The Real Effects of Carbon Disclosure: Evidence from the U.S. Greenhouse Gas Reporting Program

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Abstract: Exploiting a quasi-natural experiment of the U.S. Greenhouse Gas Reporting Program (GHGRP) in a difference-in-differences setting, we examine whether carbon disclosure affects real corporate behaviors in terms of emissions reduction and other reduction-related initiatives. We document that mandatory reporting firms significantly reduce carbon emissions subsequent to the GHGRP, relative to non-reporting peers. The effect is stronger for firms with higher carbon regulation risk, enhanced carbon governance, more environmentally responsible investors, and greater public pressure. Reporting firms are more likely to adopt carbon-curbing schemes, improve pollution management, and shun negative carbon practices, which helps explain the real effects of carbon disclosure on carbon emissions.

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1. Introduction

Corporate economic activities are a major source of greenhouse gas (GHG) emissions (a.k.a. carbon emissions) that contribute to climate change and global warming. With the threat of climate change looming larger, increased carbon awareness has triggered a tendency toward requiring corporations to disclose their GHG emissions. Jurisdictions around the world and some non-governmental organizations (NGOs) have initiated various carbon disclosure programs. This trend of information disclosure is unprecedented and unique to carbon emissions, and has significantly changed the business landscape. It is therefore important to understand the impacts of carbon reporting on corporate behaviors. Accordingly, this paper examines the *real* effects of compulsory GHG disclosure, referring to "situations in which the disclosing person or reporting entity changes its behavior in the real economy as the result of the disclosure mandate" (Leuz and Wysocki 2016, 530). Specifically, we investigate whether mandatory carbon disclosure drives companies to take environment-friendly actions that reduce the level of carbon emissions.[1]

We exploit the Greenhouse Gas Reporting Program (GHGRP) introduced in 2009 by the Environmental Protection Agency (EPA), which requires emitting sources above certain levels to report GHG emissions at the facility level—a first time in the U.S. The mandatory nature of the GHGRP with strict enforcement and the highly granular information it collects support sound, data-driven policy decisions on climate change, exposing carbon emitters to regulatory risk. Meanwhile, facility-level data allow better monitoring of GHG emissions (e.g., via identifying the

[1] Our investigation is particularly timely given the series of carbon information-killing actions taken by the Trump administration. For example, in January 2017, the administration instructed the Environmental Protection Agency to remove from its website the climate change page containing links to global warming research and emissions data; in March 2017, it withdrew the Information Collection Request requiring disclosure about methane (one of the most potent GHGs) and other harmful emissions from oil and gas companies; in May 2018, it stopped funding the National Aeronautics and Space Administration's Carbon Monitoring System (https://www.reuters.com/article/us-usa-trump-epa-climatechange/trump-administration-tells-epa-to-cut-climate-page-from-website-sources-idUSKBN15906G, https://www.sciencemag.org/news/2018/05/trump-white-house-quietly-cancels-nasa-research-verifying-greenhouse-gas-cuts, https://www.epa.gov/newsreleases/epa-withdraws-information-request-oil-and-gas-industry). Exploring the potential impacts of carbon disclosure on carbon emissions helps assess these governmental movements.

exact locations of emission sources) by various stakeholders (investors, creditors, local community, media, etc.) and facilitate environmental litigation. The detailed, comparable information about other nearby facilities also enables firm managers to seek opportunities for clean technology and energy efficiency. Envisioning these consequences, reporting firms may take preemptive actions to reduce carbon emissions.

However, the strength of the above mechanisms is an empirical issue. Mandatory disclosure may diminish the carbon improvement motives because firms are unable to showcase their pro-environment efforts as in a voluntary disclosure scheme. Detailed disclosure through the GHGRP could discourage informed trading in the financial markets, which attenuates the usefulness of market price for managerial decision-making in carbon reduction investments. Moreover, when going green is financially costly and operationally burdensome, firms may merely conform to the disclosure mandate without any corporate activities promoting carbon mitigation. Overall, the question of whether and how the GHGRP alters a firm's emitting behaviors cannot be unambiguously predicted a priori.

The GHGRP applies only to facilities with carbon emissions exceeding a certain reporting threshold, which provides an ideal regulatory setting for applying a difference-in-differences (DiD) analysis. The mandate can be viewed as a carbon disclosure-related exogenous shock to GHG reporters, but not to non-reporters. Taking advantage of this quasi-natural experiment, we compare the change in corporate carbon emission quantity around the GHGRP's implementation between mandatory reporting firms and non-reporting firms. Our analysis focuses on firm-level emissions behavior because climate change issues (including carbon reduction plans) are normally addressed at the general strategic level of a corporation (Kolk and Pinkse 2005; Hoffman 2007; Lee 2012). Firm carbon emissions are also a fair reflection of facility emissions; firm-level emissions are

closely related to the carbon efficiency within the operations of the firm's facilities (Liu et al. 2012). Moreover, we are able to obtain firm-level emissions data for both the pre- and post-GHGRP periods that facilitate our DiD analysis. These data come from the Carbon Disclosure Project (CDP) and adequately serve our research purpose by reflecting corporate carbon performance. We emphasize that, the data that the EPA requires are substantially different from the CDP data, although both are regarding carbon disclosure. This ensures that the GHGRP can be viewed as an informational shock to various stakeholders even when the CDP information is available.

We find a significant decrease in the quantity of carbon emissions from the pre- to the post-GHGRP period for reporting firms, compared to the change over the same period for non-reporting firms. The decreasing trend also holds when we scale the emission quantity by firm size. These effects survive numerous robustness tests: in particular, they are neither driven by the aftermath of the 2008–2009 global financial crisis (GFC) nor subsumed by other concurrent climate initiatives such as the Securities and Exchange Commission (SEC)'s guidance on climate change risk disclosure. Moreover, we expand our analysis to 25 countries that have adopted similar GHG disclosure mandates, and find that the emissions-reducing effect of carbon disclosure is also evident in the international setting. Collectively, these results suggest that mandatory disclosure of carbon emissions has material real effects on firms' emitting behaviors that mitigate GHG pollution and curb global warming.

We further find that the real effects of the GHGRP hinge on the levels of regulatory risk, corporate carbon governance, and external pressure. Specifically, the disclosure requirement is associated with a more substantial reduction in carbon emissions among firms that (i) face larger regulatory (climate change) risk; (ii) have better corporate governance to oversee climate change issues; (iii) have more sustainable and environmentally responsible investors; and (iv) face local

public pressure to restrain global warming. This evidence reinforces that the policy expectation and granular information brought by the GHGRP incentivize firms to improve environmental performance and cut emissions when facing increased regulatory risks and heightened concerns from various stakeholders.

We also examine the green initiatives taken by firms in response to the mandatory GHG reporting requirement. We find that in the post-GHGRP period, relative to non-reporting firms, reporting firms are more likely to adopt strong GHG reduction plans, enhance pollution management, and refrain from negative carbon practices. These activities constitute additional real effects of carbon disclosure, and reveal the channels through which carbon reporting reduces carbon emissions. Moreover, as another outcome of carbon disclosure, reporting firms show more environment-related social responsibility and commit fewer environmental regulation violations than their non-reporting peers.

This paper adds to extant studies on the real effects of environment-related disclosure policies, including the Toxics Release Inventory (TRI) program (Bui and Mayer 2003; Hamilton 2005) and the mine safety disclosure mandate under the Dodd-Frank Act (Christensen et al. 2017), both in the U.S., and China's corporate social responsibility (CSR) disclosure policy (Chen et al. 2018). Our study provides relevant but distinctive evidence from the perspective of carbon emissions. In the multidimensional construct of environmental protection, carbon pollution differs from specific toxic substances and safety issues and the overarching concept of CSR in that it causes climate change (Lash and Wellington 2007), which has become the gravest threat to human beings (IPCC 2013), engendering tremendous economic loss.[2] The threat, although devastating, is not perspicuous. Unlike mine injuries and toxic pollutants that can be more easily imagined and

[2] Economically, climate change may cause a 1 percent to 3.3 percent reduction in global GDP by 2060 (OECD 2015).

comprehended (or even witnessed), climate change has ill-defined risks and its assessment involves significant uncertainty (Matsumura et al. 2014). For carbon emissions, education helps trigger thought and reflection in which information disclosure plays a critical role, especially where climate change attracts massive political and public attention. The whole international community has devoted considerable effort to advocating knowledge about climate change, and this international effort is unique to carbon emissions.[3] Our study confirms that carbon disclosure schemes such as the GHGRP—that are initiated and mandated by the government and require reporting entities to identify specific emission sources—play a critical role in reducing carbon emissions and combating climate change. Our study also provides fresh insights into the mixed empirical evidence on the effectiveness of disclosure-based regulations on specific pollutants (e.g., toxics release), and addresses the fundamental question of how governmental intervention affects pollution levels (Pigou 1920; Coase 1960).[4, 5]

By examining carbon disclosure's real effects on firm behaviors, our work supplements previous research on carbon emissions' impact in the capital market. Matsumura et al. (2014) and Griffin et al. (2017) find that the stock market penalizes firms with higher carbon emissions, and that non-disclosing firms face an additional penalty. These market effect studies are conducted within a voluntary reporting framework.[6] In contrast, our research is based on a mandatory

[3] For example, the United Nations Framework Convention on Climate Change (UNFCCC) was initiated in 1992 to limit global temperature increase via reducing anthropogenic emissions of CO_2 and other GHGs. The Kyoto Protocol sets legally binding emissions reduction targets for the international community with effect from 2008, and the Paris Agreement of 2015 further specifies a goal to limit the global average temperature increase to below 2°C above pre-industrial level. Refer to https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en.

[4] Hamilton (2005) documents evidence that TRI spurs reductions in toxics release, which challenges the findings of Bui and Mayer (2003).

[5] In a study of the rationales for carbon reporting, Tang and Demeritt (2018) compare the carbon emissions of a small sample of U.K. firms in four industries between the first and second years (i.e., 2014 and 2015) after the U.K. mandated GHG disclosure in financial reports in 2013. Since they only focus on the time-series trend of overall emissions after the statutory disclosure requirement was introduced, their empirical method is not specifically designed to examine the effect of carbon disclosure on carbon emissions.

[6] There is also a large body of research examining how environmental performance influences voluntary environmental disclosure (e.g., Ingram and Frazier 1980; Wiseman 1982; Freedman and Wasley 1990; Fekrat et al. 1996; Patten 2002; Meng et al. 2014).

reporting arrangement that enables clear identification of the disclosure's impact. We also explore the influence of carbon emission reporting on internal managers, not the external market. As such, this study contributes to a more comprehensive understanding of the effects of GHG disclosure regulation.[7]

2. Institutional background and conceptual framework

2.1. Institutional background—the U.S. GHGRP

The GHGRP, launched by the EPA on December 29, 2009, sets criteria for mandatory reporting of GHG emissions in all sectors of the U.S. economy. As the first legally binding carbon disclosure mandate in the U.S., the GHGRP represents a milestone in the nation's GHG management history. Before the GHGRP, the U.S. government did not take a particularly proactive approach to regulating GHG. The concerned parties thus initiated legal efforts to require the EPA to regulate GHG through the Clean Air Act (CAA), leading to the birth of the GHGRP.[8] The legislation process garnered considerable public attention; the EPA held two public hearings and more than 150 meetings with industries, investors, state and regional governments, and environmental groups, and received more than 16,000 written comments as compiled in 40 volumes with accompanying EPA responses.[9]

The GHGRP requires the disclosure of seven types of GHGs that are largely consistent with the coverage of the UNFCCC and Kyoto Protocol and the Scope 1 (direct) emissions as categorized

[7] One set of studies examines the government-initiated mandatory disclosures of some particular pollution problems, such as SO_2 (Hughes 2000; Johnston et al. 2008), water pollution (Cormier and Magnan 1997), and TRI (Connors et al. 2013). However, these studies focus on the market-value relevance of environmental disclosures, rather than their real effects on firms' emission activities.
[8] The U.S. did join the UNFCCC in 1992 and subsequently signed the UNFCCC-led Kyoto Protocol in 1997. However, the Congress has never ratified the Kyoto Protocol. Refer to http://4cleanair.org/Documents/Background_and_History_%20EPA_Regulation_GHGs-Aug2013-post.pdf and http://www.nytimes.com/2007/04/03/washington/03scotus.html?pagewanted=all.
[9] See https://www.jonesday.com/en/insights/2009/10/us-epa-announces-final-rules-for-mandatory-greenhouse-gas-reporting and EPA (2012).

by the Greenhouse Gas Protocol.[10] GHG quantities are measured and reported for each facility, rather than for each firm.[11] The program generates detailed data linked to an individual facility, including facility address (city and state), latitude and longitude coordinates, industry classification code, emissions information for the selected year, emissions trend over multiple years, and total facility emissions in metric tons of CO_2 equivalent (CO_2e).

Reporting under the GHGRP is mandatory, but only for large direct emitters and suppliers of fuel and industrial GHG, with the threshold of 25,000 metric tons of CO_2e per year. The reporting requirement was implemented in two stages: in the first stage, 29 categories of sources were required to disclose their GHG emissions for reporting year 2010; and in the second stage, 12 other categories of sources were added for reporting year 2011.[12]

The EPA applies strict measures to monitor and enforce the GHGRP. Combining direct measurement and facility-specific calculations, the monitoring requires both self-certification and EPA verification.[13] To facilitate enforcement, the EPA issues administrative compliance and penalty orders, and brings civil or criminal actions. Specifically, the EPA may seek injunctive relief to compel compliance, and is authorized to issue penalties of up to US$37,500 per day of violation, up to a maximum amount of US$290,000, for civil judicial violations, and pursue higher penalties

[10] The seven types of GHGs are Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF_3), and sulfur hexafluoride (SF_6) (EPA 2009). Scope 1 emissions are direct GHG emissions that occur from sources that are controlled or owned by an organization (https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance, https://www.wri.org/initiatives/greenhouse-gas-protocol).

[11] According to the final rule of the GHGRP, "facility means any physical property, plant, building, structure, source, or stationary equipment located on one or more contiguous or adjacent properties in actual physical contact or separated solely by a public roadway or other public right-of-way and under common ownership or common control, that emits or may emit any greenhouse gas" (EPA 2009, 56260).

[12] For details of these categories, refer to https://www.epa.gov/sites/production/files/2016-03/documents/epa_greenhouse_gas_reporting_program_and_publication_tool_overview.pdf.

[13] Specifically, each facility must establish a written plan describing the processes and methods used for data collection and identify the responsible personnel. After self-certified emissions data are submitted, the EPA conducts a centralized review process to ensure completeness and accuracy, which includes assessing facility monitoring plans and procedures, checking trends by utilizing historical submissions, and comparing against similar facilities to detect anomalies and outliers. If potential discrepancies or errors are detected, the EPA follows up with relevant facilities and conducts on-site audits if necessary. By 2016, there had been over 12,500 checks of GHGRP data (McIntosh 2016). Moreover, each reporter is required to retain and make available relevant records for three years for future verification.

and imprisonment for criminal violations (EPA 2009).

Data collected via the GHGRP are disclosed in a simple, transparent manner in the EPA's Facility Level Information on GreenHouse gases Tool (FLIGHT), which allows the public to view key data elements by facility, industry, location, or gas. The FLIGHT features time-series display, and can locate reporting facilities on searchable computerized national or regional maps. The FLIGHT's Bubble Map also provides a visual representation of the location and magnitude of each facility's GHG emissions relative to one another. The FLIGHT is designed to leverage social media, and assists information sharing using common inter-operable data exchange standards and infrastructure such as eXtensible Markup Language and geographic identifiers.

In sum, the GHGRP sets up a comprehensive, state-of-the-art system for collecting accurate, complete, consistent, and easy-to-use GHG emissions information at the facility level, which is ensured by careful monitoring and stringent enforcement. The CO_2e threshold effectively differentiates companies into reporting and non-reporting groups, providing an appropriate situation for identifying the economic consequences induced by the GHGRP.

2.2. Conceptual development

As indicated above, there has been considerable interest in the data collected via the GHGRP and the material impacts of these data on business, suggesting the importance (and novelty) of the GHGRP even with the existence of other carbon disclosure arrangements.[14] The GHGRP is distinctive because it is government-initiated and imposes a compulsory reporting requirement for carbon emissions at a disaggregate (specifically, facility) level.

2.2.1. Reasons why the GHGRP may have carbon-reducing effects

First, the GHGRP's significance is manifested in its clear policy implication. The EPA

[14] Before the GHGRP there were carbon reporting schemes at aggregate (i.e., non-facility) levels, such as the National Greenhouse Gas Inventories and the voluntary reporting of firm-level emissions to some NGOs (e.g., the CDP).

explicitly states that the "Goal of GHGRP is to collect accurate and timely data on GHG emissions to inform future policy decisions" (EPA 2012, 5). International experience suggests that carbon disclosure mandates pave the way for further carbon legislation. For instance, Japan mandated emission disclosure in 2006 and then initiated a cap-and-trade scheme in 2010; Australia implemented its mandatory carbon reporting program in 2008, and subsequently introduced carbon tax regulation in 2012 (Grewal et al. 2019). Similarly, the GHGRP was rooted in a comprehensive congressional consideration of climate policies, generating expectation of governmental actions to curb global warming.[15] Facility-level emissions data, as those collected by the GHGRP, have been shown to form the backbone of cap-and-trade systems (such as the EU Emissions Trading Scheme) and carbon taxation (WRI and WBCSD 2004; Kauffmann et al. 2012). The EPA (2009, 56273) believes that "corporate reporting without facility-specific details would not provide sufficient data to assess many potential CAA GHG policies and programs." Prior research also shows that facility-level information is useful for more precisely pricing environmental risk, such as the shadow price (e.g., Thieriot and Tan 2016). As such, the GHGRP is clearly a linchpin for future climate change rules. Shortly after the GHGRP data became available, several states expressed their interest in the database for pollution control purposes.[16] These movements present an obvious regulatory risk to carbon-emitting firms, and "it is hard to view [the GHGRP] as anything other than an intentional effort to lay the groundwork for [future climate policy]" (Richardson 2012, 3).

Second, the facility-level sources of carbon emissions as revealed by the GHGRP are valuable information for the decision making of various stakeholders because environmental problems have

[15] Shortly after the GHGRP's launch at the end of 2009, the House of Representatives passed the Waxman–Markey Bill in June 2010, which aimed to create a nationwide cap-and-trade system but ultimately failed in the Senate. Refer to http://www.motherjones.com/politics/2010/03/waxman-markey-senate-climate-kerry-graham-lieberman.

[16] These states include Iowa, Washington, New Mexico, North Carolina, New Jersey, and Massachusetts. For details, refer to https://www.epa.gov/sites/production/files/2016-03/documents/epa_greenhouse_gas_reporting_program_and_publication_tool_overview.pdf.

a strong geographic connotation. Prior research (e.g., Epstein and Palepu 1999; Hope and Thomas 2008) suggests that failure to disclose information at a less aggregated geographic level hinders the shareholders' ability to monitor corporate actions. Clearly identifying a particular polluter enhances transparency and accountability. In an environmental survey conducted by the Water-Energy-Climate Nexus, 90 percent of investors reiterate the need for information at the project or facility level (Thieriot and Tan 2016). The investment industry has emphasized the importance of facility-level carbon information that "could greatly assist investors in assessing the climate-related risk of portfolio companies" (Social Investment Forum 2008, 1). Carbon-conscious creditors, such as banks adopting the Equator Principles and lenders following the Green Bond Principles, also base their funding decisions on facility- or project-level carbon emissions.[17]

The disclosure of precise locations of emission sources empowers local communities, which can potentially exercise great influence over emitting facilities' (and their parent companies') carbon performance. Geographic proximity affects the externality associated with carbon emissions; physical closeness to a polluter increases local agents' internalization of the pollution, which could trigger activist campaigns and exacerbate community resistance (Gillan and Starks 2000). The World Bank, in a series of studies, has found that civic engagement impacts individual facilities and corporate environmental performance (Pargal and Wheeler 1995; Hartman et al. 1997; Pargal et al. 2002). Kitzmueller and Shimshack (2012) argue that environmental initiatives are rooted in pressures and norms within geographic communities; Kim et al. (2019) show that local institutional ownership is negatively related to a facility's environmental damage; Sulaeman and Varma (2018) suggest that local investors avoid investing in companies that are apathetic toward the local community's environmental well-being.

[17] https://equator-principles.com/about/ and https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp/.

Information from the GHGRP may spur more salient media coverage of a particular carbon-emitting facility (Konar and Cohen 1997); a top polluter with an exact physical address can easily catch the attention of the local community in which the facility is situated.[18] Byun and Oh (2018) find that media coverage of corporate environmental engagements with impacts on local communities is a significant driver of firm value and operating performance. Detailed information about facility emissions may also ignite climate change litigation by equipping environmental advocates with more concrete evidence on the polluting source and the damage it causes (Peel 2011; Clarke and Hussain 2018), which increases an emitting firm's susceptibility to legal liability.

Third, facility-level information could assist managers to identify technological opportunities for carbon reduction. A firm operating a facility can obtain emissions data for a nearby rival facility with similar scale and production; if the rival facility generates comparable outputs with less pollution, the firm can infer unexploited opportunities to improve efficiency in energy use and exploit carbon-controlling technology (Gerarden et al. 2017).[19] The GHGRP thus helps a firm learn from its peers (Dye 1990); the process can also promote best practices or industry standards (Russo-Spena et al. 2016). This mechanism is consistent with the benchmarking channel described by Christensen et al. (2019) and the role of target-setting in emissions reduction discussed by Ioannou et al. (2016).

Fourth, the mandatory nature and strict enforcement of the GHGRP provide a mechanism for managers to credibly commit to disclosure (Rock 2002; Bushee and Leuz 2005; Stulz 2009). Clearly defined penalties for noncompliance make it costly to violate mandatory reporting rules

[18] For example, based on the GHGRP data for 2012, the Roxboro Steam Electric Plant in north-central North Carolina was easily identified as the largest GHG emitter of 146 producers in the state, and this information was widely disseminated by the media. See https://www.journalnow.com/news/local/belews-creek-plant-is-one-of-top-us-greenhouse-gas-emitters/article_80cf0fce-3eae-11e3-b484-0019bb30f31a.html.

[19] Consistent with this view, the EPA states that "Information in the database can be used by communities to identify nearby sources of greenhouse gas emissions, [and] help businesses track emissions and identify cost – and fuel – saving opportunities." https://ccdsupport.com/confluence/pages/viewpage.action?pageId=141983781.

(Ball et al. 2003; Christensen et al. 2013). Prior research (Rock 2002; Stulz 2009; Leuz and Verrecchia 2000; Kim et al. 2019) suggests that the government can enhance the credibility, salience, and perceived significance of climate change information through mandatory reporting, increasing the likelihood of this information being used in decision-making. Grewal et al. (2019) further show that when a mandatory disclosure regulation is introduced, investors update their beliefs and place a higher weight on the disclosed information in their investment decisions.[20]

Overall, the above considerations make carbon reduction a preferable solution to managers of disclosing firms, which leads us to expect that the disclosure mandate of the GHGRP steers corporate operations toward reduced carbon emissions.

2.2.2. Reasons why the GHGRP may not reduce carbon emissions

Whether the above-mentioned governmental or societal pressures and corporate technology-upgrading motive are strong enough to have economically significant effects on carbon reduction is, however, an empirical issue. For example, after over ten years since the GHGRP was first implemented, the U.S. still has no firm GHG commitments (e.g., its Kyoto target remains unratified) and no formal national climate control policy. In this political context, it is dubious whether the data collected under the GHGRP will eventually be used to regulate GHG in the U.S. (Sanchez et al. 2012). The community resistance invoked by facility-level emissions may not significantly impact nation-wide or international businesses, whose managers' allegiance lies less with the community (Grant et al. 2004). Moreover, the peer effect of environmental improvement could also work in the opposite way to that envisaged above, as Parsons et al. (2018) show that socially irresponsible corporate behaviors are largely determined by firms observing the *misbehavior* of local peers.

[20] According to the water-use survey by the Water-Energy-Climate Nexus (Thieriot and Tan 2016), 78 percent of investors advocating facility-level disclosure prefer mandatory disclosure.

Prior literature also shows that mandatory environmental disclosure may crowd out the intrinsic incentives of voluntary engagement in pro-environment behaviors to signal their achievement and build reputation (Christensen et al. 2019). Matsumura et al. (2014) find that voluntarily disclosing carbon information is associated with higher firm value and Mathios (2000) demonstrates that voluntary disclosure is an important market mechanism. As such, the GHGRP mandate could harm a disclosing firm's motive to engage in behaviors that could make the disclosed information more appealing because its peers are also required to report and potentially engage in such behaviors.

Moreover, enhanced disclosure may reduce the usefulness of market information to corporate managers. Stock price contains valuable information to corporate managers and it is determined by market traders who are incentivized to hunt for information to make informed, and thus more profitable, trading decisions. More disclosure could discourage stock traders' information hunting because the search for profit-making information becomes costlier in a transparent environment (Grossman and Stiglitz 1980). Consistent with this argument, Jayaraman and Wu (2019) find that mandatory disaggregate-level disclosure inhibits managers' ability to glean information from prices that could be useful to improve decision-making. Goldstein and Yang (2019) suggest that, to the extent that stock price reflects carbon-related market information that real decision makers care to learn about, corporate disclosure may negatively affect price informativeness and thus real efficiency. This effect could weaken the attractiveness of the disclosure of detailed information via the GHGRP.

Finally, companies may merely disclose environmental information to maintain their legitimacy by acting in accordance with societal norms, values, and beliefs, rather than actually committing to sustainability (Dowling and Pfeffer 1975; Suchman 1995; Deegan 2002;

O'Donovan 2002). Similarly, organizational theories emphasize that structural inertia drives an entity's operating procedures more than any pressure exerted by outside actors such as regulators (Hannan and Freeman 1989). In these cases, firms' compliance with carbon reporting requirements could be more symbolic than real.

To summarize, it is not obvious whether a company will act pro-environmentally just because it is mandated to disclose facility-level carbon emissions. The direction and magnitude of the GHGRP's real effects are ultimately an empirical question that warrants systematic verification.

3. Empirical design

Our basic strategy is to compare the emission levels of a firm before and after it reports the emission quantities of its facilities according to the GHGRP. The tenet is that the granular facility-level carbon disclosures bring about new information to information recipients (including the government) and make them more attentive to the emission issues, which may compel the reporting firms to alter their carbon strategy, resulting in a change of the firm-level emissions.[21] To this end, we source firm-level carbon emissions information from the CDP; to the extent that facility-specific data reported to the EPA include a nontrivial amount of new information not found in the CDP's firm-level data, the mandatory reporting under the GHGRP can be viewed as a disclosure shock to reporting companies. The CDP dataset facilitates our DiD analysis because it contains carbon information for the periods both before and after the GHGRP regarding a large number of U.S. firms, including both reporting and non-reporting firms under the GHGRP. This data source thus enables the comparison of emission quantities (and relevant corporate initiatives) across firms and over years. Moreover, the CDP follows a consistent standard to retrieve data,

[21] A key feature of corporate carbon strategy is to reduce GHG emissions (Lee 2012). Wahyuni and Ratnatunga (2015) and Gallego-Alvarez and Ortas (2017) argue that carbon strategy enables the development of higher order learning and collaborative problem solving, which empowers management in determining the sources of carbon emissions and search for measurements to reduce emission levels of the whole firm.

which is not affected by the launch of the GHGRP.[22] This helps us identify the disclosure policy change without the challenge of potential confounding effects.

Using CDP data, we compare the difference in carbon emissions from the pre-GHGRP period to the post-GHGRP period for reporting firms with the corresponding difference for non-reporting firms. Specifically, we estimate the following DiD regression model:

$$Emissions = \beta_0 + \beta_1 GHGRP + \beta_2 Sales + \beta_3 CAPX + \beta_4 PPE + \beta_5 INTAN + \beta_6 GMAR + \beta_7 LEVG + \beta_8 IND\_Emissions + \sum \beta_i Fixed\ Effects + \varepsilon \quad (1).$$

We measure the dependent variable *Emissions* in two ways: *Carbon Emissions* and *Unit Carbon Emissions*. *Carbon Emissions* refers to the natural logarithm of a firm's annual direct (i.e., Scope 1) carbon emissions. Since the absolute level of emission quantity tends to be larger for bigger firms, we also compute *Unit Carbon Emissions*, defined as the natural logarithm of the ratio of Scope 1 emissions to total sales, as an alternative measure.[23]

The key independent variable, *GHGRP*, is an indicator variable that takes the value of one for reporting firms after the implementation of the GHGRP, and zero otherwise (i.e., for reporting firms before the GHGRP and for non-reporting firms throughout the whole sample period). We include year fixed effects to control for the over-time changes in carbon emissions driven by overall business activities across economic cycles and regulations other than the GHGRP, which likely have a similar impact on all sample firms; the year fixed effects also identify the periods before and after the GHGRP was initially implemented for each firm in 2010 or 2011. We include firm fixed effects to control for time-invariant factors that may influence a firm's carbon emissions

[22] The CDP emissions data are generally considered accurate and credible, and have been used in many academic studies (e.g., Matsumura et al. 2014; Griffin et al. 2017). For many companies, emissions data disclosed to the CDP are monitored, audited, and assured internally or externally. Data quality is further affirmed by the mechanisms used to compare data across similar companies. Firms' reputation concern and repeated interactions with the CDP also increase the cost of dishonest reporting (Stanny 2013; Matsumura et al. 2014).

[23] Relative carbon emissions are a widely adopted measure in the literature, e.g., Patten (2002), Clarkson et al. (2008), and Sutantoputra et al. (2012).

and also identify reporting and non-reporting firms.[24] A similar DiD methodology has been widely adopted in the literature, e.g., Bertrand and Mullainathan (1999, 2003), Bertrand et al. (2004), Low (2009), Armstrong et al. (2012), and Christensen et al. (2017).

We follow Griffin et al. (2017) by controlling for a number of firm characteristics that could also impact firm carbon emissions. *Sales*, *CAPX*, *PPE*, and *INTAN* refer, respectively, to the natural logarithms of total sales, capital expenditures, gross PPE (i.e., property, plant and equipment, scaled by depreciation expense), and intangible assets. *GMAR* is the gross profit margin and *LEVG* is the leverage (long-term debt scaled by total assets). We also control for industry-level emissions, *IND_Emissions*, to factor out the influence on firm GHG emissions of different industries' aggregate economic activities (especially for industries affected by slowed economic growth following the GFC). Specifically, *IND_Emissions* refers either to average emissions (in natural logarithm) of a firm' industry, denoted by *IND_CE*, when the dependent variable is the absolute firm emission measure *Carbon Emissions*, or to average industry-year unit emissions (in natural logarithm), denoted by *IND_UCE*, when *Unit Carbon Emissions* is the dependent variable.[25]

4. The effects of mandatory carbon disclosure on carbon emissions: Main results

4.1. Sample and descriptive statistics

Our sample covers a ten-year period surrounding the introduction of the GHGRP, i.e., from 2005 to 2014. The sample includes U.S. firms with valid corporate-level carbon emissions information in the CDP dataset. Following the common practice in the literature, we exclude the financial services industry. We also delete observations with insufficient data to calculate the control variables. The final sample comprises 1,397 firm-year observations. Table 1, Panel A

[24] To identify the firms that need to report carbon emissions under the GHGRP, we first download from the EPA website the information on facilities, together with the parent companies' names, street addresses, zip codes, cities, and states. We then use a computer-based algorithm to match facility with company and manually validate the accuracy.

[25] We thank an anonymous referee for suggesting this control variable. We follow Griffin et al. (2017) by using ten industry sectors based on the Global Industry Classification Standard (GICS) taxonomy to compute average industry emissions.

reveals that the sample is unevenly distributed, with fewer observations in earlier years and more in later years.[26]

Panels B and C of Table 1 report basic statistics for the main testing variables in the pre- and post-GHGRP periods, respectively. Prior to the carbon reporting mandate, the mean carbon emission level, *Carbon Emissions*, for all firms is 12.540 (in natural logarithm). The mean value for GHGRP reporting firms (15.010) is higher than that for non-reporting firms (11.230). A comparison between Panels B and C shows that, subsequent to the enactment of the GHGRP, both the reporting and non-reporting firms exhibit a decreasing trend in GHG emissions. However, the reduction is greater for reporting firms than for non-reporting firms. Similar patterns are observed for *Unit Carbon Emissions*. Of the 1,397 observations, 486 (35 percent) belong to the reporting firms,[27] of which 124 (362) fall into the pre-GHGRP (post-GHGRP) period.

4.2. Baseline results

We report the baseline results of Eq. (1) in Table 2. In the *Carbon Emissions* regression (column 1), the coefficient on *GHGRP* is -0.218 (*t*-statistic = -3.22). Since the dependent variable is in logarithmic form, this result reveals that, after the GHGRP-mandated disclosure, the Scope 1 carbon emission level of reporting firms decreases by about 21.8 percent relative to non-reporting firms. Consistently, when the dependent variable is *Unit Carbon Emissions* (column 2), GHGRP carries a coefficient of -0.141 (*t*-statistic = -3.26), suggesting that the GHGRP entails a 14.1 percent reduction in carbon emissions per unit of sales. These results reveal significant mitigations in both total and unit carbon emissions surrounding the implementation of the GHGRP. The sizes of these reductions are compatible with the context of GHG emission status for the period 2005–2014, i.e.,

[26] As shown later, our results are unlikely to be biased by this distributional pattern.
[27] This pattern is not necessarily unusual because we do not require a firm's facilities to exceed the reporting threshold for all years subsequent to the GHGRP—due to the carbon reduction efforts, some entities required to report in earlier years may reduce their emissions to below the benchmark (and thus cease to report) in later years.

our sample period, during which the U.S. witnessed substantial decrease in carbon emissions. For example, according to the World Bank, carbon emissions dropped from 0.442 Kilograms (Kgs) per purchasing power parity (PPP) GDP in 2005 to 0.291 Kgs per PPP GDP in 2014, a 34 percent reduction.[28] In a Congressional Research Service report, Ramseur (2014) finds that, between 2004 and 2013, the portion of the use of renewable energies increased by 100 percent while the use of petroleum to generate electricity decreased by approximately 100 percent. Moreover, in a study based on CDP data, Griffin et al. (2017) show the natural logarithm of Scope 1 emissions for S&P 500 companies, which constitute the majority of CDP reporters in the U.S., declined by 66.6 percent from 2006 to 2012. Our sample period also largely overlaps with the tenure of the Obama administration (2008–2016), which is known for its significant efforts in curbing GHG emissions and combating climate change.[29] Therefore, the scale of GHG decrease documented in our study seems reasonable given the general background of substantial emissions reductions. Overall, our analysis shows that the application of mandatory disclosure under the GHGRP produces concrete real effects in mitigating carbon emissions.[30]

4.3. Robustness of the baseline results

4.3.1. Parallel trends test

The effectiveness of our DiD method hinges on the assumption that the reporting and non-reporting firms share the same common trend (which could be driven by potential omitted factors)

[28] https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD?locations=US.

[29] The Obama-era environment protection endeavors were landmarked by the Clean Power Plan proposed by the EPA in 2014, which was projected to reduce electricity generation-induced carbon emissions by about one-third by 2030 relative to the 2005 level. The administration also imposed regulations to limit automobile emissions, improved energy efficiency standards for appliance makers, improved the Department of Energy's investments in renewables, and promoted more sustainable practices in land use, farming, and fishing. For details, refer to https://www.globalcitizen.org/en/content/7-of-obamas-biggest-climate-change-victories/ and https://en.wikipedia.org/wiki/Clean_Power_Plan.

[30] Regarding the control variables, larger companies with more sales tend to emit more GHGs (column 1), although a high level of sales dilutes carbon intensity and decreases unit emissions (column 2); higher leverage increases with both absolute and relative carbon emissions; more PPE is associated with higher emission level. Industry-level emissions generally have positive impacts on firm-level emissions, albeit statistically significant only for *IND_CE*.

except for the different impacts of the GHGRP. In Panel A of Table 3, we assess the validity of this parallel trends assumption. Following Bertrand and Mullainathan (2003), Fauver et al. (2017), and Chen et al. (2018), we consider a set of indicators that track the effects of the reporting regulation before and after it became effective for a particular firm. Specifically, we define *GHGRPYear 0* that equals one for a reporting firm in the initial implementation year, and zero otherwise (i.e., for the reporting firm in other years and for non-reporting firms in all years). Analogously, *GHGRPYear 1* and *GHGRPYear 2+* indicate a firm's reporting of GHG emissions one year and two years (and more), respectively, after the initial implementation of the GHGRP. Prior to the implementation, the indicator variables *GHGRPYear -1* and *GHGRPYear -2* equal one for one and two years, respectively, before the reporting policy for a reporting firm, and zero otherwise. We replace the key independent variable *GHGRP* with these indicator variables in the baseline regression. The estimated results show that the indicator variables involving the post-GHGRP years (*GHGRPYear 0*, *GHGRPYear 1*, and *GHGRPYear 2+*) have significantly negative coefficients whereas those involving the pre-GHGRP years (*GHGRPYear -1* and *GHGRPYear -2*) are not significantly associated with carbon emissions variables.

This test demonstrates that, relative to the unspecified reference period, i.e., three or more years prior to the GHGRP's implementation, other pre-GHGRP years do not show a different pattern in the emissions difference (if any) between reporting and non-reporting firms. The pattern starts to change only after the enactment of the GHGRP, with carbon emissions from reporting firms becoming lower relative to non-reporting firms, that is, the difference materializes only after the GHGRP is initiated. This evidence thus confirms the validity of the parallel trends assumption and suggests that the carbon-reducing effect is likely due to the GHGRP's implementation rather than other year-specific events.

4.3.2. Pseudo policy implementation test

In Panel B of Table 3, we employ two pseudo reporting policy adoption years, one in the pre-GHGRP period and the other in the post-GHGRP period, to conduct the DiD estimation. Columns 1 and 2 report the results using 2007 as the pseudo adoption year, where *GHGRP* is set to one for reporting firms in 2007–2009, and zero for reporting firms in 2005–2006 and non-reporting firms. In other words, we compare the difference in emissions changes around 2007 between the reporting and non-reporting firms. Because reporting firms are actually not affected by the GHGRP in 2007, we expect to observe no effect. Consistent with this expectation, *GHGRP* does not have a significant coefficient in either column. In a similar manner, columns 3 and 4 show the results for the DiD test around the pseudo adoption year of 2013, which compares the two-year period before the pseudo adoption (2011–2012) with the two-year period after it (2013–2014). *GHGRP* again has insignificant coefficients in both columns, suggesting that reporting firms are impacted to the same extent as non-reporting firms when comparing years before and after the pseudo adoption. In both pseudo adoption tests, no firms are subject to a real regulation shock. In the absence of such a shock, the DiD effect disappears, implying that our results in the baseline test are caused by the implementation of the GHGRP.

4.3.3. Excluding potential influence from the GFC

Considering that the EPA introduced the GHGRP in late 2009, i.e., in the wake of the GFC, one potential concern is that the disclosers under the GHGRP could include firms suffering most from the GFC that led to a deep cut in their carbon emissions, which could contaminate the impact from carbon disclosure regulation. To alleviate this concern, we re-run the analysis after removing the firms most negatively affected by the crisis in economic activities relating to carbon emissions. Specifically, we follow Moore and Mirzaei (2016) by using industry growth decline to indicate the

negative impact of the GFC. Among the 48 industrial sectors classified by Fama and French (1997), we identify those that experienced the largest drops in sales growth during the GFC period of 2008–2009, i.e., those with sales growth lower than the bottom quartile value of all industries. We then drop firms belonging to these industries. Columns 1 and 2 of Panel C show that our DiD results continue to hold with the coefficients on *GHGRP* close to those in the baseline results reported in Table 2. To the extent that firms experiencing large sales declines are likely to shrink in production and use of carbon-emitting inputs, excluding them from our DiD estimation helps attenuate the influence of extraordinary emission patterns caused by the GFC. Our evidence thus implies that the real effects on emissions reduction due to carbon disclosure under the GHGRP are unlikely to be explained by the GFC.

In a similar manner, columns 3 and 4 of Panel C use return on assets (ROA) instead of sales growth to capture the impact of the GFC. We identify the industries with poor financial performance (ROA smaller than the bottom quartile value of the sample) during 2008–2009 and exclude firms in those industries from the sample. The re-estimated coefficients on *GHGRP* for both the absolute and scaled carbon emission levels remain significantly negative, and only become slightly lower in magnitude.[31]

4.3.4. Excluding potential influence from concurrent environmental policy

In February 2010, the SEC published a guidance under Regulation S-K for disclosure related to climate change in financial reports (10-Ks), which applies to all SEC registrants (public firms) with material exposure to climate change risks.[32] Given that this climate change-related regulation was initiated around the same time as the GHGRP, it is important to show that the real effects of

[31] We find consistent results from using firm-level measures to identify severely GFC-impacted firms according to the bottom quartiles of sales growth and ROA. We also obtain similar results if considering the GFC period as 2007–2009.
[32] *Commission Guidance regarding Disclosure Related to Climate Change; Final Rule*, SEC, 17 CFR Parts 211, 231, and 241.

the GHGRP is not attributable to this concurrent environmental policy. To do so, we exclude firms affected by the SEC guidance for climate change-related disclosure. We identify these firms by examining the change in climate change risk disclosure following the SEC's 2010 guidance. If a firm first discloses climate change risk in its 10-K after the guidance was published, then it is subject to the regulatory shock; by contrast, if a firm already released climate change risk information in its 10-K before the guidance was introduced and continued to do so thereafter, or it never discloses the related information, then it is not affected by the SEC guidance.[33]

Employing a textual analysis algorithm as detailed in Appendix B, we retrieve climate change risk information from firms' SEC filings. With this information, we identify sample firms *not* subject to the regulatory shock from the SEC guidance in 2010, i.e., the early disclosers and never disclosers as described above, and re-estimate the baseline regression in this reduced sample, which is largely free from the confounding influence of the SEC guidance. As shown in Panel D of Table 3, we find that the coefficients on *GHGRP* remain significantly negative for both *Carbon Emissions* and *Unit Carbon Emissions* regressions. This finding suggests that the decline in GHG emissions after the GHGRP is unlikely to have been driven by the SEC's climate change disclosure guidance.[34]

4.3.5. Propensity score matching (PSM) screening

As a further validity check for our DiD analysis, we adopt a PSM method to factor out the

[33] This identification scheme is consistent with previous studies such as Byard et al. (2011), Horton et al. (2013), Li and Yang (2016), and Huang et al. (2021).

[34] There is another concurrent emissions-related regulation—the EPA's GHG Tailoring Rule, issued in May 2010, that requires facilities whose GHG emissions increase by more than 75,000 metric tons per year or new facilities emitting at least 100,000 metric tons to obtain permits (*Federal Register* / Vol. 75, No. 106 / Thursday, June 3, 2010 / Rules and Regulations). This regulation, however, is unlikely to subsume our results because it only applies to significant *carbon-increasing* cases for both existing and new facilities. That is, these cases correspond to the observations for our sample firms that must have a substantially *higher* emission level relative to the previous year. With these carbon-increasing observations in our analysis, our results still show an average *decreasing* pattern in carbon emissions after the GHGRP, which means that, without these observations, our results should be even stronger. In fact, after we exclude firms of de novo (existing) facilities with emissions (emissions increase) higher than the benchmark of 100,000 (75,000) metric tons per year under the GHG Tailoring Rule, we find evidence (untabulated) consistent with this mechanism, i.e., the *GHGRP* coefficients become larger.

influences of various firm characteristics on carbon emissions. Specifically, we first screen sample firms via the PSM approach by running the following Probit model:

$$GHG\ Reporting = \alpha_0 + \alpha_1 Sales + \alpha_2 CAPX + \alpha_3 PPE + \alpha_4 INTAN + \alpha_5 GMAR + \alpha_6 LEVG + Industry\ Fixed\ Effects + Year\ Fixed\ Effects + \varepsilon \quad (2),$$

where *GHG Reporting* is an indicator for the reporting of GHG emissions under the GHGRP, and the independent variables are the same set of firm characteristics as in the baseline model, together with the industry fixed effects (using Griffin et al.'s (2017) GICS-based industry sectors) and year fixed effects. We estimate Eq. (2) for the full sample and use the estimated coefficients to compute the propensity scores (predicted likelihood) for all observations. Then we match each reporting firm with a non-reporting firm using the nearest neighbor propensity score without replacement, requiring that the difference between them is within 3 percent caliper. After this matching, the PSM sample includes firms with almost identical covariates other than the likelihood of being subject to or free from GHGRP-mandated disclosure.[35] Using this PSM-screened sample, we re-estimate our baseline regression in Eq. (1). As shown in Panel E of Table 3, the key results for the real effects of the GHGRP remain unaltered.

4.3.6. Other robustness tests

Our main analysis is conducted within an unbalanced sample covering the period of 2005–2014. To alleviate concerns over (i) some firm observations only appearing in either the pre- or post-GHGRP period, (ii) the number of CDP reporting firms being substantially smaller in 2005 than in other years (as shown in Panel A of Table 1), and (iii) potential data noise during the GHGRP's implementation years, we conduct robustness tests using various alternative samples (but do not tabulate the results for brevity). We first re-run the baseline regression for a balanced

[35] Untabulated results confirm that there is no significant difference in each covariate between the reporting and non-reporting firms, with the *p*-value being higher than 0.42. In addition, the difference in the propensity score as an aggregate measure of all variables (Shipman et al. 2017) is also insignificant, with a *p*-value of 0.542.

sample in which we require a firm to have at least seven years of observations covering both the pre- and post-GHGRP periods (i.e., at least one observation year in both periods) and find results consistent with the baseline findings. Second, we truncate the first and last (two) years of the full sample period, and again find that the results remain unchanged. Third, we exclude the GHGRP adoption years of 2010 and 2011 and repeat the test in Eq. (1), and find similar results. In addition, to factor out potential self-selection bias in the voluntarily reported CDP data, we follow Matsumura et al. (2014) by controlling for a firm's choice to voluntarily disclose carbon emissions to the CDP, and find that our baseline results continue to hold.[36]

5. The role of moderating factors in shaping the real effects of carbon disclosure: Cross-sectional tests

We contend that the mandatory disclosure of facility-level carbon emissions reveals novel information useful for potential policy-making of the government and decision-making of various stakeholders. As such, the GHGRP's effectiveness in constraining disclosing firms' emissions may depend on such moderating factors as regulatory risk, corporate carbon governance, investor vigilance, and public pressure. In this section, we explore how the GHGRP's real effects are contingent on these potential moderating factors.

5.1. Climate change-related regulatory risk

Carbon regulations increase the costs to firms of excessive emissions; compliance, legislation, and possible cleanup activities represent a major concern for emitters (Labatt and White 2007; Epstein 2008). Managers' concern about regulatory risk is summarized by the CDP, whose surveys solicit companies' assessments of potential risks posed by climate change policies. To examine

[36] Specifically, we jointly estimate our baseline regression and a regression with an indicator variable for CDP reporting as the dependent variable and the disclosure determining factors as the independent variables. The determining factors for disclosing to the CDP include a firm's environmentally proactive initiative, environmentally damaging action, proportion of carbon disclosure firms in an industry, firm size, number of management forecasts, book-to-market ratio, leverage, institutional holding, foreign sales, and lagged CDP disclosure (see Eq. (2) of Matsumura et al. (2014, 708) for more details).

whether our baseline results are differentially affected by emitting firms' perception of climate change-related regulatory risk, we construct an indicator variable based on firms' confirmation or denial of this risk. We then use this indicator to split the total sample into two subsamples: one without regulatory climate change risk (= 0) and the other with it (= 1).

Panel A of Table 4 reports the baseline regression results for each subsample. Carbon disclosure's real effects on carbon emissions are found only in the high regulatory risk group, with significantly negative coefficients on *GHGRP* for both *Carbon Emissions* and *Unit Carbon Emissions* (columns 3 and 4, respectively). In contrast, columns 1 and 2 for the low regulatory risk group do not have significant coefficients on *GHGRP*. The bottom two rows of Panel A confirm that the differences in the coefficient on *GHGRP* between the two subsamples are statistically significant for both absolute and relative carbon emissions. These results suggest that disclosing carbon emissions matters more, and the real effects of carbon disclosure tend to be stronger, for firms subject to a higher level of carbon policy risk.

5.2. Corporate carbon governance

How firms prepare for a possible carbon regulation shock also matters. In Panel B of Table 4, we show that the carbon reduction effect of GHG disclosure is conditioned upon a firm's commitment to climate change risk management. We construct a measure for the strength of carbon governance using the information about corporate carbon risk management retrieved from the CDP surveys. Specifically, we estimate the first primary component of the principal component analysis (PCA) of two variables: (i) an indicator variable that equals one if the firm has a specific climate change risk management process, and zero otherwise; and (ii) an indicator variable that equals one if the highest-level agent in charge of climate change issues is the board, a board committee, or the CEO, and zero if a lower-ranking agent is in charge (e.g., other senior managers, department, or

department managers). Using the median value of this PCA-based measure, we define sample firms with higher-than-median (lower-than-median) values as with (without) *Strong Carbon Governance*, and construct two subsamples accordingly.

In Panel B, we find that the GHGRP's emissions reduction effect is more prominent among firms with strong carbon governance, as shown by the negative coefficients on *GHGRP* being much larger (in magnitude) in columns 3 and 4 than in columns 1 and 2. The differences in *GHGRP* coefficient between the two subsamples are statistically significant, as shown in the bottom two rows of the panel. These findings suggest that the real effect of mandatory reporting is greater when a firm is more serious about addressing climate change issues.

5.3. Institutional investor vigilance

We next investigate whether and how external market pressures from institutional investors, particularly mutual funds, influence the real effects of carbon disclosure. These investors have expressed strong concerns about the carbon performance of firms in which they invest.[37] To address this issue, we identify firms under pressure from investors by checking the stock holdings of carbon-conscious mutual funds. We define carbon-conscious investors according to the socially responsible funds from the Forum for Sustainable and Responsible Investment and Thomson Reuters. We create an indicator variable, *Sustainable and Responsible Investor*, coded as one if a firm has one or more socially responsible mutual fund investors, and zero otherwise. We then form two subsamples based on the score of this variable.

As shown in Panel C, the coefficient on *GHGRP* is highly significant with an expected negative sign for the subsample of firms with sustainable and responsible investors (columns 3 and 4); its magnitude is significantly greater than that for the subsample of firms without such

[37] According to PwC (2012), institutional investors' interest in climate change risk grew 18-fold during the period from 2002 to 2012.

investors (columns 1 and 2). This suggests that firms under high pressure from external carbon-conscious investors exhibit stronger carbon mitigation effects from GHGRP-mandated carbon disclosure than those under low pressure. In short, the pressure from investors plays a nontrivial role in firms' emissions reduction efforts in response to the carbon reporting requirement.

5.4. Public pressure

In a related vein, we further examine the influences of the pressure from public opinion about carbon emissions and carbon management on the real effects of mandatory carbon disclosure. Here we are interested in concerns of the general public, rather than those of a particular stakeholder group. Our objective is to check whether public pressure, especially from the local society to which facility emissions information is more salient, affects the sensitivity of emissions behaviors to carbon disclosure.

For this purpose, we use survey data from the Yale Program on Climate Change Communication. This dataset records the local degree (percentage) of public support in the state or community for proposals to (i) regulate CO_2; (ii) set emissions limits; (iii) introduce a carbon tax; and (iv) adopt renewable energies. We incorporate these factors into a public pressure index by using the first primary component of the PCA of four variables indicating the support levels for the above survey items (refer to Appendix A for details). We define *High Public Pressure* as an indicator variable that equals one if a firm is headquartered in a high public pressure state (climate change-related pressure above the sample median), and zero otherwise, and split the total sample into two subsamples accordingly.

Panel D shows that the coefficient on *GHGRP* is negative and significant at less than the 5 percent level for the high public pressure subsample (columns 3 and 4) but not significant for the low public pressure subsample (columns 1 and 2). This finding implies that local public concerns

over carbon emissions and climate change appear to influence firms' emissions reduction activities in response to the GHGRP mandating carbon disclosure. Stated alternatively, high public pressure helps enhance the carbon performance of emitters under the reporting mandate.

To summarize, the cross-sectional results reported in Table 4 indicate that the real effects of GHGRP-mandated disclosure on carbon emissions depend on the carbon regulation risk and the carbon concerns of firms themselves and their stakeholders, including financial market investors and the general public. These factors are related to the enhanced carbon awareness of information recipients and potential follow-up actions by the government. The green movement and regulatory development are mutually reinforcing, and both could make emission disclosure sufficiently compelling to change emitters' carbon activities and ultimately reduce their emission level. We delve more into these firm activities in the next section.

6. Firms' carbon reduction actions: Potential channels for the real effects of carbon disclosure

We investigate firm actions to identify potential channels through which carbon disclosure leads to a reduction in carbon emissions. Carbon reduction connects various aspects of corporate strategy, management, and operation. We focus on internal reduction initiatives and examine how carbon disclosure under the GHGRP affects these actions and thus carbon mitigation.

The first initiative is the carbon reduction scheme as part of a firm's overall environmental strategy. The KLD dataset maintained by MSCI contains information about corporate programs for reducing pollution, contamination, and the emissions of toxic and carcinogenic substances. Utilizing this information, we examine how the GHGRP's implementation affects a firm's propensity to adopt these emissions reduction plans. Within the DiD framework of Eq. (1), we replace the dependent variable with an indicator variable, *Carbon Reduction Plan*, that equals one

for strong programs and performance in pollution reduction, and zero otherwise.[38] As shown in column 1 of Table 5, *GHGRP* has a significantly positive coefficient of 0.142 (*t*-statistic = 2.92), indicating that reporting firms are about 14.2 percent more likely than non-reporting firms to adopt strong carbon reduction schemes after the GHGRP's implementation.[39] This evidence suggests one potential channel through which mandatory carbon disclosure leads to emissions mitigation.

The second initiative we consider is the pollution management program. Using the KLD data, we define a pollution management indicator, *Pollution Management*, that equals one if the firm has an active environmental management system in place and it is certified by a third-party standard such as ISO 14001, and zero otherwise. We regress *Pollution Management* against the independent variables in Eq. (1). Column 2 of Table 5 shows that the key variable of interest, *GHGRP*, has a significantly positive coefficient (0.157, *t*-statistic = 2.52), suggesting that firms are more likely to adopt promising pollution management schemes if they are subject to mandatory reporting under the GHGRP—the propensity to improve pollution management is higher by 15.7 percent for reporting firms than for non-reporting firms.

Another corporate climate movement is from the eschewing of negative carbon practices that entail severe controversies related to firms' climate change and energy policies and initiatives. As described in the KLD dataset, factors influencing the evaluation of such controversies include, but are not limited to, a history of involvement in GHG-related legal cases, widespread or egregious impacts of corporate GHG emissions, resistance to improved practices, and criticism by NGOs and/or other third-party observers. These incidents are negatively associated with a firm's carbon performance and can severely undermine its carbon reduction practices. To examine this potential

[38] For dependent variables other than *Unit Carbon Emissions*, we use *IND_CE* when controlling for industry-level emissions.
[39] Following Kim et al. (2018), our estimation is based on a linear probability model to reduce the biases arising from nonlinear models in the presence of fixed effects (Greene 2004). However, our results are robust to a nonlinear Logit regression model.

channel, we create an indicator variable, *Negative Carbon Practices*, that equals one for more severe climate change controversies and zero for less severe controversies based on the KLD assessment. Table 5, column 3 reports the results of regression using *Negative Carbon Practices* as the dependent variable in Eq. (1). The coefficient on *GHGRP* is negative and significant at the 10 percent level. The finding is consistent with the notion that GHGRP-mandated reporting reduces the likelihood of encountering controversies regarding climate change.

7. The impacts of carbon disclosure on other environmental performance measures

Carbon emissions are only one aspect of environmental performance. Although the GHGRP focuses on carbon emissions, we now examine whether its carbon disclosure requirement influences other related environmental performance measures. Firms' environmental performance is well summarized in the environmental CSR of the KLD, which includes both the strengths and concerns (weaknesses) from various perspectives. Specifically, the strengths are reflected in firms' beneficial products and services, pollution prevention, recycling, clean energy usage, communication of environmental best practices, PPE with above-average environmental quality, commitment to environmental management, and other proactive activities. The concerns include hazardous waste, regulatory problems, ozone-depleting chemicals, substantial toxic emissions, agricultural chemicals, reliance on fossil fuel products, and other environmental controversies (KLD 2015). The KLD measures a firm's environmental CSR using an ordinal variable representing the difference between the number of strengths and the number of concerns. Although this variable does not quantify the carbon emission level, it contains a richer set of relevant information that correlates with corporate carbon performance.

To examine whether GHGRP-mandated carbon disclosure also affects a firm's environmental performance beyond narrowly defined carbon emissions, we estimate the regression model in Eq.

(1) using the KLD environmental CSR score as the dependent variable. Column 1 of Table 6 shows that the coefficient on *GHGRP* is significantly positive, suggesting that reporting firms improve their overall environmental performance in the post-GHGRP period, compared to the performance change for non-reporting firms in the same period.

In column 2, we examine the effect of carbon disclosure on the incidence of environmental regulation violation, such as payments of a settlement, fine, or penalty due to non-compliance with U.S. environmental regulations, including the CAA. For emitting firms, regulation violations are a dramatic materialization of carbon risk. We obtain information about environmental regulation violations from the KLD database, and set the indicator variable *Regulation Violation* to equal one for firms with at least one violation in a given year, and zero otherwise. The regression results reveal a significantly negative coefficient on *GHGRP*, indicating that, consistent with the emissions mitigation effect, GHG disclosure leads to a decline in environmental regulation violation. This evidence further buttresses the influence of the GHGRP on improving environmental performance and enhancing economic benefits.

Taken together, the findings in Table 6 suggest that the real effects of carbon disclosure may not be limited to carbon emissions: they may also expand to other facets of environmental protection and, in particular, corporate environmental performance and/or regulatory compliance.

8. International evidence

Requiring firms to report GHG emissions is gradually becoming a global phenomenon as an increasing number of jurisdictions adopt carbon disclosure mandates. According to the World Resources Institute (WRI), 25 countries have GHG reporting schemes in place.[40] If our general argument on the real effects of mandatory carbon disclosure holds, then we should observe GHG

[40] They are Austria, Australia, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Spain, Sweden, Turkey, the U.K., and the U.S.

reductions occurring worldwide after the adoptions of reporting schemes. It is therefore interesting to examine the international DiD effects of carbon disclosure mandates. Another merit of using the international setting is that we can more effectively identify the variation in legal enforcement, given the importance of enforcement for mandatory carbon reporting to have meaningful impacts on discloser behaviors. This global analysis can thus lend further support to our main results on the real effects of mandatory carbon disclosure, and also provide additional evidence for the role of enforcement.

In Table 7, Panel A, we report the DiD results for firms in the WRI countries with carbon disclosure mandates. We first retrieve Scope 1 carbon emissions data for firms in these countries from the CDP, which covers international data, and compute the natural logarithms of raw carbon emissions and raw emissions scaled by total sales, denoted by *Carbon Emissions* and *Unit Carbon Emissions*, respectively, as in the baseline regression of Eq. (1). We then identify the implementation year of the disclosure mandate in each country during our sample period, and define a variable *GHG Disclosure Global* to indicate firms subject to the mandate in the country after the mandate is adopted, i.e., *GHG Disclosure Global* is constructed for each country in a similar way as the variable *GHGRP* for the U.S. After aggregating all observations from all countries into an international sample, we regress the carbon emissions measures *Carbon Emissions* and *Unit Carbon Emissions* on *GHG Disclosure Global*, along with firm and year fixed effects and the variables representing firm characteristics as included in Eq. (1). The results show that the coefficients on *GHG Disclosure Global* are negative for both carbon emission quantity (column 1) and scaled emissions (column 2) as the dependent variable, although only the former effect is statistically significant. This evidence is generally consistent with the main findings, and suggests that our U.S.-based results may possibly generalize to an international setting.

Panel B further reveals that the real effects of GHG reporting mandates become more pronounced in countries with stronger legal enforcement. We measure legal enforcement by the Legal Enforcement Index (LEI), which is compiled by the World Bank to capture the extent to which agents have confidence in and abide by the rules of society.[41] The variable *LEI* is constructed to reflect the strength of legal enforcement, with a higher value indicating stronger enforcement. We then add *LEI* and its interaction with *GHG Disclosure Global* to the global DiD regressions in Panel A. Our focus is the interaction term *GHG Disclosure Global*×*LEI*; a significantly negative coefficient on it would suggest that stronger legal enforcement reinforces the emissions-reducing effects of GHG emission disclosures. The results in Panel B show that the coefficients on *GHG Disclosure Global*×*LEI* are significantly negative, irrespective of dependent variables, thus consistent with strong enforcement strengthening the effects of mandatory carbon disclosures on emissions mitigation. These findings highlight the importance of legal enforcement to the effectiveness of mandatory reporting policies.

9. Conclusion

With climate change and global warming receiving increasing attention, corporate GHG disclosure has become a critical issue in enhancing carbon transparency. What are the real business impacts of carbon disclosure practice? This paper examines whether firms change their emitting behaviors, particularly by reducing carbon emissions and improving pollution management, in response to the introduction of mandatory carbon reporting under the EPA's GHGRP. After controlling for firm characteristics and unobservables through a DiD analysis, we find that firms required to report emissions to the EPA subsequently reduce their emission level. Firms that are more concerned with carbon-related regulatory risk exhibit stronger carbon-decreasing patterns

[41] For details, refer to https://datacatalog.worldbank.org/rule-law-estimate-0.

after the GHGRP's implementation; mounting pressure from carbon-conscious investors and the general public also strengthens the emissions mitigation effect of GHG disclosure. In addition, reporting firms tend to adopt carbon reduction plans, strengthen pollution management, and curb negative carbon practices subsequent to the GHGRP. Their overall environmental performance and compliance with carbon regulations also improve.

Our evidence elucidates the effectiveness of government-initiated carbon emission reporting. The disclosure mandate reflects the firmness of a government's stance on tackling climate change, delivering additional information that cannot be conveyed by voluntary disclosure schemes. The real effects of carbon disclosure on corporate emissions behavior supplement its market effects (e.g., firm value effect) driven by investors and other external stakeholders. Relative to the market effects, the real effects are more directly related to environmental benefits, and may thus be more pertinent to judging the efficacy of carbon disclosure regulations. Overall, our findings suggest that mandatory emission disclosure boosts corporate efforts to reduce GHG emissions.

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Appendix A: Variable definitions

Variable name	Definition and construction
Carbon emissions variables	
Carbon Emissions	Natural logarithm of direct (Scope 1) carbon emissions (metric tons). Source: CDP.
Unit Carbon Emissions	Natural logarithm of the ratio of direct (Scope 1) carbon emissions (metric tons) to total sales (million US$). Sources: CDP and Compustat.
DiD method variables	
GHGRP	Indicator variable that equals one for reporting firms after the implementation of the GHGRP, and zero otherwise (i.e., for reporting firms before the GHGRP and for non-reporting firms throughout the whole sample period). Source: EPA.
GHG Disclosure Global	Indicator variable that equals one after the carbon disclosure mandates for reporting firms in countries with mandatory carbon disclosure policies, and zero otherwise (i.e., for reporting firms before the disclosure mandates and for non-reporting firms throughout the whole sample period). Source: WRI.
Control variables	
Sales	Natural logarithm of total sales (SALE) (million US$). Source: Compustat.
CAPX	Natural logarithm of capital expenditures (CAPX) (million US$). Source: Compustat.
PPE	Natural logarithm of the ratio of gross property, plant and equipment to depreciation expense (CAPX/DP). Source: Compustat.
INTAN	Natural logarithm of intangible assets (INTAN) (million US$). Source: Compustat.
GMAR	Gross profit margin = 1 – (COGS/SALE), where COGS is the cost of goods sold and SALE is total sales. Source: Compustat.
LEVG	The ratio of long-term debt to total assets (DLTT/AT). Source: Compustat.
IND_CE	Industry-year average level of carbon emissions in natrual logarithm based on Griffin et al.'s (2017) GICS-based industry sectors. Sources: EPA and Griffin et al. (2017).
IND_UCE	Industry-year average level of unit carbon emissions in natrual logarithm based on Griffin et al.'s (2017) GICS-based industry sectors. Sources: EPA, Compustat, and Griffin et al. (2017).
Variables in cross-sectional tests	
Regulatory Climate Change Risk	Indicator variable that equals one if a firm is subject to regulatory climate change risk, and zero otherwise. Source: CDP.
Strong Carbon Governance	Indicator variable that equals one if a firm has higher-than-median carbon governance score, and zero otherwise. Carbon governance score is the first primary component of the PCA of two variables: (i) an indicator variable that equals one if the firm has a specific climate change risk management process, and zero otherwise, and (ii) an indicator variable that equals one if the highest-level agent in charge of climate change issues is the board, a board committee, or the CEO, and zero if a lower-ranking agent is in charge (e.g., other senior managers, department, or department managers). Source: CDP.
Sustainable and Responsible Investor	Indicator variable that equals one if a firm has one or more socially responsible mutual fund as investors, and zero otherwise. Sources: Forum for Sustainable and Responsible Investment and Thomson Reuters (Mutual Fund Holding).
High Public Pressure	Indicator variable that equals one if a firm is headquartered in a high public pressure state, and zero otherwise. High public pressure states refer to states in which climate change-related public pressure is above the sample median. Climate change-related public pressure is the first primary component of the PCA of the following four indicator variables: *Regulate CO_2*, *Set CO_2 Limits*, *Carbon Tax*, and *Renewable Sources*. *Regulate CO_2* equals one if the

	percentage of respondents who somewhat or strongly support regulating CO_2 as a pollutant is higher than the sample median, and zero otherwise; *Set CO_2 Limits* equals one if the percentage of respondents who somewhat or strongly support setting strict CO_2 emissions limits on existing coal-fired power plants to reduce global warming and improve public health is higher than the sample median, and zero otherwise; *Carbon Tax* equals one if the percentage of respondents who somewhat or strongly support carbon tax is higher than the sample median, and zero otherwise; *Renewable Sources* equals one if the percentage of respondents who somewhat or strongly support requiring utilities to produce 20 percent electricity from renewable sources is higher than the sample median, and zero otherwise. Source: Yale Program on Climate Change Communication.
Variables in channel tests	
Carbon Reduction Plan	Indicator variable that equals one if a firm has strong programs and performance in pollution reduction based on its management of the risk of incurring liabilities associated with pollution, contamination, and the emissions of toxic and carcinogenic substances, and zero otherwise. Source: KLD.
Pollution Management	Indicator variable that equals one if a firm has an active environmental management system in place and it is certified by a third-party standard such as ISO 14001. Source: KLD.
Negative Carbon Practices	Indicator variable assessing the severity of controversies related to a firm's climate change and energy policies and initiatives. Factors affecting this evaluation include, but are not limited to, 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 NGOs and/or other third-party observers. The variable equals one for more severe climate change controversies and zero for less severe controversies. Source: KLD.
Environmental performance variables	
Environmental CSR	Total number of strengths minus total number of concerns in KLD environmental CSR. The strengths are reflected in firms' beneficial products and services, pollution prevention, recycling, clean energy usage, communication for environmental best practices, PPE with above-average environmental quality, commitment to environmental management, and other proactive activities. The concerns include hazardous waste, regulatory problems, ozone-depleting chemicals, substantial toxic emissions, agricultural chemicals, reliance on fossil fuel products, and other environmental controversies. Source: KLD.
Regulation Violation	Indicator variable that equals one if a firm has paid a settlement, fine, or penalty due to non-compliance with U.S. environmental regulations, including the CAA, and zero otherwise. Source: KLD.

Appendix B: Method for climate change risk information retrieval from 10-K

We collect information regarding climate change risk from Item 1A (risk factor disclosure) of 10-K (downloaded from the EDGAR) for all sample firms from 2005 to 2014, and identify risk factor items using specific HTML tags, following Campbell et al. (2014) and Hope et al. (2016). We first randomly select 600 firms (200 from each year of 2010–2012, i.e., the first three years subsequent to the SEC guidance on disclosure related to climate change) and summarize the regularity of climate change risk disclosure based on visual inspection, through which we identify 64 relevant keywords as listed in Table A1. Based on these keywords, we employ a textual analysis algorithm to scan the full text of Item 1A of Form 10-K; when any of the keywords is detected in a particular sentence, the algorithm extracts all climate change risk-related information from the whole sentence. To ensure the accuracy of the information retrieval of our algorithm, we conduct an out-of-sample validation check. Specifically, we randomly choose 20 firms each year from our full ten-year sample period, and manually collect climate change risk information in their risk factor disclosures in 10-Ks. 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 percent of the selected cases.

Table A1. Keywords of climate change risk disclosure in 10-K

This table lists 64 climate change risk-related keywords that we identify from risk factor disclosure (Item 1A) in 10-K.

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)	co2	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)

Table 1. Sample distribution and descriptive statistics

The sample includes all U.S. non-financial firms during 2005–2014 with valid corporate-level carbon emissions information from the CDP and non-missing control variable estimates in the baseline regression of Eq. (1). The final sample has 1,397 firm-year observations. Panel A reports sample distribution across years; Panels B and C report descriptive statistics of carbon emissions and control variables for the pre- and post-GHGRP periods, respectively. Details about variable definitions are provided in Appendix A.

Panel A: Sample distribution by year

Year	Freq.	Pct.	Cum.
2005	9	0.64	0.64
2006	40	2.86	3.51
2007	53	3.79	7.30
2008	116	8.30	15.60
2009	126	9.02	24.62
2010	139	9.95	34.57
2011	158	11.31	45.88
2012	242	17.32	63.21
2013	256	18.32	81.53
2014	258	18.47	100.00
Total	1,397	100.00	

Panel B: Descriptive statistics for the pre-GHGRP period

Var.	Obs.	Mean	Std.	P25	Median	P75
All firms						
Carbon Emissions	347	12.540	3.177	10.390	12.540	15.280
Unit Carbon Emissions	347	3.816	2.425	1.796	3.301	5.763
Sales	347	8.999	1.043	8.264	8.989	9.584
CAPX	347	6.118	1.400	5.074	6.075	7.170
PPE	347	2.667	0.553	2.368	2.716	3.010
INTAN	347	6.711	2.348	5.803	7.296	8.281
GMAR	347	0.422	0.224	0.235	0.389	0.583
LEVG	347	0.215	0.132	0.129	0.204	0.291
IND_CE	347	12.530	2.374	10.840	11.910	14.830
IND_UCE	347	3.791	1.992	1.996	3.282	5.642
Reporting firms						
Carbon Emissions	124	15.010	1.957	13.550	15.390	16.440
Unit Carbon Emissions	124	5.770	1.972	3.996	5.790	7.494
Sales	124	9.261	0.935	8.722	9.338	9.749
CAPX	124	6.892	1.214	6.302	6.973	7.769
PPE	124	2.989	0.382	2.762	2.961	3.242
INTAN	124	6.577	2.527	5.337	7.510	8.320
GMAR	124	0.387	0.209	0.206	0.346	0.550
LEVG	124	0.235	0.113	0.157	0.229	0.292
IND_CE	124	14.090	2.229	12.190	14.830	15.910
IND_UCE	124	5.085	1.927	3.328	5.642	6.743
Non-reporting firms						
Carbon Emissions	223	11.230	2.663	9.802	11.120	12.750
Unit Carbon Emissions	223	2.726	1.910	1.300	2.220	3.752
Sales	223	8.853	1.073	8.112	8.772	9.421
CAPX	223	5.688	1.310	4.834	5.493	6.402
PPE	223	2.487	0.552	2.142	2.525	2.846
INTAN	223	6.786	2.245	5.897	7.253	8.209
GMAR	223	0.441	0.230	0.258	0.430	0.587
LEVG	223	0.204	0.140	0.096	0.195	0.287
IND_CE	223	11.670	1.981	10.250	11.120	12.190
IND_UCE	223	3.071	1.634	1.992	2.339	3.377

Panel C: Descriptive statistics for the post-GHGRP period						
Var.	Obs.	Mean	Std.	P25	Median	P75
All firms						
Carbon Emissions	1,050	12.140	2.868	10.220	11.960	14.010
Unit Carbon Emissions	1,050	3.218	2.204	1.569	2.727	4.510
Sales	1,050	9.176	1.198	8.401	9.112	9.859
CAPX	1,050	6.154	1.467	5.100	5.997	7.190
PPE	1,050	2.638	0.543	2.294	2.694	3.015
INTAN	1,050	7.070	2.406	6.073	7.482	8.616
GMAR	1,050	0.430	0.208	0.266	0.394	0.570
LEVG	1,050	0.231	0.137	0.136	0.221	0.312
IND_CE	1,050	12.130	1.969	10.920	12.270	12.880
IND_UCE	1,050	3.227	1.662	2.013	3.149	3.917
Reporting firms						
Carbon Emissions	362	14.500	2.092	12.850	14.650	16.190
Unit Carbon Emissions	362	5.006	2.098	3.075	4.782	6.574
Sales	362	9.531	1.102	8.950	9.538	10.120
CAPX	362	6.952	1.374	6.089	7.008	7.851
PPE	362	2.932	0.459	2.706	2.944	3.241
INTAN	362	7.104	2.818	5.995	7.779	8.906
GMAR	362	0.398	0.203	0.248	0.360	0.531
LEVG	362	0.254	0.119	0.164	0.255	0.318
IND_CE	362	13.270	1.982	12.270	12.880	15.520
IND_UCE	362	4.195	1.827	3.149	3.562	5.950
Non-reporting firms						
Carbon Emissions	688	10.900	2.409	9.506	10.920	12.430
Unit Carbon Emissions	688	2.276	1.591	1.031	1.988	3.061
Sales	688	8.989	1.205	8.259	8.874	9.659
CAPX	688	5.734	1.334	4.857	5.541	6.612
PPE	688	2.484	0.521	2.148	2.528	2.823
INTAN	688	7.052	2.160	6.135	7.281	8.382
GMAR	688	0.447	0.209	0.285	0.428	0.590
LEVG	688	0.220	0.144	0.116	0.201	0.308
IND_CE	688	11.530	1.678	9.587	11.400	12.760
IND_UCE	688	2.718	1.307	1.742	2.110	3.426

Table 2. Effects of carbon disclosure on carbon emissions: Baseline results

The dependent variables *Carbon Emissions* and *Unit Carbon Emissions* refer to the natural logarithms of GHG emissions and the ratio of GHG emissions to total sales, respectively, for each firm in each sample year. The key independent variable is the indicator variable *GHGRP* that equals one after the GHGRP for reporting firms, and zero otherwise. Firm-level characteristic variables, industry-level carbon emissions, and firm and year fixed effects are controlled as in Eq. (1). Details about variable definitions are provided in Appendix A. Columns 1 and 2 report OLS regression results with *Carbon Emissions* and *Unit Carbon Emissions* as the dependent variable, respectively. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. For brevity, the coefficients on the firm and year dummies are not reported. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	**-0.218*** **	**-0.141*** **
	(-3.22)	**(-3.26)**
Sales	0.601***	-0.249***
	(4.98)	(-3.22)
CAPX	-0.020	-0.011
	(-0.33)	(-0.29)
PPE	0.441**	0.040
	(2.20)	(0.45)
INTAN	0.002	-0.011
	(0.07)	(-0.77)
GMAR	-0.273	-0.110
	(-0.80)	(-0.43)
LEVG	1.171***	0.470**
	(2.69)	(2.19)
IND_CE	0.141**	
	(2.26)	
IND_UCE		0.138
		(1.38)
Intercept	8.202***	9.327***
	(5.18)	(10.76)
Firm/Year Fixed Effects	Included	Included
Number of Obs.	1,397	1,397
Adjusted R^2	0.973	0.985

Table 3. Effects of carbon disclosure on carbon emissions: Robustness of the baseline results

The dependent variables are the same as in the baseline regression. The key independent variables are a set of indicator variables that track the effects of the reporting regulation before and after it became effective in Panel A, the indicator variable *GHGRP* that equals one after pseudo disclosure policy adoption years for reporting firms in Panel B, and the indicator variable *GHGRP* that equals one after the GHGRP for reporting firms in Panels C to E. In Panel C, firms in industries that experienced the largest drops in sales growth (sales growth rate lower than the bottom quartile value of all industries) or the worst financial performance (ROA smaller than the bottom quartile value) during the GFC period of 2008–2009 are excluded. In Panel D, firm subject to the SEC's 2010 guidance on climate change risk disclosure, i.e., those not reporting climate change risk information before the issuance of the guidance and starting the disclosure only after the guidance and those never reporting climate change risk information in both the pre- and post-guidance periods, are excluded. Panel E reports the baseline regression results in PSM-screened sample. Firm-level characteristic variables and industry-level carbon emissions (collectively denoted by *Controls*), as well as firm and year fixed effects are controlled as in Eq. (1). Details about variable definitions are provided in Appendix A. For brevity, only regression coefficients on key independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

Panel A: Parallel trends test

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRPYear -2	-0.197	-0.177
	(-1.29)	(-1.57)
GHGRPYear -1	-0.169	-0.147
	(-0.91)	(-1.19)
GHGRPYear 0	**-0.296***	**-0.198***
	(-1.93)	**(-1.78)**
GHGRPYear 1	**-0.375****	**-0.274****
	(-2.38)	**(-2.43)**
GHGRPYear 2+	**-0.376****	**-0.280****
	(-2.45)	**(-2.50)**
Controls	Included	Included
Firm/Year Fixed Effects	Included	Included
Number of Obs.	1,397	1,397
Adjusted R^2	0.973	0.985

Panel B: Pseudo adoption year

	Pseudo adoption year = 2007 Sample period = [2005–2009]		Pseudo adoption year = 2013 Sample period = [2011–2014]	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emission*	*Unit Carbon Emissions*
GHGRP	-0.191	-0.192	-0.041	-0.046
	(-1.48)	(-1.63)	(-0.91)	(-1.50)
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	348	348	914	914
Adjusted R^2	0.983	0.981	0.982	0.989

Panel C: Excluding the influence from the GFC

	Exclude industries experiencing large drop in sales growth during GFC		Exclude industries experiencing poor performance during GFC	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emission*	*Unit Carbon Emissions*
GHGRP	**-0.220*** **	**-0.137*** **	**-0.213*** **	**-0.119** **
	(-2.78)	**(-2.85)**	**(-2.90)**	**(-2.56)**
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	1,132	1,132	1,128	1,128
Adjusted R^2	0.972	0.986	0.977	0.989

Panel D: Excluding the influence from the SEC guidance on climate change risk disclosure

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	**-0.186** **	**-0.096** **
	(-2.22)	**(-1.91)**
Controls	Included	Included
Firm/Year Fixed Effects	Included	Included
Number of Obs.	1,000	1,000
Adjusted R^2	0.975	0.988

Panel E: PSM-screened sample

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	**-0.121** **	**-0.116** **
	(-2.21)	**(-2.20)**
Controls	Included	Included
Firm/Year Fixed Effects	Included	Included
Number of Obs.	604	604
Adjusted R^2	0.989	0.988

Table 4. Effects of carbon disclosure on carbon emissions: Cross-sectional tests

The baseline regression is conducted in two subsamples classified by various conditions. Panels A and B consider internal factors of regulatory climate change risk concern and carbon governance, respectively, and Panels C and D consider external factors of sustainable & responsible institutional investor and public pressure, respectively. Details about variable definitions are provided in Appendix A. The regression coefficients on the key independent variable *GHGRP* are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. The bottom two rows of each panel show the testing results (*p*-values) for the differences in the coefficient on *GHGRP* between columns 1 and 3 and between columns 2 and 4. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

Panel A: Regulatory climate change risk

	Regulatory Climate Change Risk = 0		*Regulatory Climate Change Risk* = 1	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	0.0170	-0.038	**-0.242*** **	**-0.135*** **
	(0.13)	(-0.41)	**(-2.61)**	**(-2.71)**
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	257	257	1,140	1,140
Adjusted R^2	0.969	0.965	0.975	0.987
p-value for the difference in *GHGRP* between columns 1 and 3			0.01***	
p-value for the difference in *GHGRP* between columns 2 and 4			0.10*	

Panel B: Carbon governance

	Strong Carbon Governance = 0		*Strong Carbon Governance* = 1	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	-0.117	-0.105	**-0.373*** **	**-0.277*** **
	(-0.93)	(-1.06)	**(-3.17)**	**(-3.50)**
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	703	703	694	694
Adjusted R^2	0.992	0.993	0.956	0.976
p-value for the difference in *GHGRP* between columns 1 and 3			0.03**	
p-value for the difference in *GHGRP* between columns 2 and 4			0.04**	

Panel C: Sustainable and responsible investor				
	Sustainable and Responsible Investor = 0		*Sustainable and Responsible Investor* = 1	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	-0.070	-0.040	**-0.470****	**-0.187****
	(-1.15)	(-0.71)	**(-2.39)**	**(-2.47)**
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	662	662	735	735
Adjusted R^2	0.986	0.984	0.959	0.987
p-value for the difference in *GHGRP* between columns 1 and 3			0.01***	
p-value for the difference in *GHGRP* between columns 2 and 4			0.03**	
Panel D: Public pressure				
	High Public Pressure = 0		*High Public Pressure* = 1	
	(1)	(2)	(3)	(4)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*	*Carbon Emissions*	*Unit Carbon Emissions*
GHGRP	-0.099	-0.046	**-0.256****	**-0.163*****
	(-1.21)	(-0.83)	**(-2.51)**	**(-2.59)**
Controls	Included	Included	Included	Included
Firm/Year Fixed Effects	Included	Included	Included	Included
Number of Obs.	598	598	799	799
Adjusted R^2	0.980	0.986	0.962	0.979
p-value for the difference in *GHGRP* between columns 1 and 3			0.35	
p-value for the difference in *GHGRP* between columns 2 and 4			0.05**	

Table 5. Effects of carbon disclosure on carbon emissions: Channel tests

The dependent variables *Carbon Reduction Plan*, *Pollution Management*, and *Negative Carbon Practices* are indicator variables for a firm's status in adopting carbon reduction scheme, managing pollution, and avoiding negative carbon practices, respectively. The key independent variable is the indicator variable *GHGRP* that equals one after the GHGRP for reporting firms. Firm-level characteristic variables, industry-level carbon emissions, and firm and year fixed effects are controlled as in Eq. (1). Details about variable definitions are provided in Appendix A. The linear regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. For brevity, the coefficients on the firm and year dummies are not reported. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

	(1)	(2)	(3)
Dep. Var.	*Carbon Reduction Plan*	*Pollution Management*	*Negative Carbon Practices*
GHGRP	**0.142*** **	**0.157** **	**-0.058***
	(2.92)	**(2.52)**	**(-1.87)**
Sales	0.097*	0.152*	0.038
	(1.82)	(1.69)	(0.84)
CAPX	-0.010	0.013	-0.030
	(-0.39)	(0.25)	(-1.14)
PPE	0.123*	0.163	0.052
	(1.90)	(1.49)	(1.63)
INTAN	0.011	-0.017	-0.011
	(0.85)	(-1.09)	(-1.23)
GMAR	-0.040	-0.107	-0.350**
	(-0.25)	(-0.34)	(-2.30)
LEVG	0.048	-0.024	0.176**
	(0.23)	(-0.09)	(2.27)
IND_CE	0.006	-0.079**	0.053***
	(0.23)	(-2.26)	(3.04)
Intercept	-1.571**	-1.510	-0.753
	(-2.34)	(-1.38)	(-1.42)
Firm/Year Fixed Effects	Included	Included	Included
Number of Obs.	1,287	1,115	1,348
Adjusted R^2	0.382	0.495	0.637

Table 6. Effects of carbon disclosure on other environmental performance measures

The dependent variables *Environmental CSR* and *Regulation Violation* refer to net strength score (number of strengths – number of concerns) in KLD environmental CSR and an indicator variable for a firm's incidence of violating environmental regulations, respectively. The key independent variable is the indicator variable *GHGRP* that equals one after the GHGRP for reporting firms. Firm-level characteristic variables, industry-level carbon emissions, and firm and year fixed effects are controlled as in Eq. (1). Details about variable definitions are provided in Appendix A. The regression coefficients on independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. For brevity, the coefficients on the firm and year dummies are not reported. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

	(1)	(2)
Dep. Var.	*Environmental CSR*	*Regulation Violation*
GHGRP	**0.379****	**-0.352*****
	(2.18)	**(-7.38)**
Sales	0.068	0.153***
	(0.26)	(2.70)
CAPX	0.013	-0.005
	(0.07)	(-0.16)
PPE	-0.183	-0.017
	(-0.61)	(-0.27)
INTAN	-0.065	-0.009
	(-1.33)	(-1.05)
GMAR	1.400	0.057
	(1.35)	(0.29)
LEVG	0.444	-0.118
	(0.55)	(-0.82)
IND_CE	-0.248**	0.0230
	(-2.58)	(0.93)
Intercept	2.576	-1.357*
	(0.86)	(-1.86)
Firm/Year Fixed Effects	Included	Included
Number of Obs.	1,095	1,266
Adjusted R^2	0.649	0.601

Table 7. Effects of carbon disclosure on carbon emissions: International evidence

The sample includes all non-financial firms in countries with mandatory GHG reporting programs. The dependent variables are corporate-level *Carbon Emissions* and *Unit Carbon Emissions* for each firm. The key independent variable is the indicator variable *GHG Disclosure Global* that equals one after the carbon disclosure mandate for reporting firms in Panel A, and the interaction term between *GHG Disclosure Global* and the variable for legal enforcement index *LEI* in Panel B. Firm-level characteristic variables, industry-level carbon emissions, and firm and year fixed effects are controlled as in Eq. (1). Details about variable definitions are provided in Appendix A. The regression coefficients on key independent variables are reported, followed by the robust *t*-statistics (in the parentheses) based on standard errors adjusted for heteroscedasticity. *, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.

Panel A: Real effects of international GHG reporting mandates

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHG Disclosure Global	**-0.177****	-0.094
	(-1.98)	(-1.28)
Controls	Included	Included
Firm/Year Fixed Effects	Included	Included
Number of Obs.	4,554	4,554
Adjusted R^2	0.936	0.964

Panel B: The role of legal enforcement in moderating the real effects of international GHG reporting mandates

	(1)	(2)
Dep. Var.	*Carbon Emissions*	*Unit Carbon Emissions*
GHG Disclosure Global×LEI	**-0.306***	**-0.171***
	(-1.74)	**(-1.80)**
Controls	Included	Included
Firm/Year Fixed Effects	Included	Included
Number of Obs.	4,554	4,554
Adjusted R^2	0.936	0.965