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The real effects of risk disclosures: evidence from climate change reporting in 10-Ks

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Abstract

We examine the economic impacts of risk disclosures in accounting reports on the real decisions made by information senders (i.e., managers of the disclosing firms). In so doing, we exploit the SEC rule enacted in 2010 regarding climate change risk (CCR) reporting in 10-Ks as a quasi-natural experimental setting in which to apply a difference-in-differences analysis. We focus on CCR because of its vast influence on economic activities and the relative ease of identifying managerial behaviors related to climate change. Our results reveal that CCR-disclosing firms tend to engage more (less) in pro-environmental (anti-environmental) activities after the SEC 2010 rule. These real effects are more pronounced in firms that are under higher pressure from climate-minded external stakeholders and when firms' businesses are more sensitive to climate change-related risks. We also find improved environmental performance in terms of reductions in the quantity, intensity, and cost of carbon emissions surrounding the SEC 2010 rule. Overall, our findings suggest that CCR disclosures alter corporate behaviors and help curb climate change.

Keywords Risk disclosure · Climate change · Real effect · 10-K

JEL codes D81 · K32 · M41 · Q54

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1 Introduction

Disclosures of qualitative (or textual) information about the risks to which a firm is exposed (hereafter, risk disclosures) constitute a significant part of corporate reporting, such as 10-K filings at the Securities and Exchange Commission (SEC).[1] It is therefore important to understand the economic consequences of risk disclosures via accounting reports. Prior research on this issue mainly examines the effects of risk disclosures on the decisions made by information *receivers* (e.g., outside financial statement users, such as equity investors, credit market traders, suppliers along value chains), but little is known about whether and how risk disclosures affect the behavior of information *senders* (e.g., inside managers). To fill this gap, our study investigates the impact of risk disclosures on real actions taken by the disclosing firms.

According to the real effects perspective of accounting disclosure (Kanodia 2006; Lambert et al. 2007; Kanodia and Sapra 2016), risk disclosures via accounting reports provide the disclosing firms with feedback useful for their real decisions via outside stakeholders' responses to the disclosed information. Relative to the reporting of hard and quantitative information, textual disclosures about firm risk contain more soft and qualitative information, and additional expertise is required to comprehend, analyze, and predict the quality and implications of the disclosures. The qualitative dimensions of firm risk that insiders identify and then report in the form of accounting disclosures thus have the potential to substantially change the information basis for various decisions to be made by outside stakeholders. Meanwhile, risk disclosures can also alter insiders' behavior when they observe or envision outsiders' responses.

Nevertheless, it is a daunting task to cleanly identify the real effects of risk disclosures for several reasons. First, corporate behaviors are normally unobservable, especially those directly relevant to the disclosed risks. Second, generic risk reporting has information implications spanning a wide range of corporate activities, making the identification of behaviors as the direct consequences of the disclosures even harder. Third, it is often difficult to clearly disentangle real effects from other confounding effects. For example, improved risk disclosures could affect the rate of return required by investors, which in turn influences firms' real investment decisions (Lambert et al. 2007; Leuz and Wysocki 2016). Fourth, the risk disclosing practices in corporate filings are often criticized as being boilerplate (Bao and Datta 2014; Dyer et al. 2017), casting doubt on their incremental informativeness and their potential impacts on firm behaviors.

To address these challenges, we infer the real effects of risk disclosures by focusing on an important type of risk—climate change risk (CCR)—for the following reasons. First, this risk is a distinct threat to the operation of a firm; it is relatively easy to identify corporate actions directly relevant to CCR, such as the adoption of clean energy technology, the mitigation of carbon emissions, and the violation of environmental regulations. These actions are less influenced by potential confounding effects (e.g., cost of capital) from capital markets. Second, CCR stems from a specific, critical environmental problem. The long-lasting climate change threat and the specificity of its damages tend to make CCR disclosures more informative to the users of financial

[1] For U.S. public firms, risk disclosures represent more than 10% of the words in their annual reports (i.e., 10-Ks) (Campbell et al. 2014).

statements (Hope et al. 2016). Third, we utilize an exogenous regulatory shock from the SEC 2010 rule that reinforces CCR disclosures in Form 10-Ks. By comparing corporate CCR-related behaviors before and after the implementation of this regulation, we make our analysis of CCR disclosure largely immune to the boilerplate problem among firms that start to disclose CCR after the SEC rule.[2]

We hypothesize that the disclosure of CCR via accounting reports makes disclosing firms adopt more pro-environmental activities and abstain from anti-environmental actions. Change in such real economic behaviors is driven by pressures from information receivers outside the firm; the initiation of CCR disclosures to outside stakeholders (i.e., financial statement users) tends to intensify their risk perception and enhance the salience of climate change threat. Climate-concerned outsiders may revise their prior beliefs about CCR and downgrade the prospects of the firm, according to the climate change information disclosed. The nature of the reporting firm in terms of the sensitivity of its business operations to climate change also matters: more climate-sensitive firms are likely to more thoroughly study the potential consequences of CCR-related regulations to the extent that they imply the regulator's increased attention and firmer commitment to addressing climate change. This motivates these firms to be more proactive in taking climate-improving actions and preparing for future regulatory changes, and more conducive to carbon mitigation and an eco-friendlier business environment.

We base our empirical investigation on the implementation of the SEC's 2010 disclosure rule related to climate change.[3] Issued in February 2010, this rule reinforces public companies' reporting of CCR in their Form 10-Ks filed at the SEC each year and clarifies the disclosure of key climate change matters with regard to regulatory, physical, and other related business risks. We find that the rule brings about a substantial jump in CCR disclosure in 10-Ks: the yearly change in the percentage of CCR-reporting firms in the first 10-K filing after the rule is four times as large as the corresponding number before the rule, thus verifying the validity of our setting in which the SEC 2010 rule is used as an exogenous shock to corporate risk disclosures.

To examine how the exogenous increase in CCR disclosure entails firms' real actions in addressing climate change issues, we identify a menu of corporate behaviors directly related to climate change. Specifically, from the KLD STATS database, we extract information regarding pro-environmental climate change strengths (clean technology application, emissions management, carbon reduction, and environmental administration) and anti-environmental climate change concerns (environmental violation and climate change controversy).

Analyzing a sample of 7,189 firm-year observations in a difference-in-differences (DiD) framework, we find that firms that start their initial reporting of climate change-related risk after the SEC 2010 rule experience a significant increase in climate change strengths and a significant decrease in climate change concerns. This effect is relative to firms that already disclosed CCR information before the rule, for which the SEC 2010 regulation represents a weaker disclosure shock. These results suggest that CCR

[2] For these firms, there was no information about the coverage and presentation of climate risk disclosure in the pre-rule period. Corporate managers thus are less likely to use a copy-and-paste strategy to disclose stale information at the initiation of the rule.

[3] *Commission Guidance regarding Disclosure Related to Climate Change; Final Rule*, Securities and Exchange Commission, 17 CFR Parts 211, 231, and 241.

disclosures bring about real effects on corporate operations that help address climate change.

We also find that CCR disclosures have a stronger impact on carbon-reducing/environment-improving behaviors for disclosing firms that (i) are under pressure from external institutions represented by major climate-minded creditors and (ii) have a higher internal sensitivity to climate change issues driven by the fundamental nature of their business. This evidence supports the roles of outsider responses and insider motives in generating the real effects of CCR disclosures. We further show that the quantity, intensity, and associated costs of carbon emissions exhibit a decreasing pattern surrounding the SEC 2010 rule, suggesting that a beneficial outcome of the rule in terms of real economic activities is to curtail greenhouse gas (GHG) emissions and other behaviors causing climate change.

Our investigation of CCR disclosures in accounting reports contributes to the literature in several ways. First, our evidence in support of the real effects complements existing findings regarding the economic consequences of risk disclosures in the capital markets and along the supply chain. The capital market consequences focus on equity investors' assessment of the level and volatility of expected cash flows (Kravet and Muslu 2013; Campbell et al. 2014; Hope et al. 2016; Campbell et al. 2019) and credit derivatives traders' perception of credit risk in the debt markets (Chiu et al. 2018). Along the supply chain, upstream firms (suppliers) rely on negative earnings or loss forecasts and other risk factor disclosures by downstream firms (customers) to make investment decisions (Chen et al. 2019; Chiu et al. 2019). The above studies make a strong case for the information receivers' feedback to the information senders, as the capital and product markets' *negative* responses to the disclosed downside risks incentivize the disclosing firms to refrain from behaviors that could enlarge their risk exposure. Our paper thus enriches the interactions of the external (market) and internal (real) effects of risk disclosures in accounting reports.

Second, there has been an ongoing debate on the efficacy of risk disclosures in annual reports, which centers around the potential vagueness and boilerplate nature of qualitative reporting (e.g., Malone 2005; SEC 2013, 2016). Prior studies show that risk disclosures provide decision-relevant information to investors and other stakeholders in the capital and product markets (Kravet and Muslu 2013; Campbell et al. 2014; Filzen 2015; Campbell et al. 2019; Chiu et al. 2019). Our study not only confirms these findings but also shows that market reactions to risk disclosures may entail *real* effects for disclosing firms. In this sense, our investigation suggests an additional channel through which to understand the usefulness of risk disclosures, at least for climate change-related risks.

Third, for the SEC 2010 rule on climate change reporting per se, our work helps evaluate its effectiveness, which has also been subject to disputes and controversies. The rule's proponents believe that the ability of investors to evaluate and price the effect of CCR depends on climate-related information disclosure, whereas opponents argue that the disclosures are not decision-useful, unnecessary, and excessively burdensome.[4] In 2016, the SEC solicited comments on the policy in a concept release, asking, "Are existing disclosure requirements adequate to elicit the information that

[4] Please refer to Section 3.1.1 for more details about the debates.

would permit investors to evaluate material climate change risk?" (SEC 2016, p. 215). Our study responds to the SEC's inquiry.

Fourth, we provide additional insights into the influences of CCR and its disclosure. Similar to the situation with general risk disclosure, the existing literature focuses mainly on the capital market effects of firms' climate change issues. Matsumura et al. (2014) and Griffin et al. (2017) document that higher levels of carbon emissions, the primary contributor to climate change, hurt the market value of a firm. Chava (2014) shows that climate change concerns significantly increase a firm's cost of capital. Unlike these studies, we do not examine the climate change matters per se. Rather, our analysis focuses on the (real) effects of *reporting* the risks associated with these matters.

Finally, by focusing on climate change-related corporate behaviors to investigate the economic consequences of disclosure regulations, this study supplements studies that examine the impacts of financial reporting in the context of corporate capital spending or expenses (Cho 2015; Ernstberger et al. 2017) or investments (e.g., Cheng et al. 2013; Chen et al. 2019; Chiu et al. 2019). Our study also enriches the real effects research (e.g., Bens and Monahan 2008) that demonstrates firms' alteration of their underlying activities in response to the new accounting rules regarding the reporting of those activities.

2 Hypotheses development

A central issue in accounting is the real economic consequences of corporate disclosure (Kanodia and Sapra 2016; Leuz and Wysocki 2016). Accounting disclosures not only influence the flow of information from inside managers to outside stakeholders but also engender a reverse information transfer from outsiders (information receivers) to insiders (information senders), depending on how the former responds to the latter's disclosures (Kanodia 2006; Lambert et al. 2007; Kanodia and Sapra 2016). Guided by this rationale, we argue that climate change-related risk disclosures not only affect the perception of stakeholders outside the firm but also bring about changes in real behaviors within the firm.

Climate change risks manifest in three main ways. First, climate change can induce global warming and consequent natural disasters; the presence of related physical risks can interrupt firm operations and impair profitability. Second, the global community has recognized the severity of this problem and devoted extensive effort to constraining climate change. As a result, we have witnessed an ever-increasing trend of climate change-related regulations, which increases the regulatory risk associated therewith.[5] Third, the promulgation of eco-friendly activities throughout the whole society has brought with it strong rhetoric that is hostile to firms involved in operations that harm the environment, which constitutes an important element of business risk.

[5] According to the database maintained by the Grantham Research Institute and the Sabin Center, there were 1,260 climate change-related laws covering 164 countries and regions in 2017, a 20-fold increase over 20 years (there were 60 laws in place in 1997) (https://www.carbonbrief.org/mapped-climate-change-laws-around-world).

Despite their potential significance in causing devastating consequences for corporate activities, CCRs are inherently complicated and hard to detect or comprehend (Wunsch 2012; CERES 2014; Hulac 2016). In particular, climate change is often generally framed as a threat to human civilization and the planet Earth; that is, climate change crisis is mostly presented as an abstraction. Except for rare cases, such as extreme weather events, it is hard to visualize how climate breakdown will affect a particular person or firm, especially in the short run (Chess and Johnson 2007; Leiserowitz 2007). In other words, the CCR exposure of an individual firm tends to be overlooked by outsiders. In contrast, corporate managers better understand the severity of how their firms' prospects are influenced by climate change. In this case, the disclosure of CCRs by firms delivers critical information that helps outsiders rectify their ignorance or underestimation of CCRs. Moreover, CCR disclosures via accounting reports, due to their systematic recording (including aggregation, classification, and verification), assurance by external auditors, and vast influence range, significantly enhance the salience of firm-level climate change information, which in turn increases the weight of CCRs in outsiders' decision making. As such, the initiation of CCR disclosure is likely to entail unfavorable responses from information receivers. Consistent with this view, Chava (2014), Matsumura et al. (2014), and Kim et al. (2021) document that shareholders and debt holders perceive CCRs as a significant negative factor that potentially affects their investment prospects.

When firms disclose CCR information in their accounting reports, they reasonably envision the potential negative market reactions.[6] Stated another way, the disclosing firms also obtain information from the market, which assists them in adjusting their operations accordingly. Revealing CCRs does not merely reduce potential information asymmetry but also involves learning on the part of insiders (information senders). This argument is consistent with the analytical accounting literature about the real effects of financial reporting, in which higher information quality improves the coordination or interaction between firms and investors and determines their behaviors at equilibrium (Kanodia 2006; Lambert et al. 2007; Kanodia and Sapra 2016).

To the extent that CCR mostly conveys information from a negative perspective about a firm, its disclosure may intensify outside stakeholders' downside risk perceptions. This, in turn, feeds back to the disclosing firm and motivates it to pursue more climate-favorable activities to ameliorate the adverse impacts of CCR reporting to outsiders, optimize corporate investments, and improve profitability and sustainability. Drawing on the above argument, we propose and test the following main hypothesis, stated in the alternative form.

- H1: *CCR disclosures foster behaviors on the part of the disclosing firms that curb climate change and discourage those that aggravate climate change, all else equal.*

A critical channel for the real effects of CCR disclosures is the induced negative responses from socially responsible external stakeholders. The SEC 2010 rule arose as a response to increasing calls from large institutional groups, which recognized the insufficiency of outsiders' understanding of individual firms' climate change-related risks and the lack of reliable information to improve their understanding. Moreover, in

[6] In this sense, CCR disclosures could be costly to the disclosing firms and thus serve as a credible signal.

a world that cares about the climate, these stakeholders have been continuously promoting environmentally responsible business practices that not only seek to provide financial returns but also make corporate operations consistent with moral values, social standards, and environmental sustainability. If these interested parties are more concerned about climate change, they tend to exhibit fiercer reactions to disclosed CCRs and stronger aversions to environmentally irresponsible firms. This sends a stronger signal to the disclosing firm and triggers a larger behavioral change toward better environmental protection. Based on the above, we propose and test the following hypothesis, stated in the alternative form.

- H2: *The pro-environmental real effects of CCR disclosures are stronger in firms with more climate-minded external stakeholders, all else equal.*

How disclosing firms react to external pressures also influences the strength of the real effects. If the firms have greater concerns about their CCRs, they are likely to be more sensitive to potential responses from outside stakeholders because these firms consider the consequences (e.g., market reactions) of publicly disclosing CCR information more detrimental to their financial performance. These firms are also more responsive to the implementation of the CCR disclosure rule because the government, through its disclosure mandate, has indicated its heightened seriousness in dealing with climate change issues associated with individual firms, which may be interpreted as a signal of additional regulations in the future. A firm with greater climange change vigilance will tend to prepare better for potential regulatory risk by adopting behaviors that mitigate its climate impact.[7] We therefore expect more carbon-sensitive firms to be more alert to these threats and to improve their climate-friendly behaviors, to a larger extent, following the SEC's CCR disclosure rule. Accordingly, we hypothesize the following.

- H3: *The pro-environmental real effects of CCR disclosures are stronger in firms that are more sensitive to climate change, all else equal.*

3 Empirical design

3.1 Identification of an exogenous shock to corporate disclosure of climate change issues

3.1.1 Institutional background of the SEC 2010 CCR disclosure rule

As an exogenous shock to firms' disclosure practices associated with climate change, we have selected the SEC 2010 rule on climate change reporting in accounting statements. The rule emerged from the growing attention to GHG emissions, climate change, and global warming, which could significantly affect corporate decisions. In the rule, the SEC emphasizes the regulatory, legislative, and other developments

[7] Increased regulatory risk as entailed by the SEC 2010 rule also contributes to the negative external responses to the initiation of CCR disclosure.

relating to climate change, including the Kyoto Protocol, the European Union Emissions Trading System (EU ETS), and climate change-related legislation in Congress (such as the pending cap-and-trade system of allowances and credits for GHG emissions introduced in the Senate in 2009). The SEC also notes that physical climate risk (e.g., extreme weather) interrupts normal operations, logistics, and distribution as well as imposing other risks related to indirect consequences of regulation or business trends. If these climate change-related risks materially affect registrants' operations and financial performance, they are expected to be disclosed to investors.[8]

Recognizing the importance of climate change, investors vigorously lobbied the SEC to improve mandatory disclosure in the context of risks related to climate change. The investor petitions gained traction from 2007 when a coalition of 22 institutional investors and investment fiduciaries (representing over US$1.5 trillion in assets under management), together with several state officials and environmental groups, petitioned the SEC to clarify public firms' legal obligation to disclose risks created by climate change.[9] The petition letter to the SEC states that "climate change risk has simply become too important to corporate performance to be left out of mandatory disclosures under the securities laws and the Commission's rules." Responding to the petition, the U.S. Senate Banking Committee's Subcommittee on Securities, Insurance, and Investment held a hearing in October 2007, at which one of the petition signatories testified that "reporting on climate issues is no longer a mere virtue, but a legal obligation and a necessity for investors."[10] Stemming in part from the hearing, Senator Chris Dodd (then chair of Senate Committee on Banking, Housing, and Urban Affairs) and Senator Jack Reed (then chair of Senate Subcommittee on Securities, Insurance, and Investment) issued a letter to the then-SEC Chair Christopher Cox, requesting the SEC to release interpretive guidance regarding mandatory CCR disclosure "to ensure that investors have access to material climate change information."[11] Against this backdrop, the SEC voted on January 27, 2010, to require registrants to disclose the potential impact of matters related to climate change. The SEC CCR disclosure rule officially came into effect on February 8, 2010.

The SEC was the first regulator worldwide to issue mandatory rules for CCR disclosure in official accounting filings. The SEC 2010 rule "is a milestone on the path towards better corporate reporting of material climate issues" (CERES 2014, p. 6). However, the regulation is not without controversies. First, despite significant pressure from institutional investors and Congress, the SEC was unresponsive to demands for

[8] For example, Mary Schapiro, then-SEC chair, commented on the SEC's approval of the 2010 CCR disclosure rule that "a company must consider whether potential legislation—whether that legislation concerns climate change or new licensing requirements—is likely to occur. If so, … the company must then evaluate the impact it would have on the company's liquidity, capital resources, or results of operations, and disclose to shareholders when that potential impact will be material" (Schapiro 2013).

[9] *Petition for Interpretive Guidance on Climate Risk Disclosure*. Available at http://www.sec.gov/rules/petitions/2007/petn4-547.pdf.

[10] *Senate Oversight Highlights Week of October 29, 2007*. Available at http://dpc.senate.gov/dpcdoc.cfm?doc_name=or-110-1-191. The quotation is from the chief investment officer of the California Public Employees' Retirement System.

[11] *Letter from Christopher J. Dodd, Chairman, U.S. Senate Committee on Banking, Housing, and Urban Affairs, and Jack Reed, Chairman, U.S. Senate Subcommittee on Securities, Insurance, and Investment, to Christopher Cox, Chairman, United States Securities and Exchange Commission* (December 6, 2007). Available at http://dodd.senate.gov/multimedia/2007/120607_CoxLetter.pdf.

regulated climate change risk disclosure until 2009, when Chair Mary Schapiro was appointed. Second, in the January 27, 2010 vote, the regulation was passed by a slim margin of three to two, reflecting a stark divergence in policymakers' opinions regarding CCR reporting.[12] Third, the debates on the regulation continued even after its official release. Academicians, practitioners, and lawmakers have all expressed supportive and opposing views.[13] These controversies even promoted legislation in the 112th Congress to repeal it.[14]

Overall, the making of the SEC 2010 CCR disclosure rule followed the evolution of the prominence of climate change issues in affecting corporate operations, but there was no unambiguous prior signal for its final introduction due to the rival perspectives on its merits. In general, the implementation of the rule in 2010 can be considered an exogenous shock to most firms regarding their reporting of climate change matters, although investor petitions and related congressional events in late 2007 could foreshadow the eventual legislation (but not its timing).

3.1.2 Validation of the SEC 2010 rule as an exogenous shock to CCR disclosure

By enhancing considerations regarding climate change and its consequences in firms' preparation of disclosure documents, the SEC 2010 rule substantially improves corporate CCR disclosures. As a validation, we use a computerized algorithm and scan the full texts of risk factor disclosures in 10-K filings of U.S. companies in the Russell 3000 index, which accounts for 98% of the U.S. equity market capitalization, to search for information related to CCRs. Appendix A provides excerpts of CCR disclosures from the 10-K reports of selected companies and Appendix B explains our textual analysis algorithm. For each 10-K filing year from 2006 to 2016, we plot the percentage of firms with CCR disclosures and its change in Panels A and B of Fig. 1, respectively.

As shown in Fig. 1, in general, there is an increasing trend in the portion of CCR-disclosing firms over time. However, there is a salient jump from the filing year of 2009 to 2010, that is, the years across the effective date of the SEC CCR disclosure rule in February 2010. The slope of the time trend line in Panel A becomes suddenly steeper, moving from around 22% in 2009 to 30% in 2010; the change in the percentage of CCR-disclosing firms in Panel B has an obvious spike in 2010, showing a value of 0.08, which is four times the values for other years. This evidence suggests that the SEC 2010 rule leads to an extraordinary and substantial increase in the number of firms

[12] For example, then-Commissioner Luis Aguilar claimed: "Climate change and related governmental action can create risks and opportunities for companies. It is clear that disclosure of this material information will inform and aid investors in their decision making ... This release clarifies that effects resulting from climate change that are keeping management up at night should be disclosed to investors" (http://www.sec.gov/news/speech/2010/spch012710laa-climate.htm). In contrast, then-Commissioner Kathleen Casey concluded: "The issuance of this release, however, at a time when the state of the science, law and policy relating to climate change appear to be increasingly in flux, makes little sense ... I do not believe that this release will result in greater availability of material, decision-useful information geared toward the needs of the broad majority of investors" (http://www.sec.gov/news/speech/2010/spch012710klc-climate.htm).

[13] For examples of such views, see Burton (2010) and Shorter (2013).

[14] Specifically, Senator John Barrasso and Representative Bill Posey introduced bills (S. 1393 and H.R. 2603, respectively) that would prohibit the enforcement of the SEC's climate change disclosure rule. Please see http://posey.house.gov/News/DocumentSingle.aspx?DocumentID=252940.

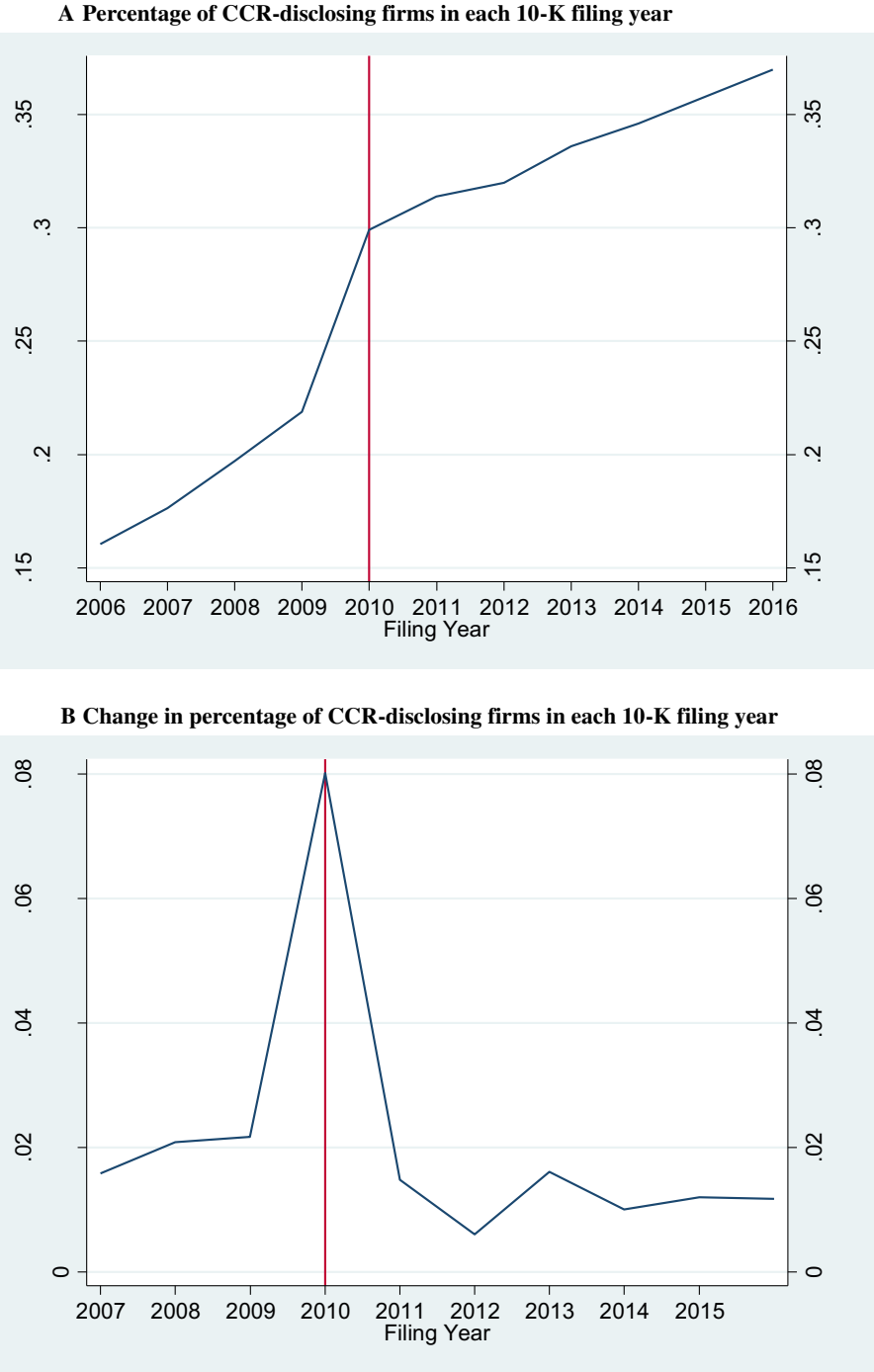

Fig. 1 CCR disclosure across years. This figure plots the percentage of CCR-disclosing firms and its yearly change in Panels A and B, respectively, for each 10-K filing year during 2006–2016. CCR disclosure is identified through the textual analysis detailed in Appendix B

starting to report CCRs after the rule. As these firms did not disclose relevant information prior to 2010, the rule brings about a significant shock to their CCR disclosures, which helps us detect meaningful changes in the risk information disclosed and avoids the potential boilerplate problems associated with qualitative risk descriptions.

3.2 Identification of climate change-related corporate behaviors

To facilitate our real effects analysis, we identify corporate behaviors that directly relate to climate change matters from KLD STATS maintained by MSCI ESG Research, which publishes a number of indicators about climate change performance outcomes each year for a large set of public firms. Specifically, MSCI ESG Research assigns a binary score (one or zero) for both the strengths (positive performance, to capture management best practices) and concerns (negative performance, to capture controversies and management weaknesses) to each indicator. KLD ratings have substantial and discernible validity with especially strong internal discriminant validity (Szwajkowski and Figlewicz 1999) and are widely accepted as objective rubrics for the corporate environmental profile in accounting studies (e.g., Chava 2014). Consistently, there is a large market and increasing willingness to pay for KLD ratings (Cronqvist and Yu 2017).

We go through the entire KLD STATS dataset and manually select all indicators that are relevant to climate change practices and available for both the periods before and after the SEC 2010 rule. We construct a measure for positive performance, denoted by *Climate Change Strength*, by counting the total number of positive indicators, and a measure for negative performance, *Climate Change Concern*, by counting the total number of negative indicators. We also obtain an aggregate measure, defined as the value of *Climate Change Strength* after netting out *Climate Change Concern* (i.e., the difference between the two), to indicate the overall status of a firm's climate change behaviors. We denote this variable by *Climate Change Practice*.

Specifically, the *Climate Change Strength* measure is the sum of the following three positive performance indicators for climate change: *Emissions Management*, *Carbon Reduction*, and *Environmental Administration*. *Emissions Management* takes a value of one if a company has strong programs to manage the risk of incurring liabilities associated with pollution and emissions of toxic substances and performs well in reducing the emissions; it takes a value of zero otherwise. *Carbon Reduction* is an indicator variable that is equal to one if a company makes strong efforts to manage the risks of increased costs linked to carbon pricing and regulatory caps, to increase the carbon efficiency of its facilities, to proactively invest in low-carbon technologies, and to reduce exposure through comprehensive carbon policies and mechanisms, including carbon reduction targets, production process improvements, installation of emission capture equipment, and/or switching to clearer energy sources; it is coded zero otherwise. *Environmental Administration* is set to one if a firm has an environmental management system in place and, it is certified by a third-party standard, such as ISO 14001, and zero otherwise.

The *Climate Change Concern* measure is the sum of the following two negative climate change performance indicators: *Environmental Violation* and *Climate Change Controversy*. *Environmental Violation* is an indicator variable that equals one if a

company has substantial payments in settlements, fines, or penalties due to noncompliance with U.S. environmental regulations, including the Clean Air Act that governs GHG emissions; otherwise it equals zero. *Climate Change Controversy* is coded one if a firm has severe controversies related to its climate change and energy policies, such as a history of involvement in GHG-related legal cases, widespread or egregious impacts due to GHG emissions, resistance to improved practices, and criticism by nongovernmental organizations and other third-party observers; it is coded zero otherwise.

By construction, *Climate Change Strength* takes discrete values of 0 to 3, and *Climate Change Concern* is valued as 0, 1, or 2. Accordingly, *Climate Change Practice*, which is the difference between the number of positive performance indicators and the number of negative performance indicators, has a possible value range from −2 to 3, with larger numbers referring to better climate change-curbing or more pro-environmental corporate behaviors.

3.3 DiD analysis of the impacts of climate change disclosure shock on corporate climate behaviors

We adopt a DiD approach to establish a causal relationship between CCR disclosures and real climate change behaviors on the part of the disclosing firms. To this end, we first identify the treatment sample of firms that change their CCR disclosing behaviors surrounding the SEC 2010 disclosure rule regarding climate change (i.e., those that did not disclose before the rule and started to report CCR in 10-Ks after the rule). The control sample contains firms that already released CCR information in 10-Ks before the introduction of the SEC 2010 rule and continued to do so after 2010. Because these control firms disclose CCRs both before and after the rule, there is no change in disclosure practice and thus little *new* information available to external stakeholders. In this sense, the control firms are early CCR disclosers on which the SEC rule has a weaker disclosure shock, whereas the treatment firms are late CCR disclosers on which the rule brings about a stronger shock.

We then examine the change in corporate climate change behaviors before and after treatment firms report CCRs in 10-Ks according to the SEC 2010 rule and compare it with the corresponding change for control firms during the same period. The DiD effect captures the difference in real behavior changes from the pre- to the post-rule period between treatment and control firms. The DiD method allows us to control for any potential time trends of climate change-related matters that are unrelated to the SEC regulation, such as society's carbon awareness (and pressure) or firms' green motive, which generally exhibit an increasing pattern over time. The comparison of real disclosure effects between the treatment and control firms also helps account for potential confounding factors (such as concurrent economic and regulatory changes other than the SEC 2010 rule) that have a common impact on all firms because the changes in environmental performance for the control firms likely reflect such impact. As such, the DiD design highlights the effects due to the change in CCR disclosure only. The way that we construct our treatment and control samples has been widely adopted in the literature. For example, Huang et al. (2021) also use early and late disclosers in the context of the SEC's generic risk factor disclosure mandate in 2005 to identify treatment and control firms;

Chhaochharia and Grinstein (2009), when studying the effects of board requirement regulations, consider firms that are already in compliance as the control and firms that are not as the treatment.

Specifically, our baseline DiD model is as follows.

$$\begin{aligned} Real\ Behaviors_{i,t} = {} & \beta_0 + \beta_1 Treatment_i + \beta_2 Post + \beta_3 Treatment_i \times Post \\ & + \beta_4 Ln(Firm\ Size)_{i,t} + \beta_5 MB_{i,t} + \beta_6 ROA_{i,t} + \beta_7 Leverage_{i,t} \\ & + \beta_8 PPE_{i,t} + \beta_9 (Sale\ Growth)_{i,t} + \beta_{10} (Firm\ Age)_{i,t} + \beta_{11} IO_{i,t} \\ & + Industry\ Fixed\ Effects + \varepsilon. \end{aligned} \tag{1}$$

In the above, the dependent variable $Real\ Behaviors_{i,t}$ refers to the measures for positive climate change performance ($Climate\ Change\ Strength_{i,t}$) and negative performance ($Climate\ Change\ Concern_{i,t}$) as well as the aggregate (net) measure ($Climate\ Change\ Practice_{i,t}$) for firm i in year t. We also examine the individual indicator for each particular performance related to climate change, i.e., $Emissions\ Management_{i,t}$, $Carbon\ Reduction_{i,t}$, $Environmental\ Administration_{i,t}$, $Environmental\ Violation_{i,t}$, and $Climate\ Change\ Controversy_{i,t}$. These variables are estimated using the KLD STATS data.

Among the independent variables, $Treatment_i$ indicates firms that are subject to CCR disclosure shocks upon the implementation of the SEC 2010 rule; it takes a value of one for late CCR disclosers ($Treatment_i = 1$ if firm i did not disclose CCRs in the pre-rule period and started to disclose after the rule) and zero for early CCR disclosers ($Treatment_i = 0$ if the firm already disclosed CCR in the pre-rule period and kept doing so after the rule). *Post* is an indicator for the period after the SEC rule in our sample years of 2005 to 2015, which correspond to the 10-K filing years of 2006 to 2016; that is, *Post* equals one for 2010–2016 and equals zero for 2006–2009.[15] The interaction term $Treatment_i \times Post$ is our key variable of interest; its coefficient reflects the change in climate change-related behaviors in the post-rule period for treatment firms, *relative to* the control firms. According to our hypothesis H1, we expect to see a significantly positive coefficient on $Treatment_i \times Post$, i.e., β_3 in Eq. (1), when the positive climate performance measures, i.e., $Climate\ Change\ Strength_{i,t}$ and its components, are the dependent variable, and a significantly negative β_3 when $Climate\ Change\ Concern_{i,t}$ and its components are the dependent variable. When the aggregate (net) score $Climate\ Change\ Practice_{i,t}$ is used as the dependent variable, H1 translates into $\beta_3 > 0$.

Following the existing literature (Hoi et al. 2013; Davidson et al. 2019), we control for a number of variables that may also affect firms' climate change-related behaviors, including the natural logarithm of firm size $Ln(Firm\ Size)_{i,t}$, market-to-book ratio $MB_{i,t}$, profitability $ROA_{i,t}$, leverage ratio $Leverage_{i,t}$, gross property, plant and equipment (PPE) scaled by total assets $PPE_{i,t}$, growth in sales $Sale\ Growth_{i,t}$, firm age measured

[15] The SEC rule came into effect on February 8, 2010. A rather small number of 10-Ks for the fiscal year 2009 were filed before this date in 2010 (i.e., between January 1 and February 7), which does not have any material impacts on our results. In Section 5.3.3, we also report robustness test results after excluding the 2010 10-K filing year.

in number of years *Firm Age*$_{i,t}$, and institutional ownership *IO*$_{i,t}$. These measures, with definitions detailed in Appendix C, are estimated each year t for each firm i using financial accounting data from Compustat. We also include industry fixed effects using Fama-French 48 industrial classifications to control for general business characteristics that may relate to a firm's carbon emissions and other climate decisions.

We use the baseline model in Eq. (1) to test hypothesis H1. For H2 and H3 about the roles of external pressure and internal managerial carbon sensitivity, we estimate Eq. (1) using the subsamples of firms with different levels of pressure and sensitivity and compare the coefficient β_3 across the subsamples.

4 Main results

4.1 Sample distribution and descriptive statistics

Our sample covers U.S. nonfinancial and non-utility public companies in the Russell 3000 index for the fiscal years 2005–2015. We require that the firms file their 10-Ks in both the pre- and post-periods surrounding the SEC 2010 CCR disclosure rule. Our final sample includes 7,189 firm-year observations in 43 industries. Panels A and B of Table 1 present the cross-year and cross-industry distributions of sample observations, respectively. The firm-year observations in our sample are quite evenly distributed over the sample period (Panel A), with slightly more observations in the introduction year of the SEC CCR reporting rule. As shown in Panel B, the sample firms span a variety of industrial sectors, whereas 41% of the observations come from six industries: retail (9.85%), oil (8.04%), electronic equipment (6.01%), business services (5.91%), transportation (5.79%), and machinery (5.48%).

Table 2 reports full-sample descriptive statistics for the key variables. As shown in Panel A, the mean values of variables for climate change-related corporate behaviors are generally small, suggesting that actions to address climate change have not been widely adopted in public firms in the U.S. during our sample period, an area with much room for improvement. Nevertheless, the standard deviations of these climate change behavior measures are quite large, ranging from two to five times the mean. This implies that there are substantial differences across companies regarding how they deal with climate change matters, a fact that facilitates our statistical investigation. In Panel B of Table 2, we identify treatment firms that take 51.5% of the total observations. About 64% of observations are in the post-period after the SEC 2010 rule.

4.2 Results for testing hypothesis H1 about the real effects of climate change disclosures

4.2.1 Baseline results

Panel A of Table 3 reports the results of our baseline regression in Eq. (1). As shown in column 1, where the positive climate change performance measure *Climate Change Strength*$_{i,t}$ is used to reflect firms' real behaviors, the coefficient on the key variable of interest, *Treatment*$_i$ × *Post*, is positive, with a magnitude of 0.131 and is significant at the 1% level (t-statistic = 4.51). This result suggests that pro-environmental

Table 1 Sample distributions

Panel A: Sample distribution by fiscal year

Fiscal Year	Freq.	Pct.	Cum.
2005	533	7.41	7.41
2006	594	8.26	15.68
2007	648	9.01	24.69
2008	689	9.58	34.27
2009	720	10.02	44.29
2010	712	9.90	54.19
2011	732	10.18	64.38
2012	731	10.17	74.54
2013	669	9.31	83.85
2014	520	7.23	91.08
2015	641	8.92	100
Total	7,189	100	

Panel B: Sample distribution by Fama-French industry

Industry	Freq.	Pct.	Cum.	Industry	Freq.	Pct.	Cum.
Agriculture	43	0.60	0.60	Autos	190	2.64	41.87
Food Products	280	3.89	4.49	Aircraft	55	0.77	42.63
Candy & Soda	31	0.43	4.92	Ships	41	0.57	43.20
Beer and Liquor	52	0.72	5.65	Guns	21	0.29	43.50
Tobacco Products	25	0.35	6.00	Gold	40	0.56	44.05
Recreation	18	0.25	6.25	Mines	80	1.11	45.17
Entertainment	139	1.93	8.18	Coal	27	0.38	45.54
Books	27	0.38	8.55	Oil	578	8.04	53.58
Consumer Goods	128	1.78	10.34	Communication	129	1.79	55.38
Apparel	203	2.82	13.16	Personal Services	67	0.93	56.31
Healthcare	84	1.17	14.33	Business Services	425	5.91	62.22
Medical Equipment	61	0.85	15.18	Computers	171	2.38	64.60
Pharmaceutical Products	149	2.07	17.25	Electronic Equipment	432	6.01	70.61
Chemicals	348	4.84	22.09	Lab Equipment	90	1.25	71.86
Rubber Products	62	0.86	22.95	Business Supplies	132	1.84	73.70
Textiles	27	0.38	23.33	Boxes	59	0.82	74.52
Construction Materials	253	3.52	26.85	Transportation	416	5.79	80.30
Construction	208	2.89	29.74	Wholesale	314	4.37	84.67
Steel Works	186	2.59	32.33	Retail	708	9.85	94.52
Fabricated Products	26	0.36	32.69	Meals	263	3.66	98.18
Machinery	394	5.48	38.17	Others	131	1.82	100
Electrical Equipment	76	1.06	39.23		7,189	100	

The sample includes 7,189 firm-year observations for treatment and control firms during the fiscal years of 2005 to 2015. Panel A reports sample distribution by fiscal year and Panel B reports the distribution across Fama-French industries

Table 2 Descriptive statistics of main testing variables

Panel A: Variables for climate change-related behaviors					
Variable	Mean	Std.	P25	Median	P75
Climate Change Strength	0.356	0.718	0.000	0.000	0.000
Climate Change Concern	0.184	0.472	0.000	0.000	0.000
Climate Change Practice	0.123	0.739	0.000	0.000	0.000
Emissions Management	0.114	0.317	0.000	0.000	0.000
Carbon Reduction	0.035	0.185	0.000	0.000	0.000
Environmental Administration	0.180	0.384	0.000	0.000	0.000
Environmental Violation	0.079	0.270	0.000	0.000	0.000
Climate Change Controversy	0.092	0.290	0.000	0.000	0.000
Panel B: DiD method variables					
Variable	Mean	Std.	P25	Median	P75
Treatment	0.515	0.500	0.000	1.000	1.000
Post	0.639	0.480	0.000	1.000	1.000
Panel C: Control variables					
Variable	Mean	Std.	P25	Median	P75
Ln(Firm Size)	7.587	1.565	6.478	7.467	8.609
MB	2.940	4.392	1.416	2.240	3.613
ROA	0.069	0.134	0.030	0.077	0.131
Leverage	0.420	0.198	0.283	0.407	0.537
PPE	0.600	0.398	0.276	0.537	0.869
Sale Growth	0.107	0.315	−0.012	0.069	0.175
Firm Age	27.620	18.150	13.000	22.000	43.000
IO	0.676	0.274	0.577	0.749	0.867

Panels A to C report descriptive statistics of variables for climate change-related behaviors, DiD method variables, and control variables in the baseline testing model, respectively. The statistics are computed from all firm-years in the full sample. Details about the variable definitions are provided in Appendix C

performance improves significantly in treatment firms from the pre- to the post-rule period, compared to the corresponding performance change in control firms for the same period. Specifically, relative to the early CCR disclosers that serve as the benchmark, the late CCR disclosers in the treatment sample have a *Climate Change Strength* score that is, on average, 0.131 higher, which is 18% of the sample standard deviation (0.718 as in Panel A of Table 2). For the pro-environmental real behaviors, our results are thus consistent with the prediction in H1. An important takeaway here is that firms that disclose CCRs in accounting reports have a greater tendency to behave in ways that help mitigate climate change, compared with other firms.

In sharp contrast, column 2 of Panel A shows that the coefficient on $Treatment_i \times Post$ is significantly negative with a value of −0.041 (t-statistic = −1.90) in the model specification with $Climate\ Change\ Concern_{i,t}$ as the dependent variable, which captures a company's real behaviors that worsen climate change. This finding suggests that the score for anti-environmental behaviors is lowered by 9% of its standard deviation in treatment firms from the pre- to the post-rule period, relative to the corresponding score

Table 3 Effects of CCR disclosures on real climate change-related behaviors

Panel A: Effects on aggregate climate change-related behaviors

	(1)	(2)	(3)
Dependent Variable	*Climate Change Strength*$_{i,t}$	*Climate Change Concern*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Treatment$_i$	−0.103***	−0.081***	−0.026
	(−5.41)	(−5.02)	(−1.09)
Post	0.164***	−0.070***	0.284***
	(8.36)	(−4.00)	(8.63)
Treatment$_i$ × *Post*	**0.131*** **	**−0.041***	**0.142*** **
	(4.51)	**(−1.90)**	**(3.09)**
Ln(Firm Size)$_{i,t}$	0.187***	0.092***	0.070***
	(29.25)	(18.62)	(8.07)
MB$_{i,t}$	0.007***	−0.000	0.006*
	(2.82)	(−0.14)	(1.78)
ROA$_{i,t}$	0.002	−0.038	−0.010
	(0.05)	(−0.91)	(−0.15)
Leverage$_{i,t}$	−0.097**	−0.078***	−0.041
	(−2.48)	(−2.71)	(−0.75)
PPE$_{i,t}$	0.024	0.090***	−0.084**
	(0.99)	(5.02)	(−2.50)
Sale Growth$_{i,t}$	0.007	−0.050***	0.127***
	(0.32)	(−2.61)	(3.34)
Firm Age$_{i,t}$	0.006***	0.003***	0.003***
	(11.72)	(7.12)	(4.31)
IO$_{i,t}$	−0.167***	−0.099***	0.011

Table 3 (continued)

	(−6.08)		(−4.70)		(0.27)
Intercept	−1.269***		−0.616***		−0.356***
	(−16.23)		(−17.51)		(−3.40)
Industry Fixed Effects	Included		Included		Included
Number of Observations	5,284		5,215		3,665
R-Squared	0.376		0.306		0.215

Panel B: Effects on specific climate change-related behaviors

	(1)	(2)	(3)	(4)	(5)
Dependent Variable	*Emissions Management*$_{i,t}$	*Carbon Reduction*$_{i,t}$	*Environmental Administration*$_{i,t}$	*Environmental Violation*$_{i,t}$	*Climate Change Controversy*$_{i,t}$
Treatment$_i$	−0.011**	−0.038***	−0.045***	−0.041***	−0.032***
	(−2.14)	(−4.66)	(−3.84)	(−4.08)	(−3.14)
Post	0.017***	0.069***	0.063***	−0.064***	−0.010
	(3.46)	(7.69)	(5.39)	(−7.01)	(−1.07)
Treatment$_i$ × *Post*	**0.014***	**0.040*****	**0.059*****	−0.001	**−0.025***
	(1.92)	**(3.19)**	**(3.43)**	(−0.07)	**(−1.88)**
Ln(Firm Size)$_{i,t}$	0.026***	0.073***	0.082***	0.039***	0.051***
	(13.42)	(24.59)	(23.78)	(16.07)	(20.55)
MB$_{i,t}$	0.001**	0.003***	0.002	0.001	−0.001*
	(2.06)	(3.35)	(1.58)	(1.06)	(−1.70)
ROA$_{i,t}$	0.019*	−0.029	0.010	−0.012	−0.032
	(1.79)	(−1.18)	(0.35)	(−0.43)	(−1.24)
Leverage$_{i,t}$	−0.008	−0.052***	−0.034	−0.036**	−0.042**
	(−0.90)	(−2.92)	(−1.49)	(−1.98)	(−2.26)
PPE$_{i,t}$	−0.002	0.008	0.026*	0.039***	0.053***

Table 3 (continued)

	(−0.26)	(0.75)	(1.75)	(3.66)	(4.89)
Sale Growth$_{i,t}$	0.000	0.014	−0.016	−0.037***	−0.011
	(0.04)	(1.47)	(−1.33)	(−3.52)	(−1.04)
Firm Age$_{i,t}$	0.001***	0.002***	0.003***	0.001***	0.002***
	(8.29)	(8.12)	(8.06)	(4.26)	(7.96)
IO$_{i,t}$	−0.037***	−0.060***	−0.045***	−0.058***	−0.041***
	(−5.58)	(−4.89)	(−2.85)	(−4.89)	(−3.32)
Intercept	−0.200***	−0.544***	−0.493***	−0.215***	−0.368***
	(−13.96)	(−21.98)	(−7.52)	(−4.87)	(−7.72)
Industry Fixed Effects	Included	Included	Included	Included	Included
Number of Observations	7,189	6,839	5,376	6,310	6,094
R-Squared	0.137	0.241	0.279	0.165	0.256

In Panel A, the dependent variables *Climate Change Strength*, *Climate Change Concern*, and *Climate Change Practice* refer to the number of positive climate change performance indicators, the number of negative climate change performance indicators, and the number of climate change strengths minus the number of climate change concerns, respectively. The dependent variables in Panel B include indicator variables for three positive climate change-related behaviors (*Emissions Management*, *Carbon Reduction*, *Environmental Administration*) and two negative climate change-related behaviors (*Environmental Violation*, *Climate Change Controversy*). The key independent variable is the interaction term between the treatment firm indicator *Treatment* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables are controlled as in Eq. (1). Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

change in control firms for the same period, reflecting a significant reduction in environment-destroying actions induced by the disclosure shock. This finding is also consistent with the prediction in H1 that CCR disclosures reduce corporate behaviors that aggravate climate change.

In column 3, where the aggregate (net) climate change practice score *Climate Change Practice*$_{i,t}$ is used as the dependent variable, we find that the coefficient on *Treatment*$_i$ × *Post* is positive and highly significant, with a magnitude of 0.142 (*t*-statistic = 3.09). This result suggests that, from the pre- to the post-rule period, the net climate change practice score increases by 0.142 more (or 19% of the sample standard deviation) in the treatment firms, relative to the control firms. This effect is economically significant, demonstrating the strong impact of the SEC climate change disclosure rule on firms' real decisions concerning climate change issues. In short, the finding comports with the prediction in H1.

These baseline results are obtained after we control for a number of firm characteristic variables and industry fixed effects. Either the control variables have insignificant influences on the dependent variables or the directions of their influences are economically inconsistent. Firm size has a significant coefficient across all model specifications, but its coefficient is always positive, suggesting that larger firms tend to take actions that can help fight against climate change, but, at the same time, they also suffer from more environmental weaknesses and controversies. Similarly, firm age, leverage, and institutional ownership affect both strengths and concerns regarding climate change in the same way. Lower sales growth and larger PPE are associated with more climate concerns and lower net climate change practice scores but appear not to influence climate strengths. Market-to-book ratio affects strength and net score only; firms with higher *MB* tend to have better environmental behaviors. In sum, various firm characteristics and differences in the nature of the industry cannot explain our findings of the real effects of CCR disclosures via accounting reports.

4.2.2 Results for individual climate change behaviors

In Panel B of Table 3, we use the five individual measures of climate change-related behavior as the dependent variable in Eq. (1) and document results consistent with those in Panel A. As shown in the first three columns, the positive climate change measures are significantly positively associated with our DiD estimator *Treatment*$_i$ × *Post*, suggesting that, relative to early disclosers, firms that started to disclose CCR after the SEC rule exhibit a significantly higher tendency to adopt pro-environmental behaviors, including stronger programs to manage pollution and emissions (as revealed by *Emissions Management*$_{i,t}$), greater efforts to lower carbon costs, improve carbon efficiency, and reduce carbon emissions (as captured by *Carbon Reduction*$_{i,t}$), and better and more credible environmental management systems for climate change issues (as reflected in *Environmental Administration*$_{i,t}$).

When the dependent variable is one of the negative climate change measures—*Environmental Violation*$_{i,t}$ and *Climate Change Controversy*$_{i,t}$, as in columns 4 and 5, respectively—we find that the coefficient on *Treatment*$_i$ × *Post* becomes negative and is significant in the *Climate Change Controversy* case. In general, this finding suggests that treatment firms, relative to control firms, try harder to refrain from behaviors that

are detrimental to the environment. The results in Panel B collectively show that CCR disclosures improve firms' various behaviors that benefit the climate and limit their particular actions that harm it.

4.3 Results for testing hypotheses H2 and H3 about the roles of external pressure and internal carbon sensitivity

4.3.1 The role of external pressure

To test H2, we examine whether and, if so, how pressures from external stakeholders influence the real effects of CCR disclosures. We focus on creditors, especially lending banks because they perform a special role as delegated monitors (e.g., Diamond 1984, 1991) and are greatly concerned about borrowers' environmental performance. As a major source of corporate financing, banks have promoted environmentally responsible behaviors and play a leadership role in disciplining borrowing firms' climate change behaviors (Kim et al. 2021). They, for example, have established prominent climate change principles, such as the Equator Principles, the Carbon Principles, and the Climate Principles, to guide eco-friendly lending decisions and ex post monitoring of facilities and projects that they finance.[16] We therefore consider firms with lending banks (or the lead banks in loan syndicates) adopting major climate change-related principles (i.e., the Equator, the Carbon, and the Climate Principles) as those under high pressure from creditors and assign them to a subsample with high external pressure. Other firms are considered to be, in a relative sense, under low pressure from lending banks and are allocated to the subsample with low external pressure.

Table 4 reports the subsample results for our baseline regression in Eq. (1). For brevity, hereafter, we only report the results using the measure of net climate change-related behavior, i.e., $Climate\ Change\ Practice_{i,t}$, as the dependent variable. In the high external pressure subsample, the coefficient on $Treatment_i \times Post$ is 0.161 (t-statistic = 2.83), whereas in the low-pressure subsample, the coefficient is 0.033 (t-statistic = 0.54). We find that the high-pressure group obviously shows far stronger impacts of CCR disclosures on real environmental behaviors than the low-pressure group. As shown at the bottom of the table, the difference in the coefficient magnitude between the two subsamples is significant at less than the 10% level (p-statistic = 0.07). This finding is consistent with our prediction in H2 regarding the role of external pressure in shaping the relationship between CCR disclosures via accounting reports and firms' real actions taken to address climate change.

[16] The Equator Principles as a risk management framework for environmental risk were formulated in 2003 and have now been adopted by 93 financial institutions in 37 countries (https://equator-principles.com.about). The Carbon Principles were established in 2008 by three leading banks (Citigroup, JP Morgan Chase, and Morgan Stanley) to assess carbon risk in financing electric power projects (https://issuu.com/tobend/docs/the_principle_matter). The Climate Principles, adopted by Crédit Agricole, Munich Re, Standard Chartered, Swiss Re, and HSBC, are a similar framework for responding to climate change (https://en.wikipedia.org/wiki/The_Carbon_Principles).

Table 4 The role of external pressure on the real effects of CCR disclosures

	Low level of external pressure (*High External Pressure* = 0)	High level of external pressure (*High External Pressure* = 1)
	(1)	(2)
Dependent Variable	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Treatment$_i$	−0.008	−0.018
	(−0.20)	(−0.46)
Post	0.205***	0.331***
	(4.44)	(8.07)
Treatment*$_i$ × *Post	0.033	**0.161*** **
	(0.54)	**(2.83)**
Ln(Firm Size)$_{i,t}$	0.091***	0.059***
	(7.87)	(5.18)
MB$_{i,t}$	0.005	0.007**
	(1.21)	(2.10)
ROA$_{i,t}$	−0.040	0.044
	(−0.39)	(0.34)
Leverage$_{i,t}$	−0.233**	0.001
	(−2.44)	(0.02)
PPE$_{i,t}$	0.046	−0.090*
	(0.93)	(−1.78)
Sale Growth$_{i,t}$	0.069*	0.200***
	(1.79)	(3.38)
Firm Age$_{i,t}$	0.001	0.004***
	(0.51)	(4.48)
IO$_{i,t}$	−0.109*	0.080
	(−1.94)	(1.46)
Intercept	−0.513***	0.171
	(−3.20)	(0.47)
Industry Fixed Effects	Included	Included
Number of Observations	1,139	2,526
R-Squared	0.253	0.240
Difference in Coef. on Treatment$_i$ × *Post*	0.07*	

The baseline model of Eq. (1) is estimated in subsamples partitioned according to the level of external pressure represented by climate-minded bank lenders. The dependent variable *Climate Change Practice* refers to the number of climate change strengths minus the number of climate change concerns. The key independent variable is the interaction term between the treatment firm indicator *Treatment* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables are controlled as in Eq. (1). Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. The last row reports the *p*-statistic of the difference between the coefficients on *Treatment*× *Post* in the two subsamples. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

4.3.2 The role of internal sensitivity

H3 is concerned with disclosing firms' sensitivities to climate change matters in the real effects of CCR disclosures. A key determinant of internal sensitivity is the industrial or business nature of the disclosing firms. Some environmentally damaging industries, including the mining, coal, and oil sectors, tend to be heavily regulated and face higher regulatory risk and other related business risks. Industries with significant nondeployable and long-lived capital assets, such as construction, communication, energy (e.g., mining and oil extraction), and healthcare, are especially vulnerable to potential damage caused by global warming and extreme weather (McCarthy et al. 2001; SASB 2016). Other industries that depend on extended supply chains and infrastructures, such as agriculture, business services, and transportation, are also subject to heightened CCRs (Fleming et al. 2006; Hsiang 2010; Challinor et al. 2014). The larger climate change exposures of these industries not only affect the industries themselves but also influence the risk perceptions of outside stakeholders that may cause additional drawbacks to firms therein. Therefore firms in these industries are more vulnerable to two layers of risks and tend to be more sensitive to any policy changes. Moreover, for the SEC CCR disclosure rule per se, these firms may be more willing to take proactive pro-environmental actions and are likely to be more alert to the regulatory consequences.

To test H3, we use the industry classifications developed by Fama and French (1997) and assign firms in the industries of agriculture, healthcare, pharmaceutical products, construction, automobile and trucks, mines, coal, oil, communication, business services, and transportation to the high-sensitivity group, and other sample firms to the low-sensitivity group. A similar identification process is adopted in such studies as the work of Huang et al. (2018). Table 5 shows that the DiD effect is stronger for firms in high-sensitivity industries than for those in low-sensitivity industries. The coefficient on $Treatment_i \times Post$ is 0.252 (t-statistic = 3.67) in high-sensitivity firms, whereas it is 0.067 (t-statistic = 1.20) in other firms. As shown in the bottom row of the table, the difference in the coefficient magnitude between the two subsamples is significant at less than the 5% level (p-statistic = 0.02). Economically, our results suggest that, when firms have a higher level of climate change vigilance, CCR disclosures via accounting reports have a larger boosting effect in that these firms are more likely to take real actions to improve their environmental performance. Overall, these findings support the prediction in H3.

5 Further analyses of the real effects of CCR disclosures via accounting reports

5.1 CCR disclosures and outsiders' risk perceptions

A key premise of our main hypothesis is that CCR disclosures enhance the perceptions of outside financial statement users regarding downside climate risk. In this section, we provide evidence for this assumption.

Table 5 The role of internal climate change sensitivity on the real effects of CCR disclosures

	Low level of climate change sensitivity (*High Internal Carbon Sensitivity* = 0)	High level of climate change sensitivity (*High Internal Carbon Sensitivity* = 1)
	(1)	(2)
Dependent Variable	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Treatment$_i$	−0.021	−0.014
	(−0.57)	(−0.29)
Post	0.367***	0.129***
	(8.72)	(2.74)
Treatment*$_i$ × *Post	0.067	**0.252*** **
	(1.20)	**(3.67)**
Ln(Firm Size)$_{i,t}$	0.088***	0.044***
	(8.12)	(3.82)
MB$_{i,t}$	0.009**	−0.001
	(2.53)	(−0.35)
ROA$_{i,t}$	0.017	−0.084
	(0.14)	(−0.74)
Leverage$_{i,t}$	−0.080	−0.056
	(−0.98)	(−0.58)
PPE$_{i,t}$	−0.086*	−0.065
	(−1.67)	(−1.29)
Sale Growth$_{i,t}$	0.144***	0.097**
	(2.61)	(2.13)
Firm Age$_{i,t}$	0.004***	0.002
	(4.14)	(1.41)
IO$_{i,t}$	−0.029	0.074
	(−0.51)	(1.32)
Intercept	−0.195	−0.123
	(−0.89)	(−0.75)
Industry Fixed Effects	Included	Included
Number of Observations	2,492	1,173
R-Squared	0.248	0.119
Difference in Coef. on Treatment$_i$ × *Post*	0.02**	

The baseline model of Eq. (1) is estimated in subsamples partitioned according to the level of climate change sensitivity of the CCR-disclosing firms. The dependent variable *Climate Change Practice* refers to the number of climate change strengths minus the number of climate change concerns. The key independent variable is the interaction term between the treatment firm indicator *Treatment* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables are controlled as in Eq. (1). Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. The last row reports the *p*-statistic of the difference between the coefficients on *Treatment*× *Post* in the two subsamples. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

5.1.1 Evidence of negative market reactions to the initiation of CCR disclosures

We first show that the initiation of CCR disclosures is associated with unfavorable investor responses in the equity market. This evidence is consistent with the view that, in the absence of relevant risk reporting by a firm, shareholders have difficulty in adequately estimating the firm's CCR exposure due to the abstract, complex nature of climate change and its impact on an individual company's operations.

To this end, we define an indicator variable $Initial\ CCR\ Disclosure_{i,t}$ that equals one if firm i is mandated to initiate its first disclosure of CCR information in the 10-K filing in year t and zero before the initial CCR disclosure.[17] We then estimate the market reaction, represented by cumulative abnormal return (CAR) (i.e., buy-and-hold stock return minus market return), for all post-rule mandated disclosure initiations, as follows.

$$\begin{aligned} CAR[-2,+2] = {} & \lambda_0 + \lambda_1 (Initial\ CCR\ Disclosure)_{i,t} + \lambda_2 \Delta Ln(MVE)_{i,t} \\ & + \lambda_3 \Delta MB_{i,t} + \lambda_4 \Delta ROA_{i,t} + \lambda_5 \Delta Leverage_{i,t} + \lambda_6 \Delta PPE_{i,t} \\ & + Industry\ Fixed\ Effects + Year\ Fixed\ Effects + \varepsilon. \end{aligned} \tag{2}$$

For the dependent variable, we use data from the Center for Research in Security Prices and estimate CAR for a five-day window (from two days before to two days after the 10-K filing date), denoted by $CAR[-2,+2]$.[18] Following Beatty et al. (2019), we control for the changes (Δ) in the firm's market value of equity (MVE, estimated as year-end stock price multiplied by common shares outstanding, in logarithmic form), market-to-book ratio, ROA, leverage ratio, and PPE from year t-1 to year t. We also control for year and industry fixed effects to account for common time trend and time-invariant industrial characteristics that could influence our inference about the market reactions to CCR disclosure initiations.

Table 6 reports the estimation results for the regression in Eq. (2). $Initial\ CCR\ Disclosure_{i,t}$ carries a significantly negative coefficient of −0.010 with a t-statistic of −2.03, suggesting that the initiation of mandated CCR disclosures brings about unfavorable responses from outside investors. Such negative market reactions buttress the notion that mandated CCR disclosure initiation, on average, enhances the downside risk perceptions of shareholders by confirming the severity of risk exposure, revealing new risk factors, or both.

5.1.2 Evidence of enhanced CCR salience after the SEC 2010 rule

After demonstrating the negative market reactions to CCR disclosure initiation, we move on to show that the SEC 2010 CCR disclosure rule enhances the salience of climate change-related risks among investors and, as a result, that equity values become more sensitive to CCR levels in the post-rule period. This evidence supports the notion

[17] To isolate the effects of initial mandated CCR disclosure, we exclude 10-K filings after the first mandated CCR disclosure year and firms with voluntary CCR disclosures in the pre-rule years.
[18] Using CARs of other window lengths delivers similar results.

Table 6 Negative market reactions to the initiation of mandated CCR disclosures

Dependent Variable	(1) *CAR[−2,+2]*
Initial CCR Disclosure$_{i,t}$	**−0.010****
	(−2.03)
$\Delta Ln(MVE)_{i,t}$	−0.005
	(−0.74)
$\Delta MB_{i,t}$	−0.001
	(−0.88)
$\Delta ROA_{i,t}$	0.069**
	(2.20)
$\Delta Leverage_{i,t}$	−0.016
	(−0.36)
$\Delta PPE_{i,t}$	−0.004
	(−0.13)
Intercept	−0.002
	(−0.17)
Industry Fixed Effects	Included
Year Fixed Effects	Included
Number of Observations	560
R-Squared	0.013

The dependent variable *CAR[−2,+2]* is the five-day (from two days before to two days after the 10-K filing date) cumulative abnormal return (i.e., buy-and-hold stock return minus market return). The key independent variable *Initial CCR Disclosure* is an indicator variable that equals one if a firm is mandated to initiate its first disclosure of CCR information in the 10-K filing in the post-rule period and zero before the initial CCR disclosure. Control variables include changes in the disclosing firm's market value of equity, market-to-book ratio, ROA, leverage ratio, and PPE. Industry and year fixed effects are also controlled. Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry and year dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

that CCR salience also contributes to the improved CCR perception induced by the disclosure mandate.

Specifically, we employ the following regression model to test the role of the SEC 2010 rule in enhancing CCR salience in the post-rule period.

$$\begin{aligned} Ln(MVE)_{i,t} = {} & \theta_0 + \theta_1 (CCR\ Index)_{i,t} + \theta_2 Post + \theta_3 (CCR\ Index)_{i,t} \times Post \\ & + \theta_4 Ln(Firm\ Size)_{i,t} + \theta_5 MB_{i,t} + \theta_6 ROA_{i,t} + \theta_7 Leverage_{i,t} \\ & + \theta_8 PPE_{i,t} + \theta_9 (Sale\ Growth)_{i,t} + \theta_{10} (Firm\ Age)_{i,t} + \theta_{11} IO_{i,t} \\ & + Industry\ Fixed\ Effects + \varepsilon. \end{aligned} \tag{3}$$

In Eq. (3), the dependent variable $Ln(MVE)_{i,t}$ proxies for the price of equity for firm i in year t; we use MVE, instead of price per share, to rectify potential mechanical price

changes due to stock splits or stock dividends.[19] For the independent variable, we follow Beatty et al. (2019) and construct a proxy for the level of CCR disclosure for firm i in year t using the number of CCR-related keywords listed in Table 12 of Appendix A, denoted by $CCR\ Index_{i,t}$. *Post* indicates the period after the SEC implemented the mandatory CCR disclosure rule in 2010, as defined in the baseline regression in Eq. (1). Other control variables are the same as in Eq. (1). As such, the general framework of Eq. (3) follows the one in the baseline model. In particular, the coefficient θ_3 on the interaction term $(CCR\ Index)_{i,t} \times Post$ reflects the enhancement of the sensitivity of equity value to CCR disclosure level after the SEC 2010 rule; a significantly negative θ_3 comports with the implication that the rule increases the salience of CCR to external investors, which adds a further drag on their evaluation of the firm's equity.

In Table 7, we find evidence consistent with the aforementioned CCR salience-increasing effect of the SEC 2010 CCR disclosure rule: the coefficient on $(CCR\ Index)_{i,t} \times Post$ is negative and significant at the 5% level (−0.021; t-statistic = −2.26). This finding supports our hypothesis in that the CCR disclosure mandate as guided by the SEC 2010 rule deepens the degree of shareholders' recognition and understanding of the focal firm's inferior CCR perspectives and strengthens the unfavorable responses from the equity market, which pressures the disclosing firms to improve their climate change-related environmental performance.

5.2 Further addressing endogeneity problems

Our baseline DiD approach aims to address the endogenously determined association between a firm's CCR disclosures and its actions taken to cope with climate change. By taking the SEC 2010 rule as an exogenous regulatory shock to CCR disclosure, this approach largely mitigates the concerns about potential spurious disclosure–performance relationships, such as those caused by correlated omitted factors (e.g., good corporate governance) that lead to improvements in both CCR disclosure and environmental performance.

However, even with the mandatory CCR reporting rule enacted by the SEC, corporate managers still have leeway in complying with the rule. For example, managers could shun CCR reporting by claiming that the firm does not face any material CCRs; they could also observe other firms' compliance behaviors when making their own disclosure decisions. Therefore managerial judgments and incentives to respond to the CCR disclosure rule could still play a role; that is, the reaction to the exogenous CCR reporting shock could still be an endogenous choice.[20] We address these concerns using several methods.

5.2.1 Controlling for the disclosure choice in response to the SEC 2010 rule

As a first effort, we control for managerial choice to respond to (or comply with) the SEC 2010 CCR disclosure rule in a two-stage treatment effect model within the

[19] In Eq. (3), we examine annual stock price change for the full sample period, during which stock splits and stock dividends are likely to occur for some firms. In contrast, in Eq. (2), we only consider a five-day window to examine stock price change, for which the mechanical price changes are unlikely to add significant noise.
[20] We thank the anonymous referee for pointing out this issue and suggesting the relevant tests.

Table 7 Enhanced CCR salience after the SEC 2010 rule

Dependent Variable	(1) $Ln(MVE)_{i,t}$
$CCR\ Index_{i,t}$	0.011
	(1.25)
Post	−0.049***
	(−3.27)
$(CCR\ Index)_{i,t} \times Post$	**−0.021****
	(−2.26)
$Ln(Firm\ Size)_{i,t}$	0.949***
	(215.47)
$MB_{i,t}$	0.040***
	(16.33)
$ROA_{i,t}$	2.419***
	(24.81)
$Leverage_{i,t}$	−0.794***
	(−16.86)
$PPE_{i,t}$	−0.064***
	(−3.08)
$Sale\ Growth_{i,t}$	−0.108***
	(−3.63)
$Firm\ Age_{i,t}$	0.000
	(−0.54)
$IO_{i,t}$	−0.022
	(−1.33)
Intercept	0.477***
	(6.44)
Industry Fixed Effects	Included
Number of Observations	13,106
R-Squared	0.858

The dependent variable *Ln(MVE)* refers to the natural logarithm of market value of equity. The key independent variable is the interaction term between the number of CCR-related keywords (as listed in Table 12) *CCR Index* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables are controlled as in Eq. (1). Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

framework suggested by Heckman (1976). The merit of this method is that we do not have to assess the degree of activeness in reacting to the rule or specify the ways that firms respond to the rule; thus we can address a large range of issues relating to the endogenous disclosure choice.

In the first stage, we estimate the following Probit model of firm-level disclosure choice under the mandatory CCR reporting scheme (i.e., in the post-period of the SEC 2010 rule).

$$\begin{aligned} CCR\ Disclosure_{i,Post} = {} & \delta_0 + \delta_1 Ln(Firm\ Size)_{i,Post} + \delta_2 ROA_{i,Post} + \delta_3 Leverage_{i,Post} \\ & + \delta_4 PPE_{i,Post} + \delta_5 (Sale\ Growth)_{i,Post} + \delta_6 (Peer\ CCR\ Disclosure)_{i,Post} \\ & + \delta_7 (Natural\ Disaster)_{i,Post} + Industry\ Fixed\ Effects + \varepsilon. \end{aligned} \tag{4a}$$

The dependent variable $(CCR\ Disclosure)_{i,Post}$ is an indicator variable that equals one if firm i discloses CCR information after the SEC 2010 rule and zero otherwise; that is, the variable reflects the choice of managers in responding to the SEC rule. Among the determinants of a firm's disclosure (or compliance) choice, we consider basic firm characteristics that could influence the firm's status in terms of CCR exposure, including the firm-level average values of size, ROA, leverage, PPE, and sales growth in the post-rule period (denoted by $Ln(Firm\ Size)_{i,Post}$, $ROA_{i,Post}$, $Leverage_{i,Post}$, $PPE_{i,Post}$, and $Sale\ Growth_{i,Post}$, respectively) as well as industry-specific features as captured by industry fixed effects. We also include the CCR disclosure behaviors of peer firms to account for the possible herding effect; the variable $Peer\ CCR\ Disclosure_{i,Post}$ is measured for firm i by the average level of $CCR\ Disclosure_{i,Post}$ (defined above) among all other firms in the same industry. Finally, we add the firm's exposure to natural disaster shocks as an additional CCR disclosure choice determinant. The rationale is that a firm that is subject to more damage from natural disasters tends to be exposed to more material CCRs, which compels it to report CCRs in its 10-Ks; hiding such risks is more difficult, given that the evidence from natural disasters can be observed by investors as well as regulators. For this purpose, we introduce a measure for natural disaster exposure by computing the average number of climate change-related natural hazard events that a firm's subsidiaries experience during our post-rule period. Specifically, we first retrieve information about natural disasters from the Spatial Hazard Events and Losses Database for the United States (SHELDUS), which covers the dates and locations of different natural hazard events relating to climate change.[21] We then obtain the subsidiaries' information for all sample firms from Dyreng et al. (2013) and match the subsidiaries' locations with the sites of the natural disasters. With the matched data, we compute the subsidiary-weighted number of natural disasters for each year and take the average in the post-period for each firm i.[22] We denote this variable by $Natural\ Disaster_{i,Post}$.

The first-stage regression generates an inverse Mills ratio for each firm to be included as an additional control variable in the second-stage regression, which adopts

[21] We consider only climate-related natural disasters, namely, coastal storms, droughts, flooding, heatwaves, hurricanes/tropical storms, landslides, lightning, severe storms/thunder storms, tornadoes, wildfires, wind, and winter weather that are recorded at SHELDUS.

[22] For example, FairChild Corp. has three subsidiaries: one in Kentucky and two in Ohio. In 2007, Kentucky and Ohio experienced 13 and 25 climate change-induced natural disasters, respectively. FairChild's subsidiary-weighted number of natural disasters for 2007 is $(1/3 \times 13 + 2/3 \times 25) = 21$. We perform a similar computation each year during the post-period, scaled the values by 100, and take the average as the final measure of the company's natural disaster exposure.

the baseline DiD framework with *Climate Change Practice* as the dependent variable, as follows.

$$\begin{aligned} \textit{Climate Change Practice}_{i,t} = {} & \mu_0 + \mu_1 \textit{Treatment}_i + \mu_2 \textit{Post} + \mu_3 \textit{Treatment}_i \times \textit{Post} \\ & + \mu_4 (\textit{Inverse Mills Ratio})_i + \textit{Controls}_{i,t} \\ & + \textit{Industry Fixed Effects} + \varepsilon. \end{aligned} \tag{4b}$$

In Eq. (4b), $\textit{Inverse Mills Ratio}_i$ represents the firm-level inverse Mills ratio estimated from the first-stage regression in Eq. (4a) for each firm i, and $\textit{Controls}_{i,t}$ refers to the control variables in the baseline model in Eq. (1). In this empirical design, the coefficient on $\textit{Treatment}_i \times \textit{Post}$ captures the effect of CCR disclosure change triggered by the SEC 2010 rule on disclosing firms' climate change-related environmental performance that is less confounded by the firms' endogenous choices of observing the reporting requirement.

Panels A and B of Table 8 report the estimation results for the first- and second-stage regressions, respectively. Panel A shows that firms' tendency to comply with the SEC disclosure rule and thus choose to report CCRs in the post-rule period is positively associated with firm size, peer firms' CCR disclosure statuses, and their exposure to physical risks from natural disasters. These results support the view that it is harder (and unwise) for bigger firms and those subject to climate change shocks to conceal CCR information, especially when other peer firms choose to disclose CCRs. Panel B further shows that the potential endogeneity in post-rule CCR disclosure practice does not exert a significant impact on our conclusion about the impact of the exogenous CCR reporting shock induced by the SEC 2010 rule. This is evidenced by the significantly positive coefficient on $\textit{Treatment}_i \times \textit{Post}$ even after controlling for the endogenous compliance choice. In particular, in the second stage of the Heckman model, $\textit{Treatment}_i \times \textit{Post}$ has a coefficient of 0.140, which is close to the coefficient value of 0.142 in the corresponding baseline regression (column 3, Panel A, Table 3). This suggests that the endogeneity associated with firms' decisions to comply with the SEC 2010 rule, if any, would exert only a trivial impact on our main empirical inference; that is, the SEC rule is largely a regulatory shock that is exogenous to most firms.

5.2.2 Alternative treatment/control identification schemes

The potential endogeneity problem as discussed above is embedded in the possibility that, due to the judgments and incentives of managers when responding to the CCR disclosure requirement, firms in the treatment and control samples are influenced by a mix of exogenous and endogenous forces. In addition to our effort in the two-stage regression approach, we further explore this issue by more clearly identifying the treatment and control groups from three aspects.

In the first aspect, we note that the exogenous climate risk disclosure shock may have started to influence firms' CCR reporting practices before the official effective date of the SEC rule in 2010. This could be due to firms' proactive reporting decisions in anticipation of the disclosure regime change. As shown in Panel B of Fig. 1, the portion of CCR reporting in 10-Ks starts to exhibit a discernible increase from 2008, which means that some firms are affected by the prospective CCR disclosure rule

Table 8 Effects of CCR disclosures after controlling for managerial choice in response to the SEC 2010 rule

Panel A: Results of the first-stage regression about disclosure choice in response to the SEC 2010 rule	
	(1)
Dependent Variable	$(CCR\ Disclosure)_{i,Post}$
$Ln(Firm\ Size)_{i,Post}$	0.129***
	(19.29)
$ROA_{i,Post}$	−0.011
	(−1.40)
$Leverage_{i,Post}$	−0.003
	(−0.49)
$PPE_{i,Post}$	0.047
	(1.18)
$Sale\ Growth_{i,Post}$	0.009
	(1.02)
$Peer\ CCR\ Disclosure_{i,Post}$	11.165***
	(3.09)
$Natural\ Disaster_{i,Post}$	0.314***
	(14.35)
Intercept	−7.554***
	(−3.60)
Industry Fixed Effects	Included
Number of Observations	8,849
Pseudo R-Squared	0.177
Panel B: Results of the second-stage regression about the DiD effect after controlling for disclosure choice in response to the SEC 2010 rule	
	(1)
Dependent Variable	$Climate\ Change\ Practice_{i,t}$
$Treatment_i$	−0.024
	(−0.60)
Post	0.284***
	(6.69)
$Treatment_i \times Post$	**0.140****
	(2.32)
$Inverse\ Mills\ Ratio_i$	0.111
	(1.04)
$Controls_{i,t}$	Included
Industry Fixed Effects	Included
Number of Observations	3,665
R-Squared	0.216

Heckman two-stage treatment effect model is estimated, with Panels A and B reporting results for the first- and second-stage regressions, respectively. For the first-stage Probit regression, the dependent variable *CCR Disclosure* is an indicator variable that equals one if a firm discloses CCR information after the SEC 2010 rule and zero otherwise. Independent variables are defined as in Eq. (4a). In the second stage, baseline OLS regression is estimated for the dependent variable *Climate Change Practice* after controlling for the inverse Mills ratio obtained from the first-stage regression and other firm characteristic variables (collectively denoted by *Controls*), as in Eq. (4b). Details about the variable definitions are provided in Appendix C. The regression coefficients on all (Panel A) and key (Panel B) independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

change prior to its actual implementation, plausibly because of the high-profile investor petitions and congressional events promoting climate change reporting in 2007. According to our baseline identification strategy, these firms are classified as control firms because they already reported CCRs in 10-Ks before 2010. To the extent that these firms' early disclosure is the result of their reaction to the CCR disclosure regulation change, they could be considered as treatment firms.

To rectify the abovementioned potential misspecification problem, we follow Chhaochharia and Grinstein (2009) and reconstruct the treatment sample by including, in addition to those that are classified as treatment firms in our baseline framework (i.e., those that did not disclose CCR information before 2010 and only reported the information after 2010), firms that started to report CCRs 10-K filings on or after 2008 (specifically, in 2008 and 2009) but did not disclose relevant information before 2008. In other words, we expand the components of the treatment sample to more comprehensively identify the firms that are affected by the SEC CCR disclosure rule. The control sample is shrunk accordingly. Under this new identification scheme, we re-estimate our baseline regression in Eq. (1). The results reported in column 1 of Table 9 show that for *Climate Change Practice*$_{i,t}$ as the dependent variable, the coefficient on the key variable of interest *Treatment*$_i$ × *Post* continues to be significantly positive with a value (0.153) slightly larger than that (0.142) in the baseline model. Therefore our main conclusion endures.

In the second aspect, we consider the possibility that potential endogeneity could be more severe among treatment firms that did not immediately respond to the SEC 2010 rule but rather initiated their CCR reporting in 10-Ks after much procrastination. For example, Panel A of Fig. 1 shows that the percentage of CCR-disclosing firms continues to increase over the years after the SEC 2010 rule took effect. This implies that there are firms that started their initial CCR reporting after a nontrivial delay subsequent to the implementation of the rule. For these laggards, their choice to disclose CCRs under the rule is more likely to be influenced by endogenous considerations. In contrast, firms that responded promptly to the SEC 2010 rule by immediately reporting CCRs are less subject to endogeneity concerns; that is, the regulatory disclosure shock tends to be more exogenous to them. For this reason, focusing on promptly initiating firms in treatment/control identification can at least partially rectify potential endogenous disclosure choice problems. This scheme is also adopted in prior DiD studies, such as the work of Chhaochharia and Grinstein (2009).

Guided by this rationale, we limit our sample period to a shorter window of 2008–2012; that is, we only consider two years after the implementation year of the SEC 2010 rule and identify treatment firms only if they initiated their CCR reporting in 10-Ks during this short post-rule period. As discussed above, these firms have a higher likelihood of being shocked by the SEC disclosure rule that exogenously triggered their CCR reporting initiation. After constructing treatment and control firms within this constrained sample, we re-estimate the baseline regression for the dependent variable *Climate Change Practice*$_{i,t}$ and report the results in column 2 of Table 9. The results show that *Treatment*$_i$ × *Post* still carries a significantly positive coefficient, consistent with the baseline results.

In the third aspect, we revise our identification strategy for control firms by focusing on those that did not disclose any CCR information in 10-Ks throughout the whole sample period; that is, we take firms that did not report CCRs before the SEC 2010 rule

Table 9 DiD results under alternative treatment/control identification schemes

	Treatment sample additionally containing CCR disclosure initiation within 2008–2009	Constrained sample period of 2008–2012	Control sample containing firms without CCR disclosures in the whole sample period
	(1)	(2)	(3)
Dependent Variable	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Treatment$_i$	−0.021	−0.047	−0.097***
	(−0.53)	(−1.24)	(−2.75)
Post	0.269***	0.125***	0.148***
	(6.03)	(4.34)	(6.78)
Treatment$_i$ × *Post*	**0.153****	**0.084****	**0.253*****
	(2.56)	**(2.01)**	**(4.96)**
Controls$_{i,t}$	Included	Included	Included
Industry Fixed Effects	Included	Included	Included
Number of Observations	3,674	1,726	5,467
R-Squared	0.215	0.175	0.201

The baseline model of Eq. (1) is estimated for the dependent variable *Climate Change Practice* under alternative treatment/control identification schemes. In column 1, the treatment sample is expanded by additionally including firms that started to report CCRs in 10-K filings on or after 2008 (i.e., in 2008 and 2009) but did not disclose relevant information before 2008, and the control sample is shrunk accordingly. In column 2, the sample period is limited to a shorter window of 2008–2012. In column 3, control firms include those that did not disclose any CCR information in 10-Ks throughout the whole sample period. The key independent variable is the interaction term between the treatment firm indicator *Treatment* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables (collectively denoted by *Controls*) are controlled as in Eq. (1). Details about the variable definitions are provided in Appendix C. The regression coefficients on key independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

and maintained the same nonreporting practice after the rule. For these firms, the SEC rule does not entail any shocks to their CCR (non)disclosing behavior, and thus they can serve as the control sample for the DiD analysis. Moreover, the never-disclosing firms, although they could feature different characteristics relative to the disclosing firms, tend to be free from the concerns relating to the CCR disclosure rule (such as the choice of early or late compliance), presenting a clearer contrast to the treatment firms that need to devote much consideration to the SEC rule. This identification design thus helps facilitate our DiD analysis from an alternative perspective.

Using the newly constructed control sample, we report the re-estimated baseline regression results in column 3 of Table 9. The coefficient on *Treatment*$_i$ × *Post* is positive and highly significant (0.253; *t*-statistic = 4.96); its magnitude is much larger than that of the same coefficient (0.142) in the baseline model. This finding confirms our main DiD results and is consistent with the sharper contrast between treatment and control firms in this particular identification scheme.

5.3 Robustness tests for the main results

5.3.1 Parallel trends test

The validity of our DiD analysis hinges on the parallel trends assumption. To check whether this assumption is violated, in column 1 of Table 10, we follow Bertrand et al. (2004) and introduce several year indicators to track the effects of the SEC climate change disclosure rule before and after it became effective. Using the policy implementation year of 2010 as the threshold, we define an indicator variable *Year 0* that equals one for 2010 and zero otherwise. Similarly, we use *Year − 1* to indicate 2009, i.e., one year before the policy, and *Year − 2* to indicate 2008, i.e., two years before the policy. Further, we use an indicator variable *Year 1+* for the years subsequent to the policy, i.e., 2011 and beyond. The unspecified years are used as the reference period. We replace *Post* in Eq. (1) with these year indicators and interact them with $Treatment_i$. In the regression with $Climate\ Change\ Practice_{i,t}$ as the dependent variable, we find that the coefficient on the interaction term is insignificant when $Treatment_i$ is interacted with the indicators for the SEC rule implementation year and the two pre-rule years but becomes significantly positive when $Treatment_i$ is interacted with the post-rule timing indicator variable. This evidence implies parallel trends in environmental performance for treatment and control firms prior to the CCR disclosure rule. Moreover, the coefficient on $Treatment_i$ itself is insignificant, suggesting that there is no difference in environmental performance between treatment and control firms in the reference period. Therefore the difference in the real effects of climate change reporting between late (treatment) and early (control) disclosers is observed only after the disclosure rule is implemented.

5.3.2 Controlling for the real effects of environmental performance information

The outcome variable of our analysis—firms' climate change-related environmental performance—is publicly available (e.g., through the KLD dataset). Outside stakeholders should be sensitive to this information, and their reactions can feed back to inside managers and compel them to further improve their firms' future environmental performance. That is, the publication of environmental performance information could also have real effects via a similar external pressure mechanism, which could be confounded with the real effects resulting from the disclosure of CCRs.[23] To ensure that our main results documented in the baseline model are not driven by the confounding real effects, we specifically control for our sample firms' past environmental performances so that they have similar effects on future climate change-related activities. In this way, the potential real effects from environmental performance information, if any, are filtered out, and the remaining effects come mainly from the disclosure of CCR information under the SEC rule.

To do so, we calculate the average of $Climate\ Change\ Practice_i$ in the pre-period before the rule for each firm *i* and, within the main DiD framework, match firms in the treatment group with those in the control group with the closest pre-period average values. This approach generates a treatment sample and a control sample with similar

[23] We are grateful to the anonymous referee for bringing this issue to our attention.

Table 10 Robustness tests for the baseline model

	Multi-period dynamic approach	Treatment-control matched sample by past environmental performance	Deleting 2010	Controlling for firm fixed effects	PSM sample	Fully interacted model
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Treatment$_i$	−0.045	−0.058	−0.023		−0.049	−0.003
	(−0.98)	(−1.64)	(−0.95)		(−1.19)	(−0.15)
Post		0.305***	0.464***		0.278***	−0.751***
		(7.15)	(10.02)		(6.32)	(−6.44)
Treatment$_i$ × *Post*		**0.136****	**0.199*****	**0.078****	**0.170****	**0.122*****
		(2.18)	**(3.26)**	**(2.15)**	**(2.57)**	**(2.66)**
Treatment$_i$ × *Year*− *2*	0.031					
	(0.48)					
Treatment$_i$ × *Year*− *1*	−0.019					
	(−0.31)					
Treatment$_i$ × *Year 0*	0.007					
	(0.10)					
Treatment$_i$ × *Year 1+*	**0.194*****					
	(3.32)					
Controls$_{i,t}$	Included	Included	Included	Included	Included	Included
Controls$_{i,t}$ × *Post*						Included
Industry Fixed Effects	Included	Included	Included		Included	Included
Firm & Year Fixed Effects				Included		

Table 10 (continued)

	Multi-period dynamic approach	Treatment-control matched sample by past environmental performance	Deleting 2010	Controlling for firm fixed effects	PSM sample	Fully interacted model
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$	*Climate Change Practice*$_{i,t}$
Number of Observations	3,665	3,348	2,945	3,665	3,037	3,665
R-Squared	0.270	0.225	0.242	0.561	0.227	0.253

The dependent variable *Climate Change Practice* refers to the number of climate change strengths minus the number of climate change concerns. In column 1, the key independent variables are the interaction terms between the treatment firm indicator *Treatment* and the indicators for the implementation year of the SEC climate change disclosure rule, *Year 0*; one year before the rule, *Year − 1*; two years before the rule, *Year − 2*; and one year after the rule and beyond, *Year 1+*. Column 2 reports baseline results in a treatment-control matched sample according to past environmental performance. Column 3 reports baseline results after deleting the SEC rule implementation year of 2010. Column 4 reports results after controlling for firm fixed effects and year fixed effects. Column 5 presents baseline results in a PSM-screened sample. Column 6 reports results after futher controlling for the interaction terms between firm characteristic control variables and *Post*. Industry fixed effects are controlled in columns 1, 2, 3, 5, and 6. Firm characteristic variables (collectively denoted by *Controls*) are controlled as in Eq. (1). *Controls* in column 1 also includes the year indictor variables of *Year − 2* to *Year 1+*. Details about the variable definitions are provided in Appendix C. The regression coefficients on key independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry, firm, and year dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

prior climate change-related environmental performance.[24] Using this matched sample, we re-estimate the baseline DiD regression and report the results in column 2 of Table 10. The key variable of interest, $Treatment_i \times Post$, has a coefficient of 0.136 with a *t*-statistic of 2.18. This finding suggests that our main conclusion regarding the real effects of CCR disclosures holds after controlling for the effects of the publication of environmental performance.

5.3.3 Excluding 2010

To mitigate the noise in identifying 2010 as the post-period after the SEC rule of CCR reporting that was implemented in February of 2010, in column 3 of Table 10, we delete the 2010 10-K filing year to more clearly detect the pre- and post-rule change in *Climate Change Practice*. The results reveal that the coefficient on $Treatment_i \times Post$ is significantly positive, with a magnitude (0.199) larger than that (0.142) in the main test. Therefore any potential noise in the implementation year of the climate change disclosure policy has only a marginal impact on our inference about the real effects of CCR disclosures via accounting reports.

5.3.4 Controlling for firm fixed effects

In column 4 of Table 10, we control for firm fixed effects in the DiD analysis, which absorb differences in climate change behaviors and other time-invariant factors between the control and treatment firms. We also include year fixed effects to control for changes over time in risk disclosure that are likely to have similar effects on both early and late CCR disclosers. The results show that the key variable of interest, $Treatment_i \times Post$, has a positive coefficient of 0.078 that is significant (*t*-statistic = 2.15). Therefore, with firm and year fixed effects controlled, we obtain the same conclusion that the introduction of the SEC rule regarding CCR disclosure in 2010 leads to a significant improvement in firms' environmental performance.

5.3.5 Propensity score matching (PSM) analysis

In column 5 of Table 10, we redo our analysis using a PSM sample in which the treatment and control firms are more comparable on firm-specific covariates. This is to further alleviate the concern that the difference in firm environmental behaviors is driven by the difference in firm features rather than in CCR disclosure actions. We first estimate the probability of being a treatment firm, employing the same set of firm characteristic variables controlled in the main test. We then match each treatment firm to a benchmark control firm, using the nearest neighbor matching technique within 3% caliper. We find that, in the PSM sample, the key variable of interest, $Treatment_i \times Post$, maintains a significantly positive coefficient, suggesting that our main results are unlikely to be driven by differences in the specified firm characteristics between early and late CCR disclosers.

[24] Untabulated test results confirm that the difference in the pre-period average value of *Climate Change Practice* between the treatment and control groups is insignificant, with a *p*-statistic of 0.92.

5.3.6 Fully interacted model

In the baseline DiD model, we control for the influences on climate change-related dependent variables from firm characteristics, including firm size, market-to-book ratio, ROA, leverage, PPE, sales growth, firm age, and institutional ownership. To further capture potential nonlinearity in the associations between the firm characteristic variables and climate change performance across the pre- and post-rule periods, we additionally control for the interaction terms between the firm characteristic variables and *Post*. As shown in column 6 of Table 10, we find that the coefficient on our key variable of interest $Treatment_i \times Post$ remains significantly positive, suggesting that the real effects of CCR disclosures cannot be subsumed by pre-to-post changes in the associated effects of firm characteristics.

6 Real behaviors and environmental improvement: The case of GHG emissions

Our analysis has thus far documented evidence that CCR disclosures via accounting reports have a broad range of positive and negative impacts on corporate real behaviors associated with climate change. In a related vein, it is natural to ask the following question: has the situation concerning climate change really improved after CCR disclosures because of these real behavior changes? After all, an environmental improvement makes the real effects more meaningful. In the context of climate change, we expect that the disclosures should not only promote pro-environmental behaviors and depress anti-environmental behaviors but also result in better environmental conditions. We measure such environmental conditions using GHG emissions. GHG is the major contributor to climate change and global warming and thus has direct relevance to our analysis. We obtain firm-level GHG-related data from Trucost, including the quantity of emissions (denoted by *GHG Emissions*), the emission quantity scaled by revenue (denoted by *GHG Emissions Intensity*), and the direct external environmental impacts through a firm's own activities (denoted by *GHG Emissions Cost*), all in the natural logarithmic forms.

We retrieve annual GHG data for each sample firm in our study, and estimate the model below.

$$\begin{aligned} GHG_{i,t} = {} & \gamma_0 + \gamma_1 Treatment_i + \gamma_2 Post + \gamma_3 Treatment_i \times Post + \gamma_4 Ln(Sales)_{i,t} \\ & + \gamma_5 Ln(CAPX)_{i,t} + \gamma_6 Ln(INTAN)_{i,t} + \gamma_7 GMAR_{i,t} + \gamma_8 LEVG_{i,t} \\ & + Industry\ Fixed\ Effects + \varepsilon. \end{aligned} \tag{5}$$

The dependent variable $GHG_{i,t}$ refers to *GHG Emissions*, *GHG Emissions Intensity*, and *GHG Emissions Cost* measured for firm i in year t, which can be considered as an alternative proxy for the real effects. The independent variables, $Treatment_i$, *Post*, and their interaction term, are the same as defined in the baseline

model. We adopt a new set of firm-level control variables that can affect a firm's carbon emissions, following Griffin et al. (2017). $Ln(Sales)_{i,t}$, $Ln(CAPX)_{i,t}$, and $Ln(INTAN)_{i,t}$ refer to the natural logarithms of total sales, capital expenditures, and intangible assets, respectively, for firm i in year t. $LEVG_{i,t}$ is the ratio of long-term debt over total assets, and $GMAR_{i,t}$ indicates gross profit margin for firm i in year t.

The results in Table 11 show that the quantity, intensity, and cost of GHG emissions decrease significantly from the pre- to the post-rule period for treatment firms, relative to those for control firms during the same period. When $GHG\ Emissions_{i,t}$ is the dependent variable in column 1, the coefficient on $Treatment_i \times Post$ is negative and highly significant, with a magnitude of −0.253 (t-statistic =

Table 11 The impact of CCR disclosures on GHG emissions

Dependent Variable	(1) $GHG\ Emissions_{i,t}$	(2) $GHG\ Emissions\ Intensity_{i,t}$	(3) $GHG\ Emissions\ Cost_{i,t}$
$Treatment_i$	−0.184*	−0.166	−0.186*
	(−1.78)	(−1.63)	(−1.80)
Post	−0.158***	−0.165***	−0.092*
	(−3.15)	(−3.37)	(−1.82)
$Treatment_i \times Post$	**−0.253*** **	**−0.251*** **	**−0.265*** **
	(−3.45)	**(−3.61)**	**(−3.58)**
$Ln(Sales)_{i,t}$	0.783***	−0.222***	0.783***
	(11.88)	(−3.44)	(11.86)
$Ln(CAPX)_{i,t}$	0.145**	0.155***	0.147**
	(2.46)	(2.74)	(2.49)
$Ln(INTAN)_{i,t}$	0.014	0.012	0.014
	(0.67)	(0.60)	(0.68)
$GMAR_{i,t}$	0.013**	0.010	0.013**
	(1.97)	(1.58)	(2.01)
$LEVG_{i,t}$	0.372	0.343	0.403
	(1.32)	(1.27)	(1.43)
Intercept	7.004***	7.008***	−3.311***
	(21.78)	(22.56)	(−10.27)
Industry Fixed Effects	Included	Included	Included
Number of Observations	3,840	3,840	3,840
R-Squared	0.766	0.689	0.765

The dependent variables *GHG Emissions*, *GHG Emissions Intensity*, and *GHG Emissions Cost* refer to the natural logarithms of the quantity, intensity, and cost of carbon emissions, respectively. The key independent variable is the interaction term between the treatment firm indicator *Treatment* and the indicator for the period after the implementation of the SEC climate change disclosure rule *Post*. Firm characteristic variables are controlled as in Eq. (5). Details about the variable definitions are provided in Appendix C. The regression coefficients on independent variables are reported, followed by the robust t-statistics (in the parentheses) based on standard errors adjusted for heteroskedasticity. For brevity, the coefficients on the industry dummies are not reported. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively

−3.45). This magnitude is equivalent to 12% of the sample standard deviation (2.180, untabulated), which is economically meaningful as well. Similar observations are obtained in columns 2 and 3 for the cases of *GHG Emissions Intensity*$_{i,t}$ and *GHG Emissions Cost*$_{i,t}$, respectively. This evidence thus buttresses and enriches our earlier finding of the real effects of CCR disclosures reflected in corporate climate-related behaviors.

7 Conclusion

We investigate the real effects of risk disclosures via accounting reports. Our analysis focuses on a particular and important risk—climate change risk (CCR). We concentrate on corporate behaviors that are directly relevant to climate change, including a firm's positive environmental performance, which helps mitigate climate deterioration, and its negative performance, which worsens the environmental situation. We identify, as an exogenous shock, the SEC's rule in 2010 regarding CCR disclosures in Form 10-Ks. We apply a DiD design to examine the impacts of the change in risk disclosures on the change in real behaviors for treatment firms that were subject to a greater exogenous shock from the SEC rule, relative to control firms that experienced less of a shock. We find that, if firms disclose CCRs after the SEC rule but did not do so beforehand, they tend to take more proactive pro-environmental actions, including more efficient emissions management, stronger emissions reduction programs, and better environmental administration in the post-rule period. These firms also engage less in anti-environmental behaviors, such as violations of environmental regulations and becoming embroiled in climate change controversies (e.g., resistance to improved practices and criticisms from environmental activists). These effects persist in any specific climate change-related behavior that we identify. Overall, we document evidence suggesting that the disclosures of CCR via accounting reports entail real changes in the disclosing firms' behaviors or actions to address climate change.

Consistent with the notion that CCR disclosures increase external pressures regarding a firm's climate change-related activities, we find that the real effects of CCR disclosures are more prominent in disclosing firms funded by climate-minded banks that tend to incorporate carbon concerns into the design and execution of corporate financing. The effects are also more pronounced for firms in industries that are vulnerable and sensitive to CCRs. We further find that CCR disclosures drive down the quantity, intensity, and cost of GHG emissions, implying that the improved climate change behaviors lead to a desirable outcome of a better environment.

Our investigation is facilitated by the unique feature of climate change and related risks that has drawn considerable attention from government regulators and private organizations, which allows us to investigate specific climate change behaviors and climate-sensitive situations. Our results concerning the real effects of CCR disclosures on the disclosing firms' environment-related actions supplement prior findings of the capital or product market effects of risk disclosures. The evidence regarding the role of external pressures buttresses the theoretical predictions about the real effects of accounting disclosures that emphasize the

importance of feedback from information receivers to information senders. Moreover, the promotion of environment-improving activities and reduction of GHG emissions post the SEC disclosure rule not only highlight an essential function of financial reporting in influencing real economic activities but also provide evidence in support of government regulation aiming to address climate change.

Appendix A Examples of climate change-related risk disclosures in 10-Ks

Goodyear Tire & Rubber Co., 2011 10-K

In addition, our manufacturing facilities may become subject to further limitations on the emission of "greenhouse gases" due to public policy concerns regarding climate change issues or other environmental or health and safety concerns. While the form of any additional regulations cannot be predicted, a "cap-and-trade" system similar to the one adopted in the European Union could be adopted in the United States. Any such "cap-and-trade" system (including the system currently in place in the European Union) or other limitations imposed on the emission of "greenhouse gases" could require us to increase our capital expenditures, use our cash to acquire emission credits or restructure our manufacturing operations, which could have a material adverse effect on our operating results, financial condition and liquidity.

Sanderson Farms, Inc., 2013 10-K

Various factors can affect the supply of corn and soybean meal, which are the primary ingredients of the feed we use. In particular, global weather patterns, including adverse weather conditions that may result from climate change, the global level of supply inventories and demand for feed ingredients, currency fluctuations and the agricultural and energy policies of the United States and foreign governments all affect the supply of feed ingredients. Weather patterns often change agricultural conditions in an unpredictable manner. A sudden and significant change in weather patterns could affect supplies of feed ingredients, as well as both the industry's and our ability to obtain feed ingredients, grow chickens or deliver products.

United Parcel Service Inc., 2014 10-K

Moreover, even without such legislation or regulation, increased awareness and any adverse publicity in the global marketplace about the GHGs emitted by companies in the airline and transportation industries could harm our reputation and reduce customer demand for our services, especially our air services.

Appendix B Algorithm of CCR information collection from 10-Ks

We download 10-K reports of all sample firms from the EDGAR database from the fiscal years 2005 to 2015. Following Campbell et al. (2014) and Hope et al. (2016), we

identify the risk factor item using specific HTML tags. However, the disclosure of CCRs does not have item heading, presenting a challenge in identifying the location of CCR-related information. We use a three-step approach to overcome this challenge. First, we summarize the regularity of CCR disclosures by examining 600 randomly selected firms (200 from each year of 2010–2012, the first three years after the SEC rule) based on visual inspection. We identify 64 keywords relevant to firm disclosures of CCR, as listed in Table 12.

In the second step, we validate the CCR reporting regularity using out-of-sample checking. To do so, we randomly choose 20 firms each year from our full 11-year sample period and manually collect CCR information in their risk factor disclosures in 10-Ks. At the same time, we employ a textual analysis algorithm to extract the related CCR information. The algorithm scans the full text of the risk factor portion in Form 10-Ks to search for the CCR keywords in Table 12; when any of the keywords is detected in a particular sentence, the algorithm extracts all CCR information from the whole sentence. We then compare the algorithm extraction with the manual collection and find that our algorithm extracts the only and correct subsections from 10-Ks in over 97.7% of the selected cases.

Based on the validated regularity, in the third step, we apply our textual analysis algorithm to extract CCR disclosures from all years' 10-Ks for all firms to generate a comprehensive dataset.

Table 12 Keywords of CCR disclosures in 10-Ks

adverse weather	climate control initiative(s)	extreme climate(s)	regulatory initiative(s)
cap and trade	climate initiative(s)	extreme temperature(s)	regulatory risk(s) from climate change
carbon dioxide	climate legislation(s)	extreme weather	rising temperature(s)
changing climate(s)	climate registr(y) (ies)	GHG(s)	Sea level(s)
clean air act	climate regulation(s)	global warming	tailoring rule
climate challenge(s)	climate risk(s)	greenhouse gas emissions legislation(s)	Title V
climate change	climate statute(s)	greenhouse gas(es)	United Nations Framework Convention on Climate Change
climate change laws	climate-change	indirect effect(s)	unseasonably warm weather
climate change legislation(s)	climate-change proposal(s)	indirect regulatory risks	unusual weather
climate change registr(y) (ies)	climate-related initiative(s)	indirect risks from climate change	volatility in seasonal temperature(s)
climate change regulation(s)	CO^2	Kyoto protocol	warm weather
climate change risk(s)	controls on emission(s)	methane	warmer than normal winter(s)
climate change statute(s)	cooler than normal summer(s)	physical risk(s) from climate change	warmer weather
climate change treat(y) (ies)	emission(s) initiative(s)	reduction(s) of the emission(s)	warming of the climate
climate condition(s)	emission(s) standard(s)	regulation risk(s) from climate change	weather concern(s)
climate control	EU ETS	regulation(s) related to climate change	weather pattern(s)

This table lists 64 CCR-related keywords that we identify from the risk factor disclosures in 10-Ks

Appendix C Variable definitions

Variable name	Definition and construction
Variables for Aggregate Climate Change-Related Behaviors	
Climate Change Strength$_{i,t}$	Number of climate change strengths for firm i in year t, i.e., the sum of the following positive performance indicator variables as defined below: *Emissions Management*, *Carbon Reduction*, and *Environmental Administration*. Source: KLD STATS.
Climate Change Concern$_{i,t}$	Number of climate change concerns for firm i in year t, i.e., the sum of the following negative performance indicator variables as defined below: *Environmental Violation* and *Climate Change Controversy*. Source: KLD STATS.
Climate Change Practice$_{i,t}$	Number of climate change strengths minus number of climate change concerns (as defined below) for firm i in year t, with higher values indicating eco-friendlier corporate behaviors related to climate change. Source: KLD STATS.
Variables for Specific Positive Climate Change-Related Behaviors	
Emissions Management$_{i,t}$	Indicator variable that equals one if a company has strong programs to manage its risk of incurring liabilities associated with pollution, contamination, and the emissions of toxic and carcinogenic substances, and performs well in reducing the emissions and zero otherwise. The variable is defined for each firm i in year t. Source: KLD STATS.
Carbon Reduction$_{i,t}$	Indicator variable that equals one if a company makes strong efforts to manage the risks of increased costs linked to carbon pricing or regulatory caps, to increase the carbon efficiency of its facilities, to proactively invest in low-carbon technologies, and to reduce exposure through comprehensive carbon policies and implementation mechanisms, including carbon reduction targets, production process improvements, installation of emission capture equipment, and/or switching to cleaner energy sources and zero otherwise. The variable is defined for each firm i in year t. Source: KLD STATS.
Environmental Administration$_{i,t}$	Indicator variable that equals one if a company has an environmental management system in place, and it is certified by a third-party standard, such as ISO 14001, and zero otherwise. The variable is defined for each firm i in year t. Source: KLD STATS.
Variables for Specific Negative Climate Change-Related Behaviors	
Environmental Violation$_{i,t}$	Indicator variable that equals one if a company has substantial payments in settlements, fines, or penalties due to noncompliance with U.S. environmental regulations, including the following nine major federal environmental health and safety laws: Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); Toxic Substances Control Act (TSCA); Endangered Species Act (ESA); Clean Water Act (CWA); Safe Water Drinking Act (SWDA); Resource Conservation and Recovery Act (RCRA); Clean Air Act (CAA); Atomic Energy Act (AEA); and Mine Act (MA) and zero otherwise. The variable is defined for each firm i in year t. Source: KLD STATS.
Climate Change Controversy$_{i,t}$	Indicator variable that equals one if a company has severe controversies related to its climate change and energy-related policies and initiatives, including a history of involvement in GHG-related legal cases, widespread or egregious impacts due to corporate GHG emissions, resistance to improved practices, and criticism by nongovernmental organizations and/or other third-party observers and zero otherwise. The variable is defined for each firm i in year t. Source: KLD STATS.

(continued)

Variable name	Definition and construction
DiD Method Variables in the Baseline Model	
$Treatment_i$	Indicator variable that equals one if firm *i* discloses climate change risk in 10-Ks starting from 2010, and equals zero if the firm already disclosed relevant information in 10-Ks before 2010 and continued to do so after 2010. Source: EDGAR.
Post	Indicator variable that equals one if the firm-year falls in the post-period (2010–2015) for the SEC climate change disclosure rule and zero otherwise.
Control Variables in the Baseline Model	
$Ln(Firm\ Size)_{i,t}$	Natural logarithm of total assets in million US$ for firm *i* in year *t*. Source: Compustat.
$MB_{i,t}$	Market-to-book ratio for firm *i* in year *t*. Source: Compustat.
$ROA_{i,t}$	Pre-tax income scaled by total assets for firm *i* in year *t*. Source: Compustat.
$Leverage_{i,t}$	Ratio of short-term debt and long-term debt scaled by total assets for firm *i* in year *t*. Source: Compustat.
$PPE_{i,t}$	Gross property, plant and equipment scaled by total assets for firm *i* in year *t*. Source: Compustat.
$Sale\ Growth_{i,t}$	Growth rate in sales for firm *i* in year *t*. Source: Compustat.
$Firm\ Age_{i,t}$	Number of years since firm *i* appears in Compustat until year *t*. Source: Compustat.
$IO_{i,t}$	Portion of institutional ownership for firm *i* in year *t*. Source: Compustat.
Sample Partitioning Variables in the Tests of the Roles of External Pressure and Internal Carbon Sensitivity	
High External Pressure	Indicator variable that equals one if a company has at least one socially responsible lending bank (or the lead bank in a loan syndicate) in the last five years and zero otherwise. Socially responsible banks refer to those that adopt one of the following major climate-related principles: the Equator Principles, the Carbon Principles, and the Climate Principles. Sources: https://equator-principles.com, https://www.banktrack.org.
High Internal Carbon Sensitivity	Indicator variable that equals one if a company is in the following climate-sensitive industries and zero otherwise: agriculture, healthcare, pharmaceutical products, automobiles and trucks, construction, mines, coal, oil, communication, business services, and transportation. Source: Fama and French (1997).
Variables in Further Analyses	
CAR[−2,+2]	Five-day (from two days before to two days after the 10-K filing date) cumulative abnormal return (buy-and-hold stock return minus market return). Source: Center for Research in Security Prices.
$Initial\ CCR\ Disclosure_{i,t}$	Indicator variable that equals one if firm *i* is mandated to initiate its first disclosure of CCR information in the 10-K filing in year *t* in the post-rule period and zero before the initial CCR disclosure. Source: EDGAR.
$Ln(MVE)_{i,t}$	Natural logarithm of market value of equity (year-end stock price times common stock shares outstanding) in million US$ for firm *i* in year *t*. Source: Compustat.
$CCR\ Index_{i,t}$	Number of CCR-related keywords as listed in Table 12 for firm *i* in year *t*. Source: EDGAR.
$CCR\ Disclosure_{i,Post}$	Indicator variable that equals one if a firm discloses CCR information in 10-Ks post the SEC 2010 rule and zero otherwise. Source: EDGAR.
$Peer\ CCR\ Disclosure_{i,Post}$	The average of $CCR\ Disclosure_{i,Post}$ (defined above) among all other firms in the same industry that firm *i* belongs to for the post-period. Source: EDGAR.

(continued)

Variable name	Definition and construction
Natural Disaster$_{i,Post}$	The mean of yearly subsidiary-weighted number of natural disasters computed for the post-period for firm *i*. Information about the dates and locations of climate change-related natural hazard events is retrieved from SHELDUS, and subsidiaries' information for all sample firms is from Dyreng et al. (2013). We match the subsidiaries' locations with the sites of natural disasters and then compute the subsidiary-weighted number of natural disasters for each year, scale it by 100, and take the average in the post-period. Sources: SHELDUS, Dyreng et al. (2013)
Variables in the Test of the Relation between CCR Disclosure and GHG Emissions	
GHG Emissions$_{i,t}$	Natural logarithm of carbon emissions in metric tons for firm *i* in year *t*. Source: Trucost.
GHG Emissions Intensity$_{i,t}$	Natural logarithm of the ratio of GHG emissions over revenue for firm *i* in year *t*. Source: Trucost.
GHG Emissions Cost$_{i,t}$	Natural logarithm of direct external environmental impacts for firm *i* in year *t*, i.e., the monetary value of those impacts that the firm has on the environment through its own GHG emissions. Source: Trucost.
Ln(Sales)$_{i,t}$	Natural logarithm of total sales in million US$ for firm *i* in year *t*. Source: Compustat.
Ln(CAPX)$_{i,t}$	Natural logarithm of capital expenditures in million US$ for firm *i* in year *t*. Source: Compustat.
Ln(INTAN)$_{i,t}$	Natural logarithm of intangible assets in million US$ for firm *i* in year *t*. Source: Compustat.
LEVG$_{i,t}$	The ratio of long-term debt scaled by total assets for firm *i* in year *t*. Source: Compustat.
GMAR$_{i,t}$	Gross profit margin calculated as one minus the ratio of cost of goods sold over total sales for firm *i* in year *t*. Source: Compustat

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