce consistent estimates under strong and unrealistic assumptions (Wooldridge, 2010). The results are illustrated in columns (7) and (8) of Table 2. We find that firms in more carbon-intensive industries are more likely to fund their innovations with green bonds. The probability of issuing green bonds increases by 5.14% on average after an increase in liability risk, and this increase is statistically significant at 1%. At first glance, it may seem odd that companies issue bonds in response to the increase in liability risk. A closer look at the next section reveals that this average response obscures heterogeneity, and it shows that some firms are more likely to do so than others.

[Insert Table 2 here]

The key assumption in the difference-in-differences estimation is the parallel trend assumption: the timing of the increase in green policies coincides with the increase in carbon liability. In order to establish causality, we adopt a "leads and lags" model described by Bertrand and Mullainathan (2003) in order to determine how the effect evolves over time. We replace variable $ETS$ in Eq. (1) with 5 indicator variables: $year2015$ (-2) for the year 2015, $year2016$ (-1) for the year 2016, $year2018$ (+1) for the year 2018, $year2019$ (+2) for the year 2019, and $year2020$ (+3) for the year 2020[4]. Figure 1 plots the point estimates and there is no indication of a difference in green innovation and green bond issuance prior to the increase in carbon liability risk. Afterward, firms exposed to more risk tend to boost their innovation and issue green bonds more frequently compared to others. The precise timing of green

[4] The national ETS is announced in December 2017, and there may be a lot of noise in the year zero. In this case, we exclude the year 2017 in the parallel trend test. When we include the year 2017 as well, we find consistent time dynamics.

policies suggests that they are primarily a consequence of the increase in carbon liability risk rather than omitted variables from company or industry traits. Additionally, the time-series dynamics confirm that our findings are robust to the choice of an examination period and that the shock is exogenous and unanticipated.

To further alleviate the concern that the baseline results are driven by unobservable heterogeneity before the announcement of the national ETS, we conduct a placebo test by replacing $ETS$ with $Placebo\_ETS$ in Eq. (1). $Placebo\_ETS$ is defined as a dummy variable equal to one if the year is greater than 2016, and zero otherwise. The pseudo-pre-treatment period is 2013-2016 and the pseudo-post-treatment period is 2017-2018. We then re-estimate Eq. (1) with firm fixed effects and province-year fixed effects and the results are reported in Table 3. Our results suggest that the pseudo-event has no significant impact on corporate green policies. The results of the placebo test alleviate the concern that the baseline results are driven by random shocks.

[Insert Table 3 here]

**4.2 Connection with corporate governance**

In this section, we examine whether firms' responses to the increase in carbon liability risk are related to corporate governance. When facing an increased risk of carbon liability that would increase firms' future compliance payments and negatively impact future cash flows, firms tend to undertake costly actions to reduce these risks. Our studies find that at-risk firms tend to conduct more innovation and may finance such activities through green bonds. Investing in green innovation may reduce carbon emissions, thereby reducing compliance costs and the likelihood of financial distress. In the aftermath of an increase in carbon liability risk, there are a number of reasons why firms choose to do so. First, if compliance payments are high and financial distress is likely, there is a general increase in managerial efforts to benefit shareholders and implement green policies. To benefit shareholders, the avoided compliance costs should be greater than the potential costs of innovation and green bonds. In contrast, the risk-related agency theory suggests that managers have a vested interest in ensuring their career and personal wealth against the company. Accordingly, they are motivated to make costly investments to reduce the firm's risk that ensures the firm's long-term survival (Jensen and Meckling, 1976; Amihud and Lev, 1981; Smith and Stulz, 1985; Holmström, 1999; Gormley and Matsa, 2011).

To explore these interpretations, we firstly implement the event study of green bond announcement. We aim to examine the stock market response to the announcement of the issuance of green bonds and perform the univariate analysis. We apply the market model and calculate the [-5, 5] days CAR. We sort the sample according to the before-treatment and after-treatment and low emission group (below the *CO2(ind)* median) and high emission group (above the *CO2(ind)* median). The results are reported in Table 4. The average CAR across all issuance are 2.44% and is significant at the 10% level. We find that raw difference-in-differences CAR estimates are around 3.89%. The positive stock market reaction suggests that investors interpret this news positively and foresee companies' commitment, particularly those with greater exposure to carbon liability risks. The green bond issuance is in the interest of shareholders.

[Insert Table 4 here]

In addition, risk-related agency problems could be serious if managers have much of their wealth tied to the value of firms' assets and have greater incentive to reduce firms' risk (Parrino and Weisbach, 1999). We collect the management shareholding data from the CNRDS database and construct the variable $Manager\ Shareholding$ which is referred as the dummy variable equal to one if the managers' shareholding of the firm is above the sample median in year *t-1*, and zero otherwise. In addition, institutional investors who own a block of shares in the company could mitigate the agency problem by monitoring the management (Shleifer and Vishny, 1986). We extract the institutional holding data from the CNRDS database and define $Fund\ shareholding$ as a dummy variable which equals one if the funds' shareholding of the firm is above the median in year *t-1*, and zero otherwise. Finally, an effective board plays a vital role in solving the agency conflicts and agency problem is less severe in a more independent board (Rosenstein and Wyatt, 1990). We use *Ratio of Independent Directors* to measure board independence and construct the dummy variable that equals one if the firm's ratio of independent directors is above the median in year *t*, and zero otherwise. The board data is from the CNRDS database.

Table 5 shows the results of the variation in the firm's green policy response based on corporate governance indicators. According to Panel A of Table 5, firms with lower management ownership are more likely to invest in technological innovation and issue green bonds to access capital. In contrast, firms with a high level of management ownership do not engage in more innovation and may even shrink. In Panels B and C, we find that firms with higher institutional ownership and more independent boards engage in more innovation and green bond issuance in order to mitigate the increased liability risk. Collectively, the event study and corporate governance results suggest that the adjustment of corporate green policies of liability-exposed firms could be driven by the shareholder's interests instead of agency conflicts. Our results reveal that corporate governance plays a vital role in corporate responses to the risk of carbon liability. Firms tend to implement more policies that address long-term environmental problems, reduce carbon emissions, and alleviate the financial burden as a result of compliance costs when the agency problems are mitigated and less severe.

[Insert Table 5 here]

### 4.3 Additional cross-sectional analysis

The purpose of this section is to explore more conditions under which the treatment effects could vary. Specifically, we analyze three factors: ownership structure, public attention, and the stage of the corporate life cycle.

#### 4.3.1 Ownership structure

Ownership concentration is prevalent in Chinese listed firms (Jiang and Kim, 2020) and the government being the controlling shareholder renders SOEs inherent political connections. Due to these connections, SOEs have easier access to resources (Allen et al., 2005; Scott, 2005; Li et al., 2014) and are more likely to be bailed out when failure occurs (Faccio et al. 2006). Innovation requires tremendous inputs of resources and high tolerance of failure (Tian and Wang, 2014) and therefore we propose that SOEs with higher carbon liability risks are more likely to engage in green innovation. Moreover, corporate green bonds require regulatory approval and due to strict scrutiny understaffing regulatory force, firms' frequent interactions with regulators could reduce information asymmetry. SOEs' inherent political connections increase communications with and reduce information costs for the regulators (Wong, 2016). Thus, we propose that SOEs with greater exposure to carbon liability risks are more likely to succeed in issuing green bonds.

We divided the sample according to the corporate ownership structure. The results are presented in Table 6. We find that the treatment effects are primarily concentrated in the group of SOEs across three green policies. Our findings thus reveal that ownership structure matters for the relationship between the firm's exposure to carbon liability risk and green policies. Easier access to resources, less severe consequence of failure, and more opportunities of communications may stimulate the SOEs to adjust their green policies.

[Insert Table 6 here]

#### 4.3.2 Public attention

ETS sparked intense discussions among policymakers, investors, corporate executives, and academics on climate change. Increasing public attention leads to stricter external scrutiny, and firms that do not strive to reduce carbon emissions could aggravate the public and incur significant reputational damage. Public attention exerts pressure on firms (Dyck and Zingales, 2002) as well as altering the costs associated with undesirable behavior (Dyreng et al., 2016). As a result, a company attracting more public attention becomes more aware of its reputation for being green and may make investments in green technology and issue green bonds in an attempt to reduce carbon emissions. We use web search volume index to proxy for external attention and create the sorting dummy variable, $WSVI$, which equals one if the firm's web search volume index is above the median in year *t-1*, and zero otherwise. We separate the sample according to $WSVI$ and re-estimate Eq. (1) for each subsample. The results are presented in Table 7. The treatment effects are most evident in the subsample with higher external attention, suggesting that in the presence of greater external attention, firms with a higher carbon liability risk invest more in high-quality green innovation.

[Insert Table 7 here]

### 4.3.3 Young life-cycle firms

Corporate life-cycle stage is an important determinant of corporate innovation. According to Allen et al. (2022), young firms are more vulnerable to the adverse effects of innovation and are likely to reduce the amount of effort they devote to innovation. As a result of their vulnerability and resource limitations, young life-cycle companies with higher carbon liability risks are less likely to engage in green innovation and, therefore, have fewer needs for green bonds. Therefore, carbon liability risk should mainly influence corporate green policies for non-young life-cycle companies.

We identify young life-cycle (YLC) firms using the variable $Young\ Life\ Cycle$. $Young\ Life\ Cycle$ is defined as a dummy variable that equals one if the firm is in young life-cycle stage in year $t\text{-}1$, and zero otherwise. A young life-cycle firm, as defined by Dickinson (2011) and Allen et al. (2022), has negative operating cash flows, negative investing cash flows, and positive financing cash flows. We divide the sample based on the sorting variable $Young\ Life\ Cycle$ and conduct subsample tests. Table 8 presents the results. The treatment effects are concentrated in the non-YLC firms. Non-YLC firms in the ex-ante carbon-intensive environment invest in green innovation and finance through green bonds, while YLC firms suppress these investments and financing activities. It appears that the incompatible life-cycle stage would lessen the effect of carbon liability risks on corporate green policies.

[Insert Table 8 here]

## 5 Robustness Tests

As regional characteristics are also important determinants of carbon emissions, we incorporate regional factors and develop a framework to account for industrial and provincial differences in corporate carbon emissions. $CO2(indprov)$ is defined as the average of total $CO_2$ emissions of all firms in an industry in a particular province during 2013-2017 and then scaled between zero and one. We replace $CO2(ind)$ with $CO2(indprov)$ and re-estimate Eq. (1) with different sets of fixed effects. Panel A of Table 9 presents the results. The majority of our treatment effect estimates remain positive and significant. The baseline results remain robust when regional differences in corporate carbon-emitting behavior are taken into account.

Furthermore, we employ an alternative measure of firms' exposure to carbon liability risk. $CO2(ind)\_PA$ is a variable defined as the average of total CO2 emissions of all firms in an industry during 2013-2017 divided by the average of total assets of these firms during this period. Panel B of Table 9 presents the results. The treatment effects are significantly positive at the 1% level, suggesting that the baseline results of green innovation and green bonds are robust to the alternative measure of the exposure to carbon liability risk.

Electricity companies are the first batch to be included in the national ETS and are prone to a greater risk of carbon liability than companies in other prospective industries due to less policy uncertainty regarding the timing of inclusion. In response to more apparent carbon liability risks, we expect that companies in the electricity industry will be more incented to engage in green innovation and use more green bonds.

We use a dummy variable to identify electricity firms in the sample and replace $CO2(ind) \times ETS$ in Eq. (1) with $Electricity \times ETS$. We conduct the analyses using $Green\ Innovation\ Ratio$, $Green\ Innovation\ Quantity$, and $Green\ Bond$ as the dependent variables. Table 10 presents the results. The treatment effect coefficients in all columns are positive and significant, suggesting that compared with other industries, electricity companies are more likely to engage in green innovation and issue green bonds as they face an apparent increase in carbon liability.

[Insert Table 9 here]

## 6 Conclusion

Our study utilizes the quasi-natural experimental setting of the national ETS in order to examine the effect of carbon liability risk on corporate green policies. The national ETS requires trading firms to pay for excess carbon emissions, which causes large cash outflows in the future and increases the likelihood of poor performance and financial difficulties in the future. A higher carbon liability risk is associated with an increase in the ratio and quantity of high-quality green innovation and the use of green bonds by firms. The results satisfy the parallel trend assumption and are robust to the placebo test and alternative measures.

Furthermore, we explore the possible mechanism by which the carbon liability risk affects the green policies of firms. As a first step, we demonstrate that the market responds positively to announcements of the issuance of green bonds, suggesting that issuing corporate green bonds is in the best interests of shareholders. We find that corporate governance plays a crucial role in inducing managerial efforts and adjusting corporate green policies when firms are exposed to greater risks associated with carbon liability. In particular, we find that lower management ownership, higher professional investor ownership, and an independent board may improve corporate governance and reduce agency problems, resulting in a more proactive response to increased carbon liability risks.

In addition, we find that the impact of carbon liability risk on green policies varies across firms with different characteristics. The authors find that SOEs with inherent political connections are more likely to engage in green innovation and issue green bonds when facing more carbon liability risks. Public attention leads to stricter external scrutiny and, as a result, firms with a greater carbon liability risk are under greater pressure to demonstrate their commitment to the environment by making more green innovations or issuance of green bonds. Moreover, young life-cycle firms are more susceptible to uncertainties, so they suppress participation in green innovation and green bond issues when exposed to greater carbon liability risks.

## References


Aghion, P., Bénabou, R., Martin, R., & Roulet, A. (2020). Environmental preferences and technological choices: Is market competition clean or dirty? (No. w26921). National Bureau of Economic Research.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political Economy*, *124*(1), 1-51.

Allen, A., Lewis-Western, M. F., & Valentine, K. (2022). The innovation and reporting consequences of financial regulation for young life-cycle firms. *Journal of Accounting Research*, *60*(1), 45-95.

Allen, F., Qian, J., & Qian, M. (2005). Law, finance, and economic growth in China. *Journal of financial economics*, *77*(1), 57-116.

Ambec, S., Cohen, M., Elgie, S., & Lanoie, P. (2013). The Porter Hypothesis at 20: Can environmental regulation enhance innovation and competitiveness?. *Review of Environmental Economics and Policy, 7*(1), 2-22.

Amihud, Y., & Lev, B. (1981). Risk reduction as a managerial motive for conglomerate mergers. *The Bell Journal of Economics*, 605-617.

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

Baker, M., Bergstresser, D., Serafeim, G., & Wurgler, J. (2018). Financing the response to climate change: The pricing and ownership of US green bonds (No. w25194). National Bureau of Economic Research.

Bank of England, B, 2019. "Climate change: what are the risks to financial stability?," Discussion paper. https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability.

Bartram, S., Hou, K., & Kim, S. (2021). Tackling climate change requires global policies. *Combatting Climate Change: a CEPR Collection*.

Bertrand, M., & Mullainathan, S. (2003). Enjoying the quiet life? Corporate governance and managerial preferences. *Journal of political Economy*, *111*(5), 1043-1075.

Bertrand, M., Schoar, A., & Thesmar, D. (2007). Banking deregulation and industry structure: Evidence from the French banking reforms of 1985. *The Journal of Finance*, *62*(2), 597-628.

Böhringer, C., Koschel, H., & Moslener, U. (2008). Efficiency losses from overlapping regulation of EU carbon emissions. *Journal of regulatory economics*, *33*(3), 299-317.

Caixin Weekly, 25 Jan 2021. Available at: https://weekly.caixin.com/2021-01-23/101654673.html

Calel, R., & Dechezleprêtre, A. (2016). Environmental policy and directed technological change: evidence from the European carbon market. *Review of economics and statistics*, *98*(1), 173-191.

Cao, J., Ho, M. S., Ma, R., & Teng, F. (2021). When carbon emission trading meets a regulated industry: Evidence from the electricity sector of China. *Journal of Public Economics*, *200*, 104470.

Chang, Y., Pan, X., Wang, J., & Zhou, Q. (2021). Depoliticization and corporate cash holdings: Evidence from the mandated resignation of directors in China. *Journal of Corporate Finance*, *69*, 102004.

Cohen, L., Gurun, U. G., & Nguyen, Q. H. (2020). The ESG-innovation disconnect: Evidence from green patenting (No. w27990). National Bureau of Economic Research.

Cui, J., Zhang, J., & Zheng, Y. (2021). The impacts of carbon pricing on firm competitiveness: Evidence from the regional carbon market pilots in China. *Available at SSRN 3801316*.

Dang, V. A., Gao, N., & Yu, T. (2022). Climate policy risk and corporate financial decisions: Evidence from the NOx budget trading program. *MANAGEMENT SCIENCE*. https://doi.org/10.2139/ssrn.3677004

Daniel, K. D., Litterman, R. B., & Wagner, G. (2016). Applying asset pricing theory to calibrate the price of climate risk (No. w22795). National Bureau of Economic Research.

Delis, M. D., de Greiff, K., & Ongena, S. (2019). Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans *(September 10, 2019). EBRD Working Paper*, (231).

Dessaint, O., & Matray, A. (2017). Do managers overreact to salient risks? Evidence from hurricane strikes. *Journal of Financial Economics*, *126*(1), 97-121.

Dickinson, V. (2011). Cash flow patterns as a proxy for firm life cycle. *The accounting review*, *86*(6), 1969-1994.

Dyck, A., & Zingales, L. (2002). The corporate governance role of the media.

Dyreng, S. D., Hoopes, J. L., & Wilde, J. H. (2016). Public pressure and corporate tax behavior. *Journal of Accounting Research*, *54*(1), 147-186.

Faccio, M., Masulis, R. W., & McConnell, J. J. (2006). Political connections and corporate bailouts. *The journal of Finance*, *61*(6), 2597-2635.

Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics*, *142*(2), 499-516.

Gormley, T. A., & Matsa, D. A. (2011). Growing out of trouble? Corporate responses to liability risk. *The Review of Financial Studies*, *24*(8), 2781-2821.

Gormley, T. A., & Matsa, D. A. (2016). Playing it safe? Managerial preferences, risk, and agency conflicts. *Journal of financial economics*, *122*(3), 431-455.

Goulder, L. H., Long, X., Lu, J., & Morgenstern, R. D. (2019). China's unconventional nationwide $CO_2$ emissions trading system: The wide-ranging impacts of an implicit output subsidy (No. w26537). National Bureau of Economic Research.

Grossman, S. J., & Hart, O. D. (1983). Implicit contracts under asymmetric information. *The Quarterly Journal of Economics*, 123-156.

Holmström, B. (1979). Moral hazard and observability. *The Bell journal of economics*, 74-91.

Holmström, B. (1999). Managerial incentive problems: A dynamic perspective. *The review of Economic studies*, *66*(1), 169-182.

Ilhan, E., Krueger, P., Sautner, Z., & Starks, L. T. (2021). Climate risk disclosure and institutional investors. *Swiss Finance Institute Research Paper*, (19-66).

Jagannathan, R., Matsa, D. A., Meier, I., & Tarhan, V. (2016). Why do firms use high discount rates?. *Journal of Financial Economics*, *120*(3), 445-463.

Jensen, M. C., & Meckling, W. H. (2019). Theory of the firm: Managerial behavior, agency costs and ownership structure. In *Corporate Governance* (pp. 77-132). Gower.

Jiang, F., & Kim, K. A. (2020). Corporate governance in China: A survey. *Review of Finance*, *24*(4), 733-772.

Kim, I., Pantzalis, C., & Zhang, Z. (2021). Multinationality and the value of green innovation. *Journal of Corporate Finance*, *69*, 101996.

Li, M. H., Cui, L., & Lu, J. (2014). Varieties in state capitalism: Outward FDI strategies of central and local state-owned enterprises from emerging economy countries. *Journal of International Business Studies*, *45*(8), 980-1004.

Lu, N., Feng, S., Liu, Z., Wang, W., Lu, H., & Wang, M. (2020). The determinants of carbon emissions in the Chinese construction industry: a spatial analysis. *Sustainability*, *12*(4), 1428.

Massa, M., & Zhang, L. (2021). The spillover effects of Hurricane Katrina on corporate bonds and the choice between bank and bond financing. *Journal of Financial and Quantitative Analysis*, *56*(3), 885-913.

Panousi, V., & Papanikolaou, D. (2012). Investment, idiosyncratic risk, and ownership. *The Journal of finance*, *67*(3), 1113-1148.

Parrino, R., & Weisbach, M. S. (1999). Measuring investment distortions arising from stockholder–bondholder conflicts. *Journal of Financial Economics, 53*(1), 3-42.

Popp, D. (2002). Induced innovation and energy prices. *American economic review*, *92*(1), 160-180.

Rogge, K. S., Schneider, M., & Hoffmann, V. H. (2011). The innovation impact of the EU Emission Trading System—Findings of company case studies in the German power sector. *Ecological Economics, 70*(3), 513-523.

Rosenstein, S., & Wyatt, J. G. (1990). Outside directors, board independence, and shareholder wealth. *Journal of financial economics*, *26*(2), 175-191.

Scott, W. R. (2005). Institutional theory: Contributing to a theoretical research program. *Great minds in management: The process of theory development*, *37*(2), 460-484.

Seltzer, L. H., Starks, L., & Zhu, Q. (2022). Climate regulatory risk and corporate bonds (No. w29994). National Bureau of Economic Research.

Servaes, H., & Tamayo, A. (2014). How do industry peers respond to control threats?. *Management Science, 60*(2), 380-399.

Shao, S., Liu, J., Geng, Y., Miao, Z., & Yang, Y. (2016). Uncovering driving factors of carbon emissions from China's mining sector. *Applied Energy*, *166*, 220-238.

Shleifer, A., & Vishny, R. W. (1986). Large shareholders and corporate control. *Journal of political economy*, *94*(3, Part 1), 461-488.

Smith, C. W., & Stulz, R. M. (1985). The determinants of firms' hedging policies. *Journal of financial and quantitative analysis*, *20*(4), 391-405.

Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds?. *Journal of Corporate Finance*, *61*, 101427.

Tian, X., & Wang, T. Y. (2014). Tolerance for failure and corporate innovation. *The Review of Financial Studies*, *27*(1), 211-255.

Wong, T. J. (2016). Corporate governance research on listed firms in China: Institutions, governance and accountability. *Foundations and Trends in Accounting*, *9*(4), 259-326.

Wooldridge, J. M. (2010). Econometric analysis of cross section and panel data. MIT press.

Zhang, D., Karplus, V. J., Cassisa, C., & Zhang, X. (2014). Emissions trading in China: Progress and prospects. *Energy policy, 75*, 9-16.

**Appendix: Variable Definitions**

| Variable | Definition |
|---|---|
| Green Innovation Ratio | The number of green invention patent applications in the listed company divided by its number of all patent applications. Winsorized at the 1% and 99% levels. |
| Green Innovation Quantity | The natural logarithm of one plus the number of green invention patent applications in the corporate group. Winsorized at the 1% and 99% levels. |
| Green Bond | A dummy variable equal to 1 if the firm issues green bonds this year, and 0 otherwise. |
| Green Investment | The natural logarithm of one plus green investments in construction work-in-progress. Winsorized at the 1% and 99% levels. |
| CO2(ind) | A continuous variable defined as the average of CO2 emission of all firms in an industry over 2013-2017, scaled between 0 and 1. Winsorized at the 1% and 99% levels. |
| ETS | A dummy variable equal to 1 if the year is equal to or greater than 2018, and 0 otherwise. |
| Size | The natural logarithm of total assets in year *t-1*. Winsorized at the 1% and 99% levels. |
| Leverage | Total liabilities divided by total assets in year *t-1*. Winsorized at the 1% and 99% levels. |
| Age | The firm's age in year *t-1*. Winsorized at the 1% and 99% levels. |
| ROE | Return on equity (in percentage) in year *t-1*. Winsorized at the 1% and 99% levels. |
| Intangible Assets | The natural logarithm of one plus intangible assets in year *t-1*. Winsorized at the 1% and 99% levels. |
| Operating Sales | The natural logarithm of one plus operating sales in year *t-1*. Winsorized at the 1% and 99% levels. |
| Manager Shareholding | A dummy variable equal to 1 if the managers' shareholding of the firm is above the median in year *t-1*, and 0 otherwise. |
| Fund Shareholding | A dummy variable equal to 1 if the funds' shareholding of the firm is above the median in year *t-1*, and 0 otherwise. |
| Ratio of Independent Directors | A dummy variable equal to 1 if the firm's ratio of independent directors is above the median in year *t*, and 0 otherwise. |
| Local SOE | A dummy variable equal to 1 if the firm is a local state-owned enterprise, and 0 otherwise. |
| WSVI | A dummy variable equal to 1 if the firm's web search volume index is above the median in year *t-1*, and 0 otherwise. |
| Young Life Cycle | A dummy variable equal to 1 if the firm is in young life-cycle stage in year *t-1*, and 0 otherwise. Following Dickinson (2011) and Allen et al. (2021), young life-cycle is identified if the firm |

| | |
|---|---|
| | has negative operating cash flows, negative investing cash flows, and positive financing cash flows. |
| Placebo_ETS | A dummy variable equal to 1 if the year is greater than 2016, and 0 otherwise. |
| CO2(indprov) | A continuous variable defined as the average of CO2 emission of all firms in an industry and province over 2013-2017, scaled between 0 and 1. Winsorized at the 1% and 99% levels. |
| CO2(ind)_PA | A continuous variable defined as the average of CO2 emission of all firms in an industry over 2013-2017, divided by the average of total assets of all firms in the same industry during this period. Winsorized at the 1% and 99% levels. |
| Electricity | A dummy variable equal to 1 if the firm is in the electricity industry, and 0 otherwise. |

**Figure 1 Parallel Trend Analysis**

The Figure plots the coefficients in the parallel trend test (leads and lags model) for three green policies. The leads and lags models include the interaction terms between the treatment variable $ETS$ and index years: $year2015$ (-2), $year2016$ (-1), $year2018$ (+1), $year2019$ (+2), and $year2020$ (+3).

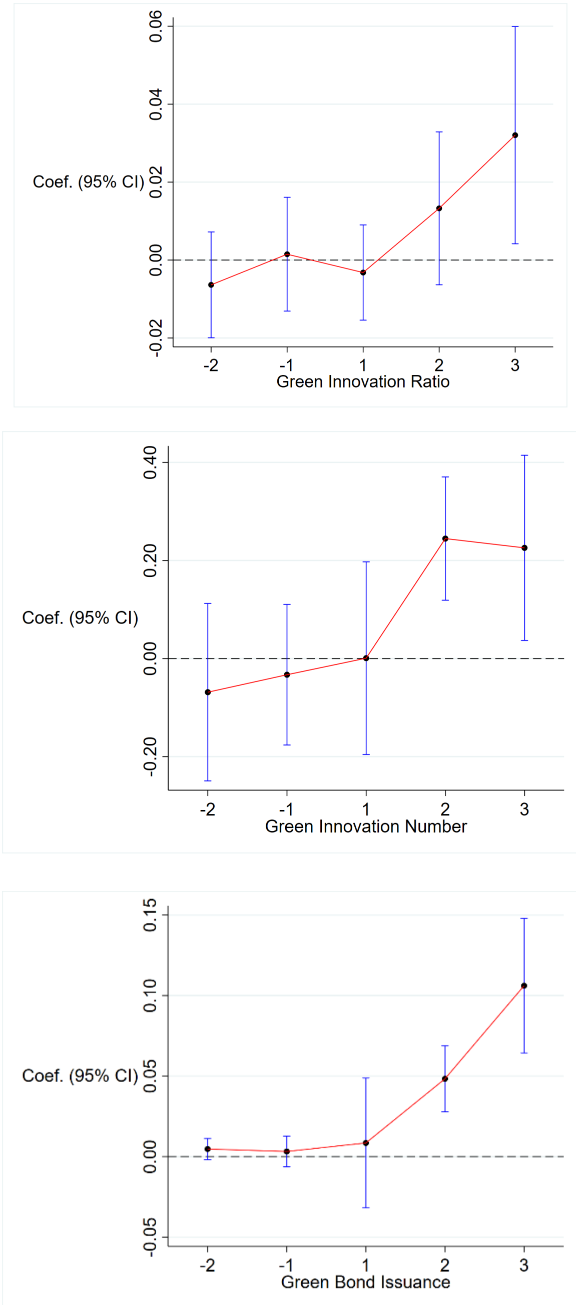

**Table 1 Descriptive Statistics**

| Variable | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Green Innovation Ratio | 10,252 | 0.0359 | 0.1141 | 0.0000 | 0.8333 |
| Green Innovation Quantity | 10,252 | 0.5790 | 0.9151 | 0.0000 | 4.2195 |
| Green Bond | 10,256 | 0.0028 | 0.0531 | 0.0000 | 1.0000 |
| Green Investment | 4,412 | 11.4599 | 8.0799 | 0.0000 | 21.7790 |
| CO2(ind) | 10,256 | 0.0598 | 0.1837 | 0.0002 | 1.0000 |
| ETS | 10,256 | 0.4439 | 0.4969 | 0.0000 | 1.0000 |
| Size | 10,256 | 22.0630 | 1.1892 | 19.6937 | 26.6227 |
| Leverage | 10,256 | 0.4186 | 0.2088 | 0.0534 | 0.9431 |
| Age | 10,256 | 17.7207 | 4.8884 | 7.0000 | 34.0000 |
| ROE | 10,256 | 4.9281 | 15.7392 | -100.3600 | 38.1400 |
| Intangible Assets | 10,256 | 18.7085 | 1.4970 | 12.5649 | 23.2004 |
| Operating Sales | 10,256 | 21.3921 | 1.3683 | 18.0080 | 25.7938 |
| Manager Shareholding | 9,954 | 0.5122 | 0.4999 | 0.0000 | 1.0000 |
| Fund Shareholding | 9,730 | 0.4740 | 0.4993 | 0.0000 | 1.0000 |
| Ratio of Independent Directors | 9,839 | 0.5579 | 0.4967 | 0.0000 | 1.0000 |
| Local SOE | 10,117 | 0.2052 | 0.4039 | 0.0000 | 1.0000 |
| WSVI | 8,335 | 0.4732 | 0.4993 | 0.0000 | 1.0000 |
| Young Life Cycle | 9,770 | 0.0852 | 0.2791 | 0.0000 | 1.0000 |
| Placebo_ETS | 6,993 | 0.3697 | 0.4827 | 0.0000 | 1.0000 |
| CO2(indprov) | 10,170 | 0.0201 | 0.0665 | 0.0000 | 0.4554 |
| CO2(ind)_PA | 10,256 | 1.9683 | 4.3169 | 0.0244 | 21.9990 |
| Electricity | 10,256 | 0.0299 | 0.1704 | 0.0000 | 1.0000 |

**Table 2 Baseline Regressions**

This table explores the effects of carbon liability risks on corporate green policies. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $ETS$ is a dummy variable which equals one for post-treatment years from 2018 to 2020, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Investment | | Green Bond | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| CO2(ind) * ETS | 0.0133** | 0.0140** | 0.1063** | 0.1585*** | -0.1513 | -0.1278 | 0.0514*** | 0.0527*** |
| | (2.38) | (2.61) | (2.16) | (3.44) | (-0.14) | (-0.11) | (16.19) | (13.21) |
| Size | 0.0102* | 0.0112* | 0.1801*** | 0.1809*** | -1.1511** | -1.0792* | 0.0039 | 0.0038 |
| | (1.73) | (1.96) | (3.33) | (3.38) | (-2.23) | (-1.71) | (1.11) | (1.03) |
| Leverage | -0.0051 | -0.0091 | -0.1312 | -0.1294 | -3.9776*** | -3.7298** | -0.0042 | -0.0039 |
| | (-0.39) | (-0.66) | (-1.19) | (-1.17) | (-2.81) | (-2.51) | (-0.72) | (-0.68) |
| Age | -0.0124 | -0.0122 | -0.0963** | -0.0968** | 0.1878 | 0.2214 | -0.0005 | -0.0008 |
| | (-1.05) | (-1.02) | (-2.40) | (-2.29) | (0.57) | (0.64) | (-0.31) | (-0.51) |
| ROE | -0.0000 | -0.0000 | 0.0013** | 0.0014** | 0.0077 | 0.0089 | 0.0000* | 0.0000* |
| | (-0.10) | (-0.14) | (2.32) | (2.40) | (1.13) | (1.35) | (1.88) | (1.77) |
| Intangible Assets | -0.0017 | -0.0013 | 0.0136 | 0.0159 | 0.8532** | 0.8704** | 0.0006 | 0.0006 |
| | (-0.87) | (-0.68) | (0.71) | (0.85) | (2.61) | (2.26) | (0.45) | (0.46) |
| Operating Sales | -0.0036 | -0.0043 | 0.0689** | 0.0618* | 0.9255** | 1.0136** | 0.0007 | 0.0005 |
| | (-0.76) | (-0.93) | (2.10) | (1.85) | (2.24) | (2.45) | (0.24) | (0.17) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Firm FE* | YES | YES | YES | YES | YES | YES | YES | YES |
| *Year FE* | YES | NO | YES | NO | YES | NO | YES | NO |
| *Province FE* | YES | NO | YES | NO | YES | NO | YES | NO |
| *Province-year FE* | NO | YES | NO | YES | NO | YES | NO | YES |
| *N* | 10,252 | 10,252 | 10,252 | 10,252 | 4,412 | 4,412 | 10,256 | 10,256 |
| adj. $R^2$ | 0.379 | 0.379 | 0.647 | 0.648 | 0.599 | 0.598 | 0.032 | 0.026 |

**Table 3 Placebo Tests**

This table presents the results of the placebo tests using 2016 as the pseudo treatment year for a sample period of 2013 to 2018. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $Placebo\_ETS$ is a dummy variable which equals one for pseudo-post-treatment years from 2017 to 2018, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Green Innovation Ratio | Green Innovation Quantity | Green Bond |
|---|---|---|---|
| | (1) | (2) | (3) |
| CO2(ind) * Placebo_ETS | 0.0077 | 0.0751 | 0.0058 |
| | (1.63) | (1.40) | (0.69) |
| Size | 0.0085 | 0.2050*** | 0.0042 |
| | (1.08) | (3.05) | (1.03) |
| Leverage | -0.0125 | -0.0492 | 0.0011 |
| | (-1.02) | (-0.40) | (0.15) |
| Age | -0.0049 | -0.1037** | 0.0012* |
| | (-0.47) | (-2.43) | (1.82) |
| ROE | 0.0000 | 0.0014* | 0.0000 |
| | (0.17) | (1.83) | (1.54) |
| Intangible Assets | 0.0016 | 0.0005 | -0.0011 |
| | (0.63) | (0.02) | (-1.07) |
| Operating Sales | -0.0049 | 0.0701* | 0.0016 |
| | (-0.94) | (1.73) | (0.95) |
| *Firm FE* | YES | YES | YES |
| *Province-year FE* | YES | YES | YES |
| *N* | 6,989 | 6,989 | 6,993 |
| adj. $R^2$ | 0.392 | 0.672 | -0.015 |

**Table 4 Market Reactions**

| t-test, CAR [-5, 5] | Low CO2(ind) | High CO2(ind) | Difference (High – Low) |
|---|---|---|---|
| Before | -0.0094 | 0.0172 | 0.0266 |
| | (-0.4394) | (0.7669) | (0.8583) |
| After | -0.0079 | 0.0576* | 0.0656 |
| | (-0.2476) | (1.9124) | (1.3510) |
| Difference (After – Before) | 0.0015 | 0.0404 | 0.0389* |
| | (0.0361) | (0.8154) | (1.8708) |

**Table 5 Corporate Governance**

This table explores the mechanism through which carbon liability risks affect corporate green policies. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $ETS$ is a dummy variable which equals one for post-treatment years from 2018 to 2020, and zero otherwise. In Panel A, $Manager\ Shareholding$ is a dummy variable which equals one if the managers' shareholding of the firm is above the median in year $t$-$1$, and zero otherwise. In Panel B, $Fund\ Shareholding$ is a dummy variable which equals one if the funds' shareholding of the firm is above the median in year $t$-$1$, and zero otherwise. In Panel C, $Ratio\ of\ Independent\ Directors$ is a dummy variable which equals one if the firm's ratio of independent directors is above the median in year $t$, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

**Panel A Managers' shareholdings**

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| Manager Shareholding | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | -0.0066 | 0.0174** | 0.0476 | 0.1994*** | 0.0030 | 0.0612*** |
| | (-0.07) | (2.54) | (0.17) | (4.58) | (0.51) | (11.08) |
| Size | 0.0173* | 0.0182** | 0.2513** | 0.1358*** | 0.0043 | 0.0011 |
| | (1.78) | (2.55) | (2.27) | (2.76) | (0.66) | (0.21) |
| Leverage | -0.0243 | -0.0052 | -0.2278 | -0.1611 | 0.0060 | -0.0104 |
| | (-1.58) | (-0.31) | (-1.20) | (-1.24) | (0.92) | (-1.10) |
| Age | -0.0102 | -0.0161 | -0.1243 | -0.0642 | -0.0003 | 0.0025 |
| | (-1.45) | (-0.64) | (-1.58) | (-0.76) | (-0.31) | (0.98) |

| | | | | | | |
|---|---|---|---|---|---|---|
| ROE | -0.0001 | -0.0000 | 0.0023** | 0.0008* | -0.0000 | 0.0000 |
| | (-0.46) | (-0.16) | (2.57) | (1.79) | (-0.28) | (0.96) |
| Intangible Assets | -0.0032 | -0.0024 | 0.0011 | 0.0186 | -0.0020* | 0.0014 |
| | (-0.91) | (-1.18) | (0.03) | (0.74) | (-1.73) | (0.65) |
| Operating Sales | -0.0021 | -0.0083 | 0.1641** | 0.0206 | 0.0031 | 0.0015 |
| | (-0.28) | (-1.30) | (2.29) | (0.51) | (1.22) | (0.27) |
| | | | | | | |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 5,094 | 4,856 | 5,094 | 4,856 | 5,098 | 4,856 |
| adj. $R^2$ | 0.457 | 0.319 | 0.641 | 0.672 | -0.061 | 0.039 |

**Panel B Funds' shareholdings**

| Fund Shareholding | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | 0.0481*** | -0.0149*** | 0.4986*** | 0.0338 | 0.0943*** | 0.0283*** |
| | (4.52) | (-2.88) | (4.55) | (0.44) | (6.31) | (5.32) |
| Size | 0.0145 | 0.0136* | 0.1746* | 0.1754** | 0.0087 | 0.0018 |
| | (0.79) | (1.79) | (1.72) | (2.37) | (1.10) | (0.70) |
| Leverage | -0.0001 | -0.0076 | -0.0826 | -0.1287 | -0.0062 | -0.0032 |
| | (-0.00) | (-0.49) | (-0.37) | (-1.08) | (-0.36) | (-0.95) |
| Age | 0.0077 | -0.0341 | 0.0540 | -0.2016** | 0.0018 | -0.0030 |
| | (0.68) | (-1.40) | (0.66) | (-2.32) | (1.17) | (-0.77) |
| ROE | -0.0002 | 0.0001* | -0.0001 | 0.0012** | -0.0000 | 0.0000 |
| | (-1.01) | (1.95) | (-0.04) | (2.18) | (-0.21) | (0.66) |
| Intangible Assets | -0.0032 | -0.0017 | -0.0137 | 0.0232 | -0.0023 | 0.0000 |
| | (-0.49) | (-0.86) | (-0.43) | (0.96) | (-0.77) | (0.02) |
| Operating Sales | -0.0004 | -0.0064* | 0.0838 | 0.0338 | -0.0046 | 0.0006 |
| | (-0.04) | (-1.85) | (1.06) | (0.97) | (-0.77) | (0.43) |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 4,612 | 5,115 | 4,612 | 5,115 | 4,612 | 5,118 |
| adj. $R^2$ | 0.422 | 0.351 | 0.697 | 0.545 | 0.036 | 0.095 |

**Panel C Ratio of independent directors**

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| Ratio of Independent Directors | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | 0.0297** | 0.0010 | 0.3127*** | 0.0657 | 0.0687*** | 0.0412*** |
| | (2.69) | (0.10) | (5.97) | (0.89) | (5.66) | (4.25) |
| Size | 0.0267*** | -0.0012 | 0.2377*** | 0.1399** | 0.0024 | 0.0070 |
| | (2.75) | (-0.14) | (3.21) | (2.16) | (0.58) | (1.14) |
| Leverage | -0.0248** | 0.0212 | -0.1010 | -0.1553 | 0.0018 | -0.0083 |
| | (-2.11) | (0.71) | (-0.76) | (-0.84) | (0.15) | (-0.70) |
| Age | 0.0023 | -0.0359 | -0.0326 | -0.1636** | 0.0001 | 0.0008 |
| | (0.25) | (-1.02) | (-0.56) | (-2.28) | (0.17) | (0.36) |
| ROE | 0.0000 | -0.0001 | 0.0024** | 0.0006 | 0.0000 | 0.0001 |
| | (0.05) | (-0.81) | (2.55) | (0.70) | (0.95) | (1.34) |
| Intangible Assets | -0.0020 | 0.0000 | 0.0166 | 0.0139 | -0.0004 | 0.0022 |
| | (-0.63) | (0.00) | (0.46) | (0.57) | (-0.26) | (0.61) |
| Operating Sales | -0.0147* | 0.0042 | 0.0167 | 0.1148** | 0.0045 | -0.0054 |
| | (-1.82) | (0.57) | (0.37) | (2.05) | (0.94) | (-1.36) |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 5,485 | 4,350 | 5,485 | 4,350 | 5,489 | 4,350 |
| adj. $R^2$ | 0.389 | 0.386 | 0.657 | 0.634 | 0.041 | -0.009 |

**Table 6 Ownership Structure**

This table explores the effects of carbon liability risks on corporate green policies conditional on ownership structure. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $ETS$ is a dummy variable which equals one for post-treatment years from 2018 to 2020, and zero otherwise. $Local\ SOE$ is a dummy variable which equals one if the firm is a local state-owned enterprise, and zero otherwise. Control variables are measured at year *t-1*. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| Local SOE | LSOE | Non-LSOE | LSOE | Non-LSOE | LSOE | Non-LSOE |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | 0.0326** | 0.0012 | 0.2275** | 0.1509 | 0.0562*** | 0.0432*** |
| | (2.49) | (0.09) | (2.61) | (1.66) | (4.31) | (5.31) |
| Size | 0.0056 | 0.0106* | 0.1914** | 0.1593** | 0.0026 | 0.0036 |
| | (0.49) | (1.70) | (2.17) | (2.56) | (0.37) | (0.83) |
| Leverage | -0.0158 | -0.0007 | 0.0718 | -0.1127 | 0.0018 | -0.0042 |
| | (-0.44) | (-0.05) | (0.46) | (-0.94) | (0.09) | (-0.58) |
| Age | -0.0346 | -0.0119 | -0.5461** | -0.0890* | -0.0047 | -0.0015 |
| | (-1.19) | (-0.99) | (-2.16) | (-2.00) | (-1.39) | (-0.92) |
| ROE | -0.0001 | 0.0001 | 0.0001 | 0.0018** | 0.0001 | 0.0000 |
| | (-0.78) | (0.76) | (0.13) | (2.58) | (1.11) | (0.80) |
| Intangible Assets | 0.0004 | -0.0025 | 0.0399 | 0.0193 | 0.0059 | -0.0001 |
| | (0.07) | (-1.15) | (0.75) | (0.83) | (1.16) | (-0.04) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Operating Sales | -0.0032 | -0.0044 | -0.0250 | 0.0830** | -0.0080 | 0.0022 |
| | (-0.37) | (-0.89) | (-0.50) | (2.08) | (-1.62) | (0.55) |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 2,076 | 8,037 | 2,076 | 8,037 | 2,076 | 8,041 |
| adj. $R^2$ | 0.286 | 0.400 | 0.716 | 0.629 | 0.040 | 0.034 |

**Table 7 Public Attention**

This table explores the effects of carbon liability risks on corporate green policies conditional on public attention. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $ETS$ is a dummy variable which equals one for post-treatment years from 2018 to 2020, and zero otherwise. $WSVI$ is a dummy variable which equals one if the firm's web search volume index is above the median in year $t$-$1$, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| WSVI | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | 0.0262*** | 0.0070 | 0.3320*** | 0.0906* | 0.0795*** | 0.0370*** |
| | (2.78) | (0.41) | (3.45) | (1.89) | (5.79) | (4.74) |
| Size | 0.0061 | 0.0102 | 0.1881*** | 0.1495** | -0.0054 | 0.0060 |
| | (0.58) | (0.85) | (2.76) | (2.26) | (-0.77) | (0.84) |
| Leverage | -0.0107 | -0.0088 | -0.3943* | -0.0070 | 0.0102 | -0.0106* |
| | (-0.39) | (-0.41) | (-1.73) | (-0.06) | (0.81) | (-2.00) |
| Age | -0.0346 | -0.0040 | -0.0146 | -0.1307** | 0.0006 | -0.0025 |
| | (-0.71) | (-0.69) | (-0.09) | (-2.37) | (0.32) | (-0.65) |
| ROE | 0.0000 | -0.0002 | 0.0017*** | 0.0016 | 0.0001 | -0.0000 |
| | (0.50) | (-1.15) | (2.76) | (1.36) | (1.10) | (-0.43) |
| Intangible Assets | -0.0007 | 0.0001 | 0.0122 | 0.0224 | 0.0038 | 0.0007 |
| | (-0.19) | (0.06) | (0.29) | (0.88) | (0.84) | (0.55) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Operating Sales | 0.0019 | -0.0073 | 0.1009* | 0.0269 | 0.0081 | -0.0003 |
| | (0.26) | (-0.93) | (1.75) | (0.88) | (0.73) | (-0.08) |
| | | | | | | |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 3,944 | 4,391 | 3,944 | 4,391 | 3,944 | 4,391 |
| adj. $R^2$ | 0.351 | 0.394 | 0.704 | 0.577 | 0.050 | 0.090 |

**Table 8 Young Life-Cycle Firms**

This table explores the effects of carbon liability risks on corporate green policies conditional on corporate life-cycle stages. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. $CO2(ind)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017, scaled between zero and one. $ETS$ is a dummy variable which equals one for post-treatment years from 2018 to 2020, and zero otherwise. $Young\ Life\ Cycle$ is a dummy variable which equals one if the firm is in young life-cycle stage in year $t$-$1$, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| Young Life Cycle | YLC | Non-YLC | YLC | Non-YLC | YLC | Non-YLC |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(ind) * ETS | -0.1337 | 0.0147** | -0.3297 | 0.1699*** | 0.0229 | 0.0552*** |
| | (-1.25) | (2.50) | (-0.74) | (3.28) | (0.74) | (11.62) |
| Size | 0.0018 | 0.0148* | 0.2278 | 0.1764*** | 0.0226 | -0.0007 |
| | (0.16) | (1.84) | (0.95) | (3.15) | (0.85) | (-0.22) |
| Leverage | -0.0177 | -0.0035 | -0.0254 | -0.1251 | -0.1074* | -0.0015 |
| | (-0.50) | (-0.24) | (-0.13) | (-0.96) | (-2.00) | (-0.20) |
| Age | -0.0409 | -0.0098 | 0.1426 | -0.1173** | -0.0127 | -0.0000 |
| | (-0.80) | (-0.70) | (0.58) | (-2.10) | (-0.30) | (-0.07) |
| ROE | -0.0002 | -0.0000 | -0.0011 | 0.0016* | 0.0003 | 0.0000 |
| | (-0.83) | (-0.09) | (-0.74) | (1.77) | (1.29) | (1.19) |
| Intangible Assets | 0.0082 | -0.0020 | 0.0702 | 0.0139 | 0.0118 | 0.0010 |
| | (1.06) | (-0.90) | (0.86) | (0.59) | (0.97) | (0.71) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Operating Sales | 0.0088 | -0.0070 | 0.0618 | 0.0582 | 0.0118 | 0.0022 |
| | (0.86) | (-1.12) | (0.64) | (1.53) | (0.80) | (0.61) |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Province-year FE* | YES | YES | YES | YES | YES | YES |
| *N* | 832 | 8,934 | 832 | 8,934 | 832 | 8,938 |
| adj. $R^2$ | 0.620 | 0.354 | 0.679 | 0.647 | -0.239 | 0.010 |

## Table 9 Robustness Tests

This table considers various measures of firms' exposure to carbon liability risks and their impact on corporate green policies. The dependent variables are $Green\ Innovation\ Ratio$, which is the number of green invention patent applications in the firm divided by its number of all patent applications in year $t$, $Green\ Innovation\ Quantity$, which is the natural logarithm of one plus the number of green invention patent applications in the corporate group in year $t$, and $Green\ Bond$, an indicator variable which equals one if the firm issues green bonds in year $t$. In Panel A, $CO2(indprov)$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry and a province during 2013-2017, scaled between zero and one. In Panel B, $CO2(ind)\_PA$ is a continuous variable defined as the average of total $CO_2$ emissions of all firms in an industry during 2013-2017 divided by the average of total assets of all firms in the same industry during this period. In Panel C, $Electricity$ is a dummy variable which equals one if the firm is in the electricity industry, and zero otherwise. Control variables are measured at year $t$-$1$. All variables are defined in the Appendix. Robust standard errors are clustered at the industry level and t-statistics are reported in parentheses. All models include a constant and fixed effects as shown on the table, but the coefficients are not reported. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

**Panel A Industry-province level analysis**

| | Green Innovation Ratio | | Green Innovation Quantity | | Green Bond | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| CO2(indprov) * ETS | 0.0255 | 0.0283 | 0.3286** | 0.4478*** | 0.1456*** | 0.1513*** |
| | (1.53) | (1.60) | (2.43) | (4.14) | (5.49) | (5.23) |
| *Controls* | YES | YES | YES | YES | YES | YES |
| *Firm FE* | YES | YES | YES | YES | YES | YES |
| *Year FE* | YES | NO | YES | NO | YES | NO |
| *Province FE* | YES | NO | YES | NO | YES | NO |
| *Province-year FE* | NO | YES | NO | YES | NO | YES |
| *N* | 10,166 | 10,166 | 10,166 | 10,166 | 10,170 | 10,170 |
| adj. $R^2$ | 0.382 | 0.381 | 0.647 | 0.648 | 0.033 | 0.027 |

**Panel B Alternative measure**

| | Green Innovation Ratio | Green Innovation Quantity | Green Bond |
|---|---|---|---|
| | (1) | (2) | (3) |
| CO2(ind)_PA * ETS | 0.0008*** | 0.0081*** | 0.0018** |
| | (3.16) | (3.89) | (2.26) |
| | | | |
| *Controls* | YES | YES | YES |
| *Firm FE* | YES | YES | YES |
| *Province-year FE* | YES | YES | YES |
| *N* | 10,252 | 10,252 | 10,256 |
| adj. $R^2$ | 0.379 | 0.648 | 0.022 |

**Panel C Electricity firms**

| | Green Innovation Ratio | Green Innovation Quantity | Green Bond |
|---|---|---|---|
| | (1) | (2) | (3) |
| Electricity * ETS | 0.0140*** | 0.1347*** | 0.0516*** |
| | (6.71) | (5.67) | (15.77) |
| | | | |
| *Controls* | YES | YES | YES |
| *Firm FE* | YES | YES | YES |
| *Province-year FE* | YES | YES | YES |
| *N* | 10,252 | 10,252 | 10,256 |
| adj. $R^2$ | 0.379 | 0.648 | 0.024 |