Navigating Emission Reduction:

The Interaction of Disclosure Regulation and Institutional Support in China*

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Abstract

We examine the impact of a disclosure regulation on corporate carbon emissions and the critical factors that influence its efficacy. In 2021, the Chinese Securities Regulatory Commission (CSRC) introduced a disclosure regulation which requires all public firms to create and report their ESG activities in a specifically designed environmental and social responsibility section in their annual financial statements, and explicitly urged firms to disclose the measures undertaken to reduce their carbon emissions and the outcomes in the section. Using a difference-in-differences design, with the treatment firms defined as those affected by the regulation and the control firms as those indicating its inapplicability, we find a significant decrease in the treatment firms' carbon intensity (emissions) compared to control firms. Motivated by field evidence, we examine and find that the emission reduction effect of the disclosure regulation is observed solely among firms benefiting from the existence of institutional support that facilitate their carbon reduction efforts. Our findings underscore the importance of complementing carbon disclosure regulations with the necessary institutional support.

Key words: disclosure regulation, carbon emissions, ESG, real effects

JEL: Q54, Q58, M41, M48

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1 Introduction

As the impacts of climate change are experienced across the globe, reducing carbon dioxide emissions has become more imperative than ever. In the worldwide discourse on mitigating climate change, China is an indispensable country that cannot be overlooked. China currently stands as the largest carbon dioxide emitter among all countries, being responsible for 27 percent of global carbon dioxide emission and a third of the world's greenhouse gas emission (World Bank, 2022). China's transition to a low-carbon economy is thus crucial for the world to achieve global climate goals. Meanwhile, government plays a significant role in influencing firms' behaviors to achieve stakeholders' objectives through industry policies and regulations. This stakeholder-focused approach may make sustainability reporting regulations in China effective in fulfilling their objectives (Cheng et al. 2022). In this paper, we examine whether a recent disclosure regulation can curtail carbon emissions in Chinese firms and the key conditions necessary for the regulation to achieve its intended purpose.

The disclosure regulation we examine was announced by the Chinese Securities Regulatory Commission (CSRC) on June 28th, 2021, to support the country's "dual carbon" goals (CSRC, 2021a).[1] Specifically, the CSRC mandates listed firms to include an "Environmental and Social Responsibility" section in their annual reports and encourages them to disclose within that section the measures taken to reduce their carbon emissions during the reporting period and the effects of these measures (CSRC, 2021b). As a standard practice, firms create a subsection for this carbon

[1] In September 2020, Chinese President Xi Jinping announced at the 75th session of the United Nations General Assembly that China will aim to peak its carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. The two goals are often referred to together as the "dual carbon" goals in China.

disclosure regulation and select between two options: "applicable" and "not applicable," based on whether they believe the disclosure of carbon management practices is relevant to the firm. Those that select "applicable" then proceed to describe how they attempted to reduce emissions and the results they achieved. We contend that in China's institutional landscape, where the government emphasizes the "dual carbon" goals and closely monitors firms' carbon emissions, firms will choose "not applicable" only if they have an insignificant amount of carbon emissions. Our interpretation of the regulation is supported by survey evidence and a determinant test.

We posit that the disclosure regulation would induce firms to reduce carbon emissions because the increased transparency about the firms' carbon reduction efforts can facilitate monitoring by the government and other stakeholders. However, given the inherent complexities involved in reducing carbon emissions, we expect the disclosing firms to successfully reduce emissions only when they receive institutional support invested by local governments that provides them with the necessary human capital and financial resources.

Using a difference-in-differences design, we compare the change in carbon intensity and carbon emissions among the firms that disclosed their carbon reduction efforts in the 2021 annual reports (treatment firms) with the changes among the firms that indicating that the disclosure regulation did not apply to them (control firms). We focus on CSI 800 firms for which carbon emissions data are available from QuantData between 2018 and 2021, [2] and match treatment and control firms with the level of carbon emission in 2018.[3] We run our analysis using a matched

[2] The China Securities Index (CSI) 800 consists of large, mid, and small-cap stocks listed in the Shanghai Stock Exchange and Shenzhen Stock Exchange. QuantData is a data provider that collects voluntarily disclosed annual carbon emissions (scope 1 and scope 2) from firms in the CSI 800 index and estimates the emissions for the remaining CSI 800 firms.

[3] Treatment sample firms have a wide range of carbon emissions, which allows us to use coarsened exact matching (CEM).

sample formed using coarsened exact matching (CEM), such that the treatment firms and control firms in our sample have similar incentives to reduce emissions prior to the regulation.

Our results show that on average, treatment firms decrease their carbon intensity and emissions relative to control firms following the disclosure regulation. This provides initial evidence of the real effect of the disclosure regulation on carbon emissions reduction. However, unlike many other corporate activities, the task of reducing carbon emissions is one that firm managers are relatively unfamiliar with. Achieving a sustainable reduction in carbon emissions often requires relevant knowledge and resources that may not be readily available to firms (Lu et al. 2021).[4] Therefore, while the disclosure regulation may motivate firms to reduce carbon emissions, such motivation may not translate into actual results unless the firms are supported by institutional infrastructure that facilitate their efforts.

We next test the hypothesis that the disclosure regulation can successfully reduce emissions only if firms receive the relevant institutional support. We construct two measures of institutional support invested by local governments, corresponding to human capital support and green financing support respectively. The institutional support experienced by a firm is measured as the support in the region where its headquarter is located. We re-estimate the difference-in-differences model, interacting the institutional support variable with the *Treat* and *Post* variables. Consistent with our prediction, we find the treatment firms affected by the disclosure regulation reduce carbon intensity more than the control firms only when institutional support is available.

[4] In Lu et al. (2021), which is a white paper featuring a survey of 3836 board secretaries of Chinese listed firms, responses from 597 survey respondents show that the top three difficulties faced by their firms in incorporating ESG topics into their strategic planning are: (1) the lack of detailed EGS reporting guidance (42%), (2) the lack of support from specialized ESG departments or professionals (37%), and (3) the lack of relevant knowledge and skills related to ESG (37%).

These findings underscore the importance of institutional support in reducing firms' carbon emissions. While a disclosure regulation may urge a firm to cut emissions, the motivation alone does not guarantee a decline in emissions. The disclosure regulation can only have a real effect on carbon emissions when complemented by an institutional environment that facilitates the process. Our results hold up to a variety of robustness checks. Moreover, we conduct several additional tests to rule out alternative explanations and bolster our findings with the support of survey results.

Our study contributes to the growing literature on the real effects of greenhouse gas (GHG) disclosure regulations. Prior and contemporaneous studies find that firms reduce their carbon emissions in response to disclosure mandates that require them to report the amount of their GHG emissions (Downar et al. 2021; Jouvenot and Krueger 2021; Tomar 2023). Downar et al. (2021) and Jouvenot and Krueger (2021) examine a UK mandate which requires all listed UK-incorporated firms to report their GHG emissions in annual reports, while Tomar (2023) investigates the public disclosure of industrial facilities' GHG emissions by the US Environmental Protection Agency. What distinguishes our paper is that while prior studies examine carbon disclosure regulations in isolation, we show in our paper that the effectiveness of the disclosure regulation in decreasing corporate carbon emissions hinges on the complementary institutional support that facilitates firms' carbon reduction efforts. Unlike other developed countries, China is still developing and new to the field of carbon emission control. The lacking of skills, knowledge, and financial support have been considered as three top major barriers to introducing ESG activities (Lu et al. 2021), so having such complementary human capital and financial policy support could be crucial in making firms react to the new disclosure policy.

Our paper also adds to the broader literature on the real effects of ESG and CSR reporting by providing empirical evidence from China. Several prior studies examine how the mandatory

disclosure of a specific ESG-related issue, such as mine-safety records, human rights performance, or carbon emissions, affects corporate behavior and the corresponding ESG outcome (Christensen et al. 2017, She 2022, Grewal et al. 2022). Beyond the accounting domain, economic literature provides evidence on the real effects of mandatory disclosure related to restaurant hygiene, workplace safety, public health, and extraction payments (Jin and Leslie 2003; Johnson 2020; Dranove et al. 2003; Rauter 2020). In addition, Chen et al. (2018) examine the impacts of a general CSR reporting requirement in China and show that the cities most impacted by the regulation experience a decrease in wastewater and sulfur dioxide emissions.

Compared to the real effects examined above, whether the disclosure regulation in China can lead to a reduction of carbon emission is less clear for two reasons. First, unlike mine accidents or human right abuse incidents that may attract immediate media attention and trigger public outrage, the adverse consequences of excess carbon emissions manifest in a less tangible manner. It is possible that even after the disclosure, stakeholders still do not pressurize firms sufficiently for them to cut down emissions. Second, reducing carbon emissions is inherently more challenging compared to altering other corporate activities, particularly in regions of China where regulatory support may be lacking. Our study highlights the fact that institutional support facilitates the disclosure regulation to achieve its goal of reducing carbon emissions. Additionally, it provides evidence on the progress of China's emission reductions.

The rest of our paper is organized as follows. Section 2 describes the institutional background. Section 3 introduces our empirical predictions. Section 4 outlines the research design and describes our sample and data. Section 5 presents the empirical findings. Section 6 shows additional analyses and robustness tests. Section 7 concludes the paper.

2 Institutional Background

The reduction of carbon emissions has been a policy priority for the Chinese government in the recent decade. In a joint statement with the US in 2014, China announced a target to peak carbon emissions around 2030. Furthermore, at the 75th session of the United Nations General Assembly in 2020, Chinese President Xi Jinping announced China's "dual carbon" goals—reaching peak carbon emissions by 2030 and carbon neutrality by 2060. To meet these ambitious goals, the central government has set binding carbon reduction targets for each province and integrated these targets into the evaluation criteria for local government officials since 2014.[5] As a result, local government officials have greater incentives to actively monitor and control corporate carbon emissions within their jurisdiction.

To support the "dual carbon" goals, the Chinese Securities Regulatory Commission (CSRC) announced a new disclosure regulation on June 28th, 2021 (henceforth referred to as the "2021 carbon disclosure regulation"). Specifically, the CSRC mandates listed firms to include an "Environmental and Social Responsibility" section in their annual reports and encourages them to disclose within that section the measures taken to reduce their carbon emissions during the reporting period and the effects of these measures (CSRC, 2021b).[6] As a standard practice, firms create a subsection for this carbon disclosure regulation and select between two options "applicable" and "not applicable" based on whether they believe the disclosure of carbon management practices is relevant to the firm. Those that select "applicable" would then continue to describe how they

[5] The ""*Notice of the State Council on Issuing the Work Plan for Controlling Greenhouse Gas Emissions during the 'Twelfth Five-Year Plan' Period*" published in 2012 set a goal of reducing total carbon emissions by 18% by 2015. Starting from 2014, the regional carbon reduction goals have been incorporated into the performance evaluation of local government officials. Officials rated as "excellent" in completing their targets receive commendation priority consideration in relevant project arrangements. Failing to meet these targets results in public notice, corrective actions, and potential legal consequences for officials responsible for inadequate rectification.

[6] This is reflected in Article 41, Item 7 of the *Guidelines for the Content and Format of Information Disclosure by Companies Offering Securities No.2 – Content and Format of Annual Reports* (2021 Version).

attempted to reduce emissions and the results they achieved. Examples of firms' disclosure can be found in Appendix B.

We argue that all listed firms with a substantial amount of carbon emissions will select "applicable" and make the required disclosure in response to the 2021 carbon disclosure regulation, while firms whose carbon emissions are insignificant will select "not applicable." While one may be concerned that firms opportunistically select "applicable" or "not applicable" depending on whether they have achieved a satisfactory reduction in emissions, we contend that such behavior is unlikely in China's institutional environment. Given the government's emphasis on the "dual carbon" goals and the requirement for firms to disclose environmental information in the "Environmental and Social Responsibility" section, the carbon disclosure regulation serves as a governmental signal prompting firms to pledge their commitment in reducing emissions. Within China's institutional landscape, firms feel compelled to heed government signals as maintaining a favorable relationship with the government is pivotal for accessing capital, resources, and economic opportunities (Haveman et al., 2017; Sun et al., 2014). Adhering to the carbon disclosure provision serves as a strategic move for firms to establish political legitimacy (Marquis and Qian 2014). Even if a firm had not initiated carbon reduction measures before the provision, it would be more advantageous for them to commence such measures and disclose them rather than refraining from disclosure, which might attract unwanted regulatory attention. Moreover, since the provision does not mandate the disclosure of exact carbon emission amounts, the proprietary and preparation costs of the disclosure are both relatively low. Given that the benefit of disclosure outweighs the cost, we expect firms to select "applicable" and disclose their carbon reduction efforts unless their carbon emissions are insignificant.

In addition, we expect firms' disclosure to truthfully reflect their carbon reduction efforts because the government can verify their disclosure through private channels. In China's plan-oriented code-law environment, corporate governance is characterized by a stakeholder model (in contrast to the shareholder model in common-law countries), where information asymmetry between a firm and its stakeholders tends to be resolved through private "inside" communications (Ball et al., 2000a; Ball et al., 2000b; 2003, Lu et al. 2023). Anecdotal evidence also suggests that local governments regularly assess a firm's carbon emissions to meet their carbon reduction targets.[7] If a firm were to greenwash itself by fabricating its carbon reduction efforts, the untruthful disclosure can be easily detected in government inspections or when government officials compare the alleged efforts with the firm's actual change in carbon emissions. Once discovered, such misleading disclosure in the financial report would be punishable under the security law. We therefore expect firms to avoid untruthful disclosures due to its costly consequences. In other words, firms are unlikely to greenwash by disclosing carbon reduction measures that they actually did not implement.

To corroborate the above arguments, we examine the response of firms in the first reporting year after 2021 carbon disclosure regulation was announced. Specifically, we download 2021 annual reports of 4,659 firms listed on the Shanghai Stock Exchange and the Shenzhen Stock Exchange. These annual reports all become available after April 2022. Within the "Environmental and Social Responsibility" section of their annual reports, we search for the text "measures taken to reduce carbon emission during the reporting period and the effects of such measures." We find that 1,958 (42%) firms selected "applicable" in response to the text and disclosed their carbon

[7] Two authors of the study travelled to Jiangsu province, China, in July 2023 and had meetings with the officials from the Development and Reform Commission of several municipal governments. They claim that they have their own assessment of carbon emissions per unit of economic output for each enterprise in the respective city.

reduction efforts, while the rest of the firms chose "not applicable." In Table 1 Panel A, we present the industry distribution of the disclosing firms. In carbon intensive industries such as ferrous metal smelting, mining, and chemical fiber manufacturing, majority of the firms disclosed their carbon reduction efforts in their 2021 annual reports. The industries with the smallest percentage of disclosing firms are residential services, cultural/educational/art/sports/entertainment goods manufacturing, and education, which tend to have low carbon emissions. This is consistent with our claim that the non-compliers (firms that chose "not applicable") mostly comprise of firms that had insignificant carbon emissions. We further support this point by presenting survey evidence and by conducting a determinant test.

2.1 Survey Evidence

We conduct a nationwide survey to understand a firm's decision to disclose (or not disclose) its carbon reduction efforts in its 2021 annual report. Following Lu et al. (2023), we targeted board secretaries as our survey audience because they are responsible for their respective firms' information disclosure. We collaborated with New Fortune Magazine to distribute our survey questionnaire. In 2023, New Fortune Magazine distributed a smartphone/website link containing our survey questions to the board secretaries of 4,662 listed firms in China. We received 535 valid responses, yielding a response rate of 11.5%.

Using the survey responses, we examine whether firms disclosed their carbon reduction measures and outcomes in response to the 2021 carbon disclosure regulation and the reasons behind their decisions. 64% of the respondents indicate that their firms disclosed according to the new requirement, while 36% indicate that their firms chose "not applicable" in the sub-section of their annual reports titled "measures taken to reduce carbon emission during the reporting period and the effects of such measures." Figure 1 Panel A shows the reasons for non-disclosure. Among

the non-disclosing firms, 52% indicate that they had inherently low carbon emissions and perceived no necessity to reduce them. 31% indicate that they were unclear about the disclosure requirements, 15% indicate other reasons, while only 2% indicate that they abstained from disclosure because they had not initiated emissions reduction. Taken together, at least 83% of our survey respondents interpreted the 2021 carbon disclosure regulation as if it were a mandatory requirement and disclosed their carbon reduction efforts unless their carbon emissions were insignificant to begin with. Only less than 1% of the respondents strategically avoided disclosure because they had not reduced emissions.

Furthermore, since the 2021 carbon disclosure regulation was introduced to support the country's "dual carbon" goals, we examine whether the disclosing firms increased their carbon reduction efforts in response to the disclosure regulation. As shown in Figure 1 Panel B, 45% of the disclosing firms indicate that they did increase carbon reduction efforts. Figure 1 Panel C presents the reasons behind these firms' decisions. 95% of these firms chose to reduce emissions due to their perception that the disclosure regulation aligns with the country's broader policy trends. Additionally, 71% of the firms indicated that the increased attention from investors, regulators, and other stakeholders served as a motivating factor for their emissions reduction efforts. These findings suggest that a significant number of firms take the 2021 carbon disclosure regulation as a signal from the government and respond by disclosing and taking actions to reduce their carbon emissions.

2.2 The Determinant of Carbon Disclosure

To examine the characteristics that determine a firm's disclosure decision, we run a logistic regression where the dependent variable is an indicator equal to one if a firm selected "applicable" in response to the 2021 carbon disclosure regulation, and zero otherwise.

We include three categories of explanatory variables in the logistic regression. First, we include the stakeholder demand for a firm's environmental information, which is measured using current-year firm characteristics including size, return on assets, price to book ratio, state ownership, institutional holdings, holdings by oversea investors, and analyst coverage. Second, to capture a firm's historical environmental awareness and reporting quality, we use firm characteristics measured in 2020, including the firm's ESG rating, the filing of a corporate social responsibility (CSR) report, the mention of "dual carbon" goals in its annual report, and a rating for the firm's reporting quality. Third, we include a firm's carbon emissions prior to the 2021 disclosure regulation, which is measured using the first principal component of the firm's scope 1 and 2 carbon emission and carbon intensity measured in 2020 (*EmissionPCA*).

Because the carbon emission data are only available for CSI 800 firms (data source is described in Section 4.3), we conduct this analysis over the subsample of CSI 800 firms with the required data on control variables. Table 1 Panel B presents the results of the logistic regression. Among all the statistically significant explanatory variables, *EmissionPCA* has the largest economic magnitude and is positive and significant at the 1% level. This is consistent with our expectation that firms with historically low carbon emissions may consider the carbon disclosure regulation to be irrelevant and choose not to disclose their carbon reduction efforts. In addition, firms with a larger size and lower price-to-book ratio are also more likely to disclose. Notably, the coefficients on *CSRReport* and *MDA2020* are both positive but statistically insignificant. If the 2021 disclosure regulation had not changed firms' incentives to disclose their carbon reduction efforts, we would expect the majority of the disclosers in 2021 to be those firms that had previously filed CSR reports or discussed about carbon reduction in the past. However, our test result suggests

otherwise, further supporting the view that firms did not interpret the 2021 disclosure regulation as merely an encouragement for voluntary disclosure.

3 Hypothesis Development

The primary purpose of the 2021 carbon disclosure regulation is to motivate firms to reduce carbon emissions. In this section, we first develop a hypothesis about the average effect of this disclosure regulation, then develop a second hypothesis about the key conditions for the regulation to effectively achieve its purpose.

We posit that the disclosure regulation would induce firms to reduce carbon emissions because the increased transparency about the firms' carbon reduction efforts can facilitate monitoring by the government and other stakeholders. Due to the top-down pressure to achieve the "dual carbon" goals, local governments in China have been monitoring and controlling corporate carbon emissions in their jurisdictions. The 2021 carbon disclosure regulation allows the government to quickly assess the measures taken by firms to reduce carbon emissions and identify firms that need to improve their carbon emissions management. In addition, other stakeholders such as ESG rating agencies and corporate customers who need to reduce the carbon footprint throughout their supply chain would respond favorably to reductions in the firm's carbon emissions and react negatively if the firm fails to reduce its emissions. In expectation of such stakeholder behavior, the firm's management is likely to take actions to reduce carbon emissions (Matsumura et al. 2014; Downar et al. 2021; Amel-Zadeh and Serafeim 2018; Christensen et al. 2021).

However, since a firm's total carbon emission varies with its production and sales, it is unclear whether the firm's carbon reduction efforts would lead to a decrease in the absolute level of emissions in the short run. For instance, a firm may improve the carbon intensity (i.e., the

amount of carbon dioxide emitted per unit of economic output) in its production process, but still report higher total emissions simply because it produces more units of goods in the same period. Therefore, we state separate hypotheses for carbon intensity and carbon emissions.

First, we expect that on average, the firms that are affected by the 2021 carbon disclosure regulation (i.e., firms that selected "applicable" and disclosed their carbon reduction efforts) will experience a decrease in carbon intensity relative to the unaffected firms (i.e., firms that selected "not applicable" in the carbon-disclosure section of their annual reports). We define carbon intensity as the natural logarithm of carbon emissions to sales over the reporting period.

H1a: *Firms that are affected by the disclosure regulation reduce carbon intensity more than the unaffected firms.*

We expect that, on average, the affected firms will decrease the level of carbon emissions relative to the unaffected firms. However, considering China's high GDP growth in 2021, firms might ramp up their production, potentially counteracting the improvements in the disclosing firms' carbon intensity.[8] In that case, we may observe an increase in carbon emissions across all firms. Nevertheless, if the disclosure regulation motivates firms to increase their carbon reduction efforts, we expect the affected firms to show a smaller increase in carbon emissions compared to their unaffected counterparts.

H1b: *Firms that are affected by the disclosure regulation reduce carbon emissions more than the unaffected firms.*

[8] According to the World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=CN), China's annual GDP growth rate was 6.7%, 6%, 2.2% and 8.4% in 2018, 2019, 2020, and 2021, respectively.

An assumption underlying the above hypotheses is that as long as firms decide to take action following the disclosure regulation, they can effectively reduce carbon intensity (emissions). However, unlike managing financial performance, emission reduction may not be familiar to every firm's management, and it might not be easily attainable even with greater motivation. In fact, a global survey conducted by the Boston Consulting Group in 2021 reveals that while 96% of surveyed companies set emissions reduction targets, only 11% achieved these targets over the past five years (Degot et al. 2021).

We contend that firms are faced with two major challenges in this process. First, many lack access to professionals with expertise in emissions management. Such professionals can help firms measure their carbon emissions accurately and develop effective strategies to reduce emissions. The measurement of carbon emissions involves identifying emission sources, collecting activity data, selecting emission factors, utilizing calculation tools, and aggregating data at the corporate level (Ranganathan et al. 2004). Many firms lack access to emission factors and guidance, resulting in incomplete and inaccurate measurements (Degot et al. 2021).[9] Thus, professionals specialized in verifying carbon emissions and devising emission reduction strategies are highly necessary. However, such human capital remains a scarce resource in China (Lu, Shin, and Wang, 2023). The firms respond that lack of detailed ESG reporting guidance and lack of ESG-related experts and knowledge are listed as the top obstacles. Second, firms may face inadequate financial support during the process of reducing emissions. Efforts to reduce carbon emissions often involve investing in renewable energy, improving energy efficiency in the manufacturing process, or

[9] According to the Boston Consulting Group's global survey in 2021, 81% of respondents omitted some of their scope 1 and 2 emissions, and respondents estimate a 30% to 40% average error rate in their emission measurements. The emission estimates are often computed by multiplying operating data with emission factors. 49% of respondents identified granular operating data as "hard" or "very hard" to find, and 55% of respondents identified granular emission factors as "hard" or "very hard" to find.

switching to sustainable suppliers. Such projects often require substantial upfront investments but have a longer payback period before they start generating significant returns. Securing funding for such ventures can prove challenging.

Given the complexities involved, we predict that the successful reduction of carbon intensity (emission) in firms hinges upon their access to institutional support that provide essential human capital, knowledge, and financial resources. In the absence of such support, we expect no change in a firm's carbon intensity (emissions) following the disclosure regulation.

H2: *The affected firms experience an incremental decrease in carbon intensity (emissions) relative to the unaffected firms only when the necessary institutional supports are available.*

4 Research Design and Data

4.1 Empirical Tests for Hypothesis 1a and 1b

To test our first hypothesis, we apply a difference-in-differences approach on a sample formed by coarsened exact matching (CEM). We estimate the following equation:

$$Carbon_{it} = \beta_0 + \beta_1 \times Treat_i \times Post_t + \sum Controls_{it} + Firm\ FE + Year\ FE + \varepsilon_{it} \quad (1)$$

where $Carbon_{it}$indicates $Intensity_{it}$ when we test hypothesis 1a and $Emission_{it}$ when we test hypothesis 1b. Appendix A provides detailed definitions of all variables. $Emission_{it}$ is defined as the natural logarithm of yearly emissions of carbon dioxide in metric tons. $Intensity_{it}$ is defined as the natural logarithm of yearly emissions of carbon dioxide scaled by sales over the same period.

$Post_t$ is an indicator variable equal to one for fiscal year 2021, and zero otherwise. The fiscal year for all Chinese listed firms starts on January 1st and ends on December 31st. Since the disclosure regulation we examine is effective starting from June 28th, 2021, fiscal year 2021 is the first year of its implementation.

$Treat_i$ is an indicator variable equal to one for firms that selected "applicable" in response to the 2021 carbon disclosure regulation, and zero otherwise. In other words, the treatment group consists of firms that disclosed their work on reducing carbon emissions in their annual reports for fiscal year 2021, while the control group comprises of firms to which the regulation was not applicable. The coefficient on the interaction term *Treat* × *Post* captures the effect of disclosure regulation on carbon emissions (intensity). We expect this coefficient to be negative and significant.

We control for observable firm characteristics that may influence the carbon emission of a firm. Following Downar et al. (2021), we include firm size, asset intensity, price-to-book ratio, and leverage in our regression model. We include firm fixed effect and year fixed effect to account for unobserved firm characteristics that persist through time and shocks to the economy that may affect firms' emissions in a particular year. To mitigate the influence of outliers, we winsorize all continuous variables at the 1st and 99th percentiles.

One concern with the difference-in-differences design, however, is that our treatment group may not be randomly selected. As shown in Table 1 Panel B, treatment firms tend to have larger carbon emissions historically. These firms may have faced more regulatory pressure to curtail emissions throughout our sample period compared to the control firms. Consequently, even without the influence of the disclosure regulation, treatment firms might have consistently reduced emissions every year in response to existing regulatory pressure, while the control firms might not have been under similar pressure. In this case, the coefficient on *Treat* × *Post* reflects not only the effect of the disclosure regulation, but also the inherent difference in the carbon reduction behaviors of the treatment and control firms.

To mitigate this concern, we use coarsened exact matching (CEM) to match treatment firms with control firms based on their carbon reduction incentives at the beginning of our sample period. Specifically, we match treatment and control firms on their carbon emissions and carbon intensity measured in 2018. The CEM method divides all observations into distinct bins based on the characteristics we specify, discards extreme observations in strata that either have no treatment or no control observations, then assigns weights to control observations such that the representation of the control group in each stratum matches that of the treatment group (Blackwell et al. 2009; Iacus et al. 2008). Matched firms are likely to experience similar regulatory pressure and therefore have similar incentives to reduce emissions throughout our sample period. As shown in Figure 2, the treatment and control groups in the CEM-matched sample exhibit parallel trends in both carbon emissions and intensity in the pre-treatment period. In an untabulated test, we estimate a modified version of Eq. (1) where *Post* is replaced with indicator variables for year 2019, 2020, and 2021. For both carbon emissions and carbon intensity, the coefficients on *Treat* × *2019* and *Treat* × *2020* are statistically insignificant. We can thus conclude with more confidence that any post-treatment difference in emissions between the two groups is attributable to the disclosure regulation. We present our main results using the CEM-matched sample.

4.2 Empirical Test for Hypothesis 2

In Section 3, we contend that firms need to have adequate human capital and financial resources in order to successfully reduce emissions. To test this hypothesis, we construct two measures of institutional support that corresponds to each of these resources.

First, to assess support in terms of human capital, we gauge the presence of authorized carbon emission verification agencies in the province where a firm's headquarter is located. These verification agencies function as independent entities responsible for evaluating and validating the

accuracy of reported carbon emissions. They may also perform tasks such as conducting audits, verifying emission reduction projects, and certifying the legitimacy of carbon credits. Given the complexity of these responsibilities, verification agencies are staffed with qualified professionals with skills and expertise related to emissions management. In particular, verification agencies that are authorized by the government to participate in the emissions trading system are required to maintain a minimum number of certified carbon-verification professionals within their organization.[10] Therefore, we use the number of authorized verification agencies as a proxy for the number of skilled professionals within a region. We manually gather data on authorized verification agencies from publicly disclosed government procurement contracts found on regional governments' websites. We then construct a variable "*Personnel",* which is the number of authorized verification agencies in a region scaled by the corresponding regional GDP (in trillion RMB), to measure the availability of skilled professionals within that region.

Second, to measure support in terms of financial resources, we use the implementation of "re-lending" policy in the province where a firm's headquarter is located. Re-lending is a monetary policy tool used by the People's Bank of China or its provincial branches to provide low-cost credit loans to commercial banks to subsidize their lending to green projects. Typically, banks may be hesitant to finance carbon reduction projects due to their long payback periods. The central bank's re-lending, featuring low interest rates and prolonged repayment cycles, may encourage such funding. Therefore, we use the availability of the re-lending tool at the provincial level as an

[10] In order to create a market-based mechanism for reducing carbon emissions, China has established eight carbon trading pilot regions since 2013 (i.e., Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Shenzhen, and Chongqing). Each pilot region sets up and independently manages its own emissions trading system (ETS). The national ETS was launched in July 2021. Although the national ETS only covers the power sector so far, more industries will be required to participate in the future. In preparation for the national or local ETS, most of the provincial governments in China have appointed authorized carbon emission verification agencies through procurement contracts. Authorized verification agencies generally have to be local, sufficiently funded, and have at least a certain number of carbon-verification professionals affiliated with the agency.

indicator of the financial backing for carbon reduction initiatives. We obtain the re-lending policy data from the 2020 and 2021 *Annual Report on the Development of Local Green Finance in China*.[11] We then construct an indicator variable, *GreenFinance*, which is equal to one if a region has re-lending support for green projects by the end of 2021 and equal to zero otherwise.

After constructing the two measures of institutional support, we test the second hypothesis by estimating the following equation on the CEM-matched sample:

$$Carbon_{it} = \beta_0 + \beta_1 \times Treat_i \times Post_t \times PolicySupport_i + \beta_2 \times Treat_i \times Post_t + \beta_3 \times Post_t \times PolicySupport_i + \sum Controls_{it} + Firm\ FE + Year\ FE + \varepsilon_{it} \quad (2)$$

where *i* indicate firm and *t* indicate year. The dependent variable, $Carbon_{it}$, takes the value of $Intensity_{it}$ or $Emission_{it}$. $PolicySupport_i$ is the number of distinct types of supportive policies within the region where firm *i* is headquartered, and takes the value of 0, 1, or 2.

To examine the specific effect of a particular type of support, we estimate a modified version of Eq. (2), where we replace $PolicySupport_i$ with $Personnel_i$ or $GreenFinance_i$. $Personnel_i$ is a proxy for the availability of emissions management professionals in a region and is computed as the number of authorized verification agencies in the region in 2021 scaled by the corresponding regional GDP (in trillion RMB). $GreenFinance_i$ is an indicator variable equal to 1 if a region has refinancing support for green projects by the end of 2021, and equal to 0 otherwise. The detailed definition of all variables can be found in Appendix A.

We expect the coefficient on $Treat_i \times Post_t \times PolicySupport_i$ to be negative and significant, and the coefficient on $Treat_i \times Post_t$ to be statistically insignificant. In other words,

[11] The report is published by scholars from the International Institute of Green Finance at the Central University of Finance and Economics. It summarizes the regional re-lending policies supporting green initiatives since 2010. The report has been cited by the People's Bank of China in the *China Regional Financial Operations Report*.

we expect the disclosure regulation to result in effective emission reductions when it is complemented with institutional support. In places without institutional support, the disclosure regulation alone may not lead to significant emission reductions.

4.3 Data and Sample

Since the listed firms in China are not required to disclose the amount of carbon emissions, we obtain emissions data from QuantData, a database that provides scope 1 and scope 2 carbon emission data for CSI 800 firms from 2018 onwards. QuantData collects carbon emissions that CSI 800 firms voluntarily disclose and use that data to estimate the emissions of the other firms within the CSI 800 index. Data for the control variables are obtained from the China Security Market and Accounting Research (CSMAR) database. Data on verification agencies are hand-collected from government procurement contracts found on provincial governments' websites, and data for re-lending is obtained from the 2020 and 2021 *Annual Report on the Development of Local Green Finance in China*. Appendix C provides details on the institutional support offered by each region.

We delineate the sample selection process in Table 2. Our initial sample consists of CSI 800 firms for which carbon emissions data are available for the period 2018-2021 (768 unique firms, 2750 firm-year observations). We exclude 122 firm-years that are missing data required for the control variables in Eq. (1). We also exclude firms without at least one observation each in the periods before and after the implementation of the disclosure regulation in 2021. This drops another 114 firm-years (98 unique firms) from our sample.

Next, we remove firms that experience any year-over-year change in carbon emission that ranks among the top or bottom 1% among all firm-years. This is because our manual reading of the sample firms' CSR reports suggests that such drastic changes in carbon emission usually result

from endogenous changes in the scope of measurement or data errors.[12] We drop 35 firms (134 firm-years) that exhibit such drastic changes, so that they do not confound our results. This leaves us a sample of 633 unique firms and 2380 firm-years, which we refer to as the "CSI 800" sample.

In the last step, we use the CEM method to match the treatment and control firms on their carbon emissions and carbon intensity measured in 2018. The CEM method "coarsens" all observations into distinct bins based on the characteristics we specify and discards extreme observations in bins that lack either treatment or control observations (i.e., lack of common support). After the CEM method drops observations that lack common support, our final sample comprises of 492 unique firms and 1961 firm-year observations. We refer to this final sample as the "CEM-matched sample" and use it for our main analysis.

Table 3 presents descriptive statistics for the CSI 800 sample (Panel A) and the CEM-matched sample (Panel B). The average natural logarithm of yearly carbon emission is 10.132 for the CSI 800 sample (equivalent to 25,135 metric tons), and 9.819 for the CEM-matched sample (equivalent to 18,380 metric tons). The average carbon intensity is -6.322 for the CSI 800 sample and -6.514 for the CEM-matched sample. Compared to the CSI 800 sample, the CEM-matched sample consists of firms that emit less carbon dioxide both in terms of the absolute amount and intensity, indicating that some firms with higher emissions are dropped in the matching process due to the lack of common support. The CEM-sample also exhibits lower average and median values in firm size, asset intensity, price-to-book ratio, and leverage.

[12] For example, China Merchants Bank (600036.SH) disclosed its total carbon emissions from 2019 to 2021 in its sustainability report for 2021. However, the emissions reported for 2019 and 2020 only account for emissions from the head office building, whereas the reported emissions for 2021 include both the head office and 44 additional branches in mainland China. This expansion in the measurement scope results in China Merchants Bank's carbon intensity in 2021 being 22.41 times greater than that of 2020.

Panel C of Table 3 reports the difference in means between treatment and control groups for the CSI 800 sample (before matching) and for the CEM-matched sample (after matching) respectively. Before matching, treatment firms have significantly higher carbon emissions and intensity than control firms. Since firms that emit more tend to face greater regulatory and social pressure to reduce their emissions, one may be concerned that such external pressure is the driving force behind both treatment firms' decision to comply with the disclosure regulation and their reduction in carbon emissions. After CEM matching, however, the treatment and control firms do not exhibit a significant difference in carbon emissions or intensity.

Panel D of Table 3 shows the Pearson correlations among the variables used in Eq. (1). We do not observe any high correlations among control variables.

5 Empirical Results

5.1 The effect of disclosure regulation on carbon intensity and emissions

Table 4 presents our findings on the effect of the disclosure regulation on carbon intensity and emissions. The first two columns report our main result obtained by estimating Eq. (1) on the CEM-matched sample. Column (1) uses carbon intensity as the dependent variable and shows a negative coefficient on *Treat* × *Post* (coefficient= -0.078, p-value < 0.05). This implies that the treatment firms reduce their emissions per yuan of sale by 7.5% (1 - exp(-0.078)). Column (2), in which the dependent variable is carbon emissions, also shows a significantly negative coefficient on *Treat* × *Post* (coefficient= -0.09, $p < 0.10$). In economic terms, the coefficient of -0.09 indicates that the treatment firms reduce their carbon emissions by 8.6% (1 - exp(-0.09)) on average in response to the disclosure regulation. The low statistical significance may reflect the counteracting effects of reduced carbon intensity and increased production quantity.

These results are consistent with the visual evidence presented in Figure 2, which plots the carbon intensity and carbon emissions for the CEM-matched firms throughout our sample period. Figure 2 depicts a decline in carbon intensity for treatment firms following the disclosure regulation. In addition, it shows an increase in carbon emissions for both treatment and control firms in 2021, likely attributable to increased production across the board driven by the high GDP growth in 2021. However, in line with our prediction, the treatment firms exhibit a smaller increase in carbon emissions compared to the control firms.

To assess the robustness of our results, we re-estimate Eq. (1) using the CSI 800 sample and report the results in columns (3) and (4) of Table 4. For both carbon emissions and carbon intensity, the coefficients on *Treat* × *Post* remain negative and statistically significant. Overall, we interpret the results in Table 4 and Figure 2 as evidence that the disclosure regulation reduces carbon intensity and emissions on average.

5.2 The effect of disclosure regulation with and without institutional support

Table 5 reports the results of estimating Eq. (2). In Panel A, we aggregate both types of institutional support into one measure named *PolicySupport*. The variable takes the value of 0, 1, or 2 depending on the number of distinct supportive policies available within the region where a firm is headquartered. Accordingly, the carbon reduction effect of the disclosure regulation alone (i.e., without any institutional support) is captured by the coefficient on *Treat* × *Post*, while the effect of the disclosure regulation supported by other policies is reflected by the coefficient on *Treat* × *Post* × *PolicySupport*.

In column (1) of Panel A, the coefficient on *Treat* × *Post* × *PolicySupport* is negative and significant (coefficient= -0.119, p-value < 0.05), indicating that when institutional support is available, the treatment firms affected by the disclosure regulation reduce carbon intensity more

than the control firms. On the other hand, the coefficient on *Treat* × *Post* is statistically insignificant, suggesting that the treatment firms cannot successfully reduce carbon intensity without additional institutional support. Column (2) shows similar results for carbon emissions, with the coefficient on *Treat* × *Post* × *PolicySupport* being negative and significant (coefficient= -0.123, p-value < 0.05) and the coefficient on *Treat* × *Post* being statistically insignificant. These findings are consistent with our prediction that even with the disclosure regulation, firms can successfully reduce carbon intensity (emissions) only when they receive institutional support that facilitates their efforts.

In Table 5 Panel B, we re-estimate Eq. (2), replacing *PolicySupport* with specific types of institutional support. In columns (1) and (2), we replace *PolicySupport* with *Personnel*, which measures the availability of emissions management professionals in the region where a firm is headquartered. In columns (3) and (4), we replace *PolicySupport* with *GreenFinance*, which is an indicator variable equal to one if a region has policies providing refinancing support for green projects. Column (1) shows a negative and significant coefficient on *Treat* × *Post* × *Personnel* (coefficient= -0.032, p-value < 0.05), whereas column (3) shows a more negative coefficient on *Treat* × *Post* × *GreenFinance* (coefficient= -0.216, p-value < 0.05). This suggests that both types of institutional support are effective in helping firms reduce carbon intensity, and the effect of providing green loans is stronger. In both columns (1) and (3), the coefficient on *Treat* × *Post* is statistically insignificant, consistent with the results presented earlier. The results for carbon emissions are shown in columns (2) and (4) and are similar to the results for carbon intensity. Overall, Panel B demonstrates that both types of institutional support can facilitate firms' carbon reduction efforts, and green finance provides better support than verification agencies.

Collectively, the findings presented in Table 5 underscore the crucial role of institutional support in mitigating firms' carbon emissions. When such supports create an institutional environment with adequate human capital and financial resources, the implementation of a disclosure regulation can lead to a reduction in carbon emissions through increasing firms' efforts. But in the absence of such support, disclosure regulation by itself cannot yield substantial carbon reduction.

6 Additional Analyses and Robustness Tests

We present several additional tests to corroborate our findings. First, we exclude the power sector from our analysis to mitigate the concern that our results are affected by the launch of the national emissions trading system in 2021 which requires firms in power sector to participate. Second, we run a falsification test to show that our results are not driven by the policy trend related to the "dual carbon" goals announced in 2020. Third, we run cross-sectional tests to strengthen our inference that institutional support affects the effectiveness of firms' carbon reduction efforts. Fourth, we conduct a falsification test to address the alternative explanation that the political pressure for local governments to reduce carbon emissions drives both the level of institutional support and local firms' carbon emissions. Lastly, we conduct several robustness checks.

6.1 Excluding the Power Sector

One potential concern is that our results may be driven by contemporaneous changes in the institutional environment. In particular, China established the national ETS in July 2021, obliging firms in the power sector to measure their emissions and participate in carbon trading in the national market. It is possible that firms in the power sector started reducing their emissions in response to the launch of the national ETS and were at the same time more likely to disclose their carbon reduction efforts in the annual report.

To mitigate this concern, we exclude firms in the electricity, heat production and supply industry (CSRC industry classification code D44) from the CEM-matched sample and re-run our analysis for hypotheses 1. Table 6 presents the results from this analysis. In column (1), the coefficient on *Treat* × *Post* is negative and marginally significant, suggesting that there is still a decrease in the treatment firms' carbon intensity (coefficient= -0.072, p-value < 0.10) following the 2021 disclosure regulation. In column (2), the coefficient on *Treat* × *Post* is negative but marginally insignificant (coefficient= -0.070, t=-1.571). Using the sample excluding the firms in the power sector to test hypothesis 2, we find that the results are only significant for the firms in the regions with institutional support. These findings suggest that our results are robust to the sample without the firms in the power sector.

6.2 Falsification Tests

We conduct falsification tests to address alternative explanations of our findings. An alternative explanation for the results in testing our hypothesis 1 is that carbon-intensive firms have been reducing emissions in response to the "dual carbon" policy goals announced in 2020, and the actions they took resulted in the reduction in their emissions in 2021. For example, a firm could have started installing solar energy facilities following the announcement of the "dual carbon" policy in September 2020 and, upon the completion of the project, disclosed it as a carbon reduction measure in its annual report in fiscal year 2021. If that is the case, we cannot attribute the reduction in carbon emissions to the 2021 disclosure regulation.

To mitigate this concern, we conduct a falsification test by re-estimating Eq. (1) and replacing $Treat_i$ with $MDA2020_i$, which is an indicator variable equal to one if a firm mentioned "carbon peak", "carbon neutrality", or "dual carbon" in the Management Discussion and Analysis section of its annual report for fiscal year 2020, and 0 otherwise. We use $MDA2020_i$ to capture

whether a firm actively responded to the announcement of the "dual carbon" policy goals in 2020. If our results are driven by firms' response to the "dual carbon" policy announcement, we should observe a negative and significant coefficient on $MDA2020_i \times Post_t$. However, as shown in Table 7 Panel A, the coefficient on $MDA2020_i \times Post_t$ is statistically insignificant. This evidence provides some assurance that the treatment firms' reduction in emissions is attributable to the 2021 carbon disclosure regulation instead of their response to the "dual carbon" policy announcement.

Similarly, an alternative explanation of our hypothesis 2 result is that the political pressure for local governments to reduce carbon emissions may drive both the level of institutional support and local firms' carbon emissions. As explained in Section 2, the central government has been assigning carbon reduction targets to each province and has integrated these targets into the evaluation criteria for local government officials. When a local government faces greater pressure to reduce emissions, it may invest more in institutional support and simultaneously push local firms to reduce emissions after the 2021 disclosure regulation.

We run another falsification test to rule out this alternative explanation. To measure the political pressure faced by each local government, we take the regional carbon reduction targets announced in the 13th Five-Year Plan (covering the period from 2016 to 2020) and construct a variable, $Target_i$, which is the intended percentage of reduction in greenhouse gas emissions for a region. We first re-estimate Eq. (2), replacing $PolicySupport_i$ with $Target_i$. The regression results are shown in columns (1) and (2) of Table 7 Panel B. The coefficient on $Treat_i \times Post_t \times Target_i$ is statistically insignificant for both columns, suggesting that greater political pressure faced by a local government does not drive local firms to reduce emissions more in response to the 2021 disclosure regulation. In columns (3) and (4), we simultaneously include $PolicySupport_i$, $Target_i$, and their respective interactions with $Treat_i \times Post_t$ in the regression.

In both columns, the coefficients on $Treat_i \times Post_t \times PolicySupport_i$ are negative and statistically significant, while the coefficients on $Treat_i \times Post_t \times Target_i$ are statistically insignificant. Therefore, we conclude that variation in the political pressure faced by local governments does not drive our results.

6.3 Carbon Management Experience

To corroborate our findings on how institutional support facilitates firms' carbon reduction efforts, we show that the effectiveness of institutional support varies according to firms' pre-existing carbon management experience. We consider a firm to be experienced in carbon management if it has been required to participate in one of China's regional emission trading systems (ETS).[13] Since the establishment of these regional ETSs in 2013 and 2016, participating firms have been regularly measuring their carbon emissions and working to restrict their emissions below the given quota.[14] With this experience, such firms are likely to have utilized carbon management professionals and devised carbon reduction strategies before the 2021 disclosure regulation.

Since the experienced firms already have access to the necessary human resources, we expect that external institutional support in terms of human capital will not have a significant impact on their carbon emissions. We test this by estimating Eq. (2) separately for experienced and inexperienced firms, replacing $PolicySupport_i$ with $Personnel_i$. Panel A of Table 8

[13] As a part of the country's efforts to test-run a market-based solution for reducing carbon emissions, China established eight pilot regions for carbon emissions trading—Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen in 2013, and Fujian in 2016. The regulator in each pilot region identifies a list of locally registered firms that emit a large amount of carbon dioxide and requires these firms to participate in the ETS.
[14] Within each pilot region, the regulator sets a cap on the total amount of greenhouse gases that could be emitted by the covered firms. The total allowance is then allocated to the covered firms in the form of emission permits. Covered firms who exhaust their emission permits would have to buy additional permits from other firms in the market to offset their own emissions. On the other hand, firms who have not used up their permits could sell them for a profit. The price of the emission permits is determined by supply and demand.

presents the regression results for experienced firms in columns (1) and (2), and the results for inexperienced firms in columns (3) and (4). Consistent with our expectation, the coefficient on $Treat_i \times Post_t \times Personnel_i$ is statistically insignificant for experienced firms and is negative and significant for inexperienced firms.

On the other hand, we expect experienced firms to reduce carbon emissions more effectively than inexperienced firms when green finance policies are available. This is because the experienced firms may already have a clear understanding of how to reduce their emissions and can readily use the funding provided through green finance to implement their strategies. To test this, we estimate Eq. (2) separately for experienced and inexperienced firms, replacing $PolicySupport_i$ with $GreenFinance_i$. Panel B of Table 8 presents the regression results. As shown in columns (1) and (3), when the dependent variable is $Intensity_{it}$, the coefficient on $Treat_i \times Post_t \times GreenFinance_i$ is negative and statistically significant both for experienced firms (coefficient= -0.338, p-value < 0.05) and for inexperienced firms (coefficient= -0.196, p-value < 0.05). This suggests that green finance policies help all the treatment firms reduce carbon intensity after the disclosure regulation, although this effect is stronger for experienced firms. Columns (2) and (4) show that when the dependent variable is $Emission_{it}$, the coefficient on $Treat_i \times Post_t \times GreenFinance_i$ is negative and statistically significant for experienced firms (coefficient= -0.549, p-value < 0.01) and is statistically insignificant for inexperienced firms (coefficient= -0.169, p-value > 0.10). This indicates that experienced firms can better leverage the green finance policies to reduce their carbon emissions.

6.4 Ex-post Policy Support

We further show that if a policy is provided to reward firms ex-post instead of facilitating the process of reducing emissions, then the policy will have limited effectiveness in helping firms

reduce emissions. Specifically, besides designating carbon verification agencies and introducing green finance policies, many regions have also announced carbon-reduction reward programs. By the end of 2021, Beijing, Shenzhen, Shanghai, and Guangdong have each introduced their own program, offering monetary payments to qualified projects that mitigate pollution or improve energy efficiency through technological transformations of a firm's existing production process. For example, the Beijing municipal government awards up to 50% of the investment cost to projects that applied green technology to a firm's production process and achieved significant energy savings or reductions in emission.

Unlike policies providing human capital or green finance, reward policies are conditional on the successful completion of green projects and are less likely to benefit firms that have relatively less experience in green innovation. To test this, we construct a measure $Reward_i$ which is an indicator variable equal to 1 if a regional government offers rewards or subsidies for carbon reductions by the end of 2021, and 0 otherwise. We then re-estimate Eq. (2), replacing $PolicySupport_i$ with $Reward_i$. The results are presented in Table 9. Columns (1) and (2) shows that the reward policy indeed does not have a significant impact for the full sample of firms, as the coefficient on $Treat_i \times Post_t \times Reward_i$is statistically insignificant.

We then run the same regression separately for experienced firms and inexperienced firms. We expect rewards to provide experienced firms with additional incentive to invest in sustainable projects, resulting in lower carbon intensity. On the other hand, we expect reward policies to have no effect on inexperienced firms' carbon intensity or emissions, because the incentive alone cannot help them overcome the technical or financial difficulties of reducing emissions. Consistent with our expectation, the coefficient on $Treat_i \times Post_t \times Reward_i$ is negative and statistically significant only in column (3) (coefficient= -0.333, p-value < 0.05), suggesting that ex-post

rewards can help experienced firms reduce carbon intensity, but is ineffective for inexperienced firms.

6.5 Robustness tests

Because our analyses are based on a CEM-matched sample, we conduct several robustness tests of our main findings, varying the conditions involved in the matching process. The results are shown in the Online Appendix. First, we increase the number of bins used in the CEM matching process to achieve more precise matching. Second, we match treatment and control firms using additional firm characteristics (i.e., Size, Asset intensity, PB, and Leverage measured in 2021) along with the carbon emissions and intensity measured in 2018. Lastly, we match on an alternative proxy for a firm's incentive to reduce emissions—the GHG rating provided by the Rankings ESG Ratings (RKS) database, which evaluates the planning, implementation, and performance of firms' greenhouse gas emission management. For all three robustness tests, the results for both hypotheses 1 and 2 remain unchanged. Our results are also robust to the use of industry-year or province-year clustering.

7 Conclusion

This study contributes to the literature on the real effects and the limitations of ESG-related disclosure regulations. While prior studies examine carbon disclosure mandates as standalone regulations, we underscore the importance of supporting policies in making such disclosure regulations effective in reducing firms' carbon emissions.

Exploring variations in the level of institutional support across different provinces in China, we find that the disclosure regulation reduces carbon intensity and emissions for firms benefiting from public investment in establishing knowledge, skills, and green financing infrastructure but have no significant effect in the absence of the investment in institutional support. These findings

have important policy implications—disclosure regulations intended to reduce carbon emissions should be accompanied by other policies that provide firms with the human capital and financial resources that facilitate their carbon reduction efforts.

Our findings, however, should be interpreted with two caveats in mind. First, China is an economy with connected stakeholders in which central and local governments could significantly affect firms' economic activities through their specific institutional support and intervention. Whether the findings are generalizable to other shareholder-based markets remains to be tested. Second, while we contend that the 2021 disclosure regulation operates as a mandatory requirement due to the political cost of non-disclosure, we acknowledge that it may not be as binding as a formal mandatory regulation. Consequently, we cannot fully rule out the possibility of self-selection—firms that have already been reducing their emissions before 2021 may be more inclined to disclose their carbon reduction efforts in the annual reports, whereas others may refrain from disclosure. In that case, the treatment effect for our first hypothesis will be overestimated. Although we alleviate this concern by using a CEM-matched sample to conduct our analysis, we recognize that this concern cannot be fully addressed. We hope that our field work provides additional insights to mitigate the effect of the self-selection limitation.

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Appendix A. Variable Definitions

Variable	Definition	Data source
Main regressions		
Intensity	Natural logarithm of annual greenhouse gas emissions (scope1 + scope2) scaled by sales (in thousand RMB)	QuantData
Emissions	Natural logarithm of annual greenhouse gas emissions (scope1 + scope2) in metric tons of CO_2eq	QuantData
Treat	An indicator variable equal to 1 if the firm disclosed its carbon reduction measures and results in the annual report for 2021, and 0 otherwise.	Hand collected from firms' annual reports
Post	An indicator variable equal to 1 for fiscal year 2021, and 0 otherwise.	
Size	Natural logarithm of a firm's market value in thousand RMB.	CSMAR
AssetIntensity	Fixed assets divided by total assets.	CSMAR
PB	Market value to book value of equity.	CSMAR
Leverage	Total liabilities divided by total assets.	CSMAR
Personnel	The number of authorized carbon verification agencies in a region in 2021, scaled by the corresponding regional GDP (in trillion RMB) in 2020.	The China Government Procurement Network (http://www.ccgp.gov.cn/), its regional branches, and other government websites
GreenFinance	An indicator variable equal to 1 if a region has refinancing support for green projects by the end of 2021, and 0 otherwise.	The Annual Report on the Development of Local Green Finance in China (2020) (2021)
PolicySupport	The number of distinct types of supportive policies within the region where firm i is headquartered. For example, if *Personnel* is above sample median and *GreenFinance* equals 1, then *PolicySupport* score is 2.	
Determinant model		
ROA	Net income divided by total assets.	CSMAR
SOE	An indicator variable equal to 1 for state-owned enterprises whose ultimate controlling owner is the government, and 0 otherwise.	CSMAR
InstHolding	The number of shares held by funds divided by the total number of outstanding shares.	CSMAR
Oversea	An indicator variable equal to 1 if the firm has at least one oversea shareholder among its top 10 shareholders, and 0 otherwise.	CSMAR
AnalystCov	Natural logarithm of the number of analysts (teams) covering the firm.	CSMAR

ESG	A firm's ESG rating provided by WIND (1: C, 2: B, 3: BB, 4: BBB, 5: A, 6: AA). There is no rating lower than "C" or higher than "AA" in 2020.	WIND
CSRReport	An indicator variable equal to 1 if the firm issues a standalone CSR report, and 0 otherwise.	CSMAR
MDA2020	An indicator variable equal to 1 if the firm discussed "carbon peak," "carbon neutrality," or "dual carbon" in the Management Discussion and Analysis section of its annual report for 2020, and 0 otherwise.	Hand collected from firms' annual reports
RepQuality	A firm's reporting quality rating provided by the stock exchanges (0: D, 1: C, 2: B, 3: A).	CSMAR
EmissionPCA	The first principal component of *Emission* and *Intensity* obtained from a principal component analysis. Both *Emission* and *Intensity* are measured in 2020.	QuantData
Additional tests		
Experience	Identified by firms' participation in regional or national carbon emission trading systems (ETS).	CSMAR
Reward	An indicator variable equal to 1 if a regional government offers rewards or subsidies for carbon reductions by the end of 2021, and 0 otherwise.	Hand collected from government websites
Target	The intended percentage of reduction in greenhouse gas emissions in a region during the 13th Five-Year Plan (2016-2020), as stipulated by the central government's emission reduction objectives.	Hand collected from government websites

Appendix B. Examples of carbon reduction measures

This table summarizes the carbon reduction measures disclosed by the firms in our sample that achieved the most substantial carbon reduction in 2021. We start from the treatment firms in our sample, sort them based on the change in carbon intensity (defined as the natural logarithm of annual carbon emissions scaled by sales) from the pre-period to the post-period, and take the 42 firms whose decrease in carbon intensity rank among the top 10% for further examination. We manually read the disclosures made by each of these firms and categorize the carbon reduction measures they mentioned. In the following table, the first column lists the category of carbon reduction measures adopted, the second column shows the percentage out of the 42 firms that adopted each category of measures, and the third column presents real examples of the carbon disclosure that falls under each category.

Category of carbon reduction measures	% of adoption	Examples of disclosure
Management and accounting	50%	Transfar Zhilian Co.,Ltd, stock code 002010: Transfer Zhilian has established a special task force for dual carbon goals. Focused on the national dual carbon goals, the task force aims to comprehensively assess its carbon footprint, identify effective reduction strategies, and solidify its carbon management system and capabilities. This initiative seeks to clarify the group's dual carbon objectives and implementation roadmap, enhancing its technical expertise to provide low-carbon services throughout the supply chain. By aligning with the green transformation trend, the company aims to seize new opportunities and drive the overall upgrade of the group's sustainability efforts. BGI Genomics Co., Ltd., stock code 300676: To embody the concept of green operations, the company initiated the calculation of the ISO 14067 product carbon footprint during the reporting period. This process provides a quantitative benchmark for setting the company's carbon reduction goals and measures, contributing the necessary corporate effort towards the national 'dual carbon' strategic objectives.
Green production and operations	45%	Guotai Junan Securities Co Ltd., stock code 601211: 1. To reduce paper usage, the company has implemented electronic stamping, online approval and attendance processes, and electronic document management methods. We have adopted online meetings through corporate WeChat, and materials for these meetings are digitized. Paper printing is minimized by utilizing double-sided printing, resizing, and recycling waste paper. 2. To save electricity, the company encourages employees to turn off unnecessary electrical devices during non-working hours, and all non-essential switches are turned off. Energy-efficient light tubes have been

		installed in office spaces to comprehensively reduce power consumption.
Low-carbon lifestyles	45%	Lingyi iTech (Guangdong) Co. A, stock code 002600: We incorporate energy-saving knowledge into our daily training programs, including "low energy consumption" as a criterion for factory and office equipment procurement. We launch an "Energy Saving and Consumption Reduction Initiative" among employees, instilling awareness of resource conservation. We encourage paperless offices, promote electricity conservation, minimize standby time for office computers and production equipment, and promptly turn off unnecessary electrical appliances and lighting switches. We have established relevant policies to ensure lights are turned off after work and during breaks, set the air conditioning temperature no lower than 26 degrees Celsius in summer, and organize regular inspection teams to eliminate wasteful practices.
Energy replacement: using renewable and clean energy	38%	Will Semiconductor Co Ltd Shanghai., stock code 603501: The company constructed a rooftop solar photovoltaic power station in the Songjiang Park, Shanghai, with a total installed capacity of 1.61MW. As of the end of this reporting period, the cumulative electricity generation from the rooftop photovoltaic system at the Shanghai Songjiang Park reached 2,170,920 kWh.
Enhancing the efficiency of vital energy-consuming equipment	38%	Yunnan Tin Co Ltd, 000960: The company advanced the transformation of high-efficiency energy-saving equipment, applying variable frequency speed control technology to more than 1,000 sets of equipment, including fans and pumps. Over 500 sets of high energy-consuming and low-efficiency sand and water pumps underwent transformation. SH15-type energy-saving transformers were selected to replace high-energy-consuming S-type and SJ-type transformers, with an updated capacity of over 100,000 kilovolt-amperes. Additionally, more than 1,500 sets of high-energy-efficient motors were used to replace inefficient motors with high energy consumption.
Resource recycling	26%	Shanxi Lu'an Green Energy Co., Ltd, stock code 601699: In 2021, Lu'an Green Energy Co., Ltd.'s nine coal mining units comprehensively utilized extracted coal mine gas (for power generation and oxidation heating), with an annual utilization volume of approximately 126 million cubic meters.

Green products and services	24%	Orient Securities Co. Ltd, stock code 600958: As a financial enterprise, the company leverages its financial expertise to support the development of green and environmentally friendly businesses through investment and financing. In the field of financing, in 2021, the company assisted Huzhou Urban Investment and Development Group Co., Ltd. in issuing the nation's first carbon-neutral corporate bonds dedicated to constructing green buildings. Additionally, the company underwrote the issuance of Three Gorges Group's inaugural carbon-neutral green corporate bonds.
Green power procurement	12%	Pharmaron Beijing Co., Ltd., stock code 300759: In response to the calls and guidance from the local governments where our operations are located, we actively utilize clean energy to promote the reduction of carbon emissions. Taking the example of Pharmaron UK's Hoddesdon campus, 43% of its annual electricity consumption is derived from clean power sources.
Enhancement of ecological system carbon sink capacity	12%	Hainan Mining Co., stock code 601969: Enhancing Carbon Sequestration Capacity in Mines: During the reporting period, our afforestation team cultivated 360,000 seedlings, and we invested 7.363 million RMB in environmental land reclamation. This resulted in the successful reclamation of 100.8 acres of land.
Green and low-carbon transportation	10%	China Molybdenum, stock code 603993: Phasing out outdated, high-emission old vehicles, rigorously implementing environmental protection measures, uniformly retiring non-mobile machinery below National Emission Standard III and transportation vehicles below National Emission Standard V. Actively promoting the use of pure electric new energy vehicles for mining transportation.
Integrating green and low-carbon principles into supply chain processes	10%	China Securities Co.,Ltd., stock code 601066: The company also actively fulfills its corporate social responsibility for green procurement. During the procurement process, suppliers are required to sign a "Qualified Supplier Commitment Letter," urging them to strengthen their emphasis on energy conservation, carbon reduction, and the use of renewable energy.
Investment in green industries	10%	Metallurgical Corporation Ltd., stock code 601618:

		The company closely follows the national low-carbon development strategy, using environmental innovation technology as a lever. It actively leverages its role in the metallurgical industry, accelerating the layout of green industries such as green metallurgy, wastewater treatment, waste-to-energy, and clean energy. The company attracts financial resources, including green and low-carbon loans, to lead the transformation of its business towards green and sustainable development.
Research and development to advance green and low-carbon technologies	10%	Metallurgical Corporation Ltd., stock code 601618: The company focuses on the development of energy-saving and environmental protection technologies to support energy conservation and consumption reduction in the steel and metallurgy industry. The company initiated the "181 Plan," a major research and development project covering areas such as steel and metallurgy processes, green development, intelligent manufacturing, and cutting-edge technologies. Additionally, the company vigorously promotes green and low-carbon metallurgical technologies, with green steel as a core focus. It efficiently integrates research and development resources, actively promotes collaborative innovation among its subsidiaries, and initiates key technology research and development projects related to energy conservation, energy recycling, waste disposal, and resource utilization in metallurgical production, achieving positive progress.
Green Building	2%	37 Interactive Entertainment Network Technology Group Co. Ltd., stock code 002555: The construction project of the company's headquarters building in Guangzhou follows the highest three-star standard of China's green building guidelines. It emphasizes land conservation, intensive land use, and employs sponge city technology to achieve the cyclic utilization of water resources. The project focuses on the green performance throughout the entire lifecycle of the building, including sustainable construction sites, water resource utilization, and energy-efficient design. It strictly aligns with the internationally recognized and influential LEED standards for green buildings, aiming to reduce carbon emissions during future operation.

Appendix C. Details of Institutional Support

Panel A: Number of authorized carbon verification agencies

Carbon emissions verification agencies play an important role as intermediaries in the carbon market. These agencies are staffed with certified experts in carbon accounting and verification. In our effort to approximate the region's human capital and expertise related to carbon reduction, we focus on these agencies.

We gather data on carbon verification agencies primarily from publicly disclosed government procurement contracts found on regional government websites. Despite these contracts not encompassing all potential agencies, we rely on this data for several reasons. First, such contracts undergo government quality assessments, where suppliers are scored based on specific criteria, and projects are awarded to the highest scoring suppliers. Second, these contracts are expected to correlate positively with the overall number of agencies in a region. Usually, there are multiple suppliers winning contracts in our context, as governments seek competition to ensure service quality. Therefore, governments in regions with more qualified agencies tend to establish contracts with more agencies, whereas limited agency availability may impede procurement success due to an excessive number of packages, as observed in the case of Sichuan. Third, verification agencies often have multiple branches across regions. The information available on the websites of different agencies often lack uniformity and stability, potentially introducing unknown noise in the proxy.

Additionally, we reference government evaluations of carbon verification agencies. Some regional governments conduct evaluations, categorizing agencies as either “qualified” or “unqualified” based on their performance in carbon verification. In instances where the number of qualified agencies from evaluations surpasses those from contracts, we incorporate the evaluation data into our analysis.

	Number of authorized carbon verification agencies in 2021	GDP (in trillion RMB)	Personnel score
Ningxia	8	0.39	20.41
Qinghai	6	0.30	19.96
Guizhou	20	1.78	11.22
Heilongjiang	15	1.37	10.95
Shenzhen	22	2.76	7.97
Gansu	7	0.90	7.76
Shanxi	13	1.77	7.36
Beijing	25	3.61	6.92
Chongqing	11	2.50	4.40
Tianjin	6	1.41	4.26
Nei Mongol	7	1.74	4.03
Guangdong	30	8.31	3.61
Shanghai	13	3.87	3.36
Jilin	4	1.23	3.25
Xinjiang	4	1.38	2.90
Hebei	10	3.62	2.76
Jiangxi	7	2.57	2.72
Fujian	11	4.39	2.51
Yunnan	6	2.45	2.45
Hunan	10	4.18	2.39
Guangxi	5	2.22	2.26
Shandong	16	7.31	2.19
Hubei	8	4.34	1.84
Hainan	1	0.55	1.81

Zhejiang	11	6.46	1.70
Anhui	6	3.87	1.55
Sichuan	6	4.86	1.23
Henan	6	5.50	1.09
Liaoning	2	2.51	0.80
Jiangsu	4	10.27	0.39
Shaanxi	1	2.62	0.38
Tibet	0	0.19	0.00
Data source	The China Government Procurement Network (http://www.ccgp.gov.cn/), its regional branches, and other government websites	CSMAR	

Panel B. Example of re-lending policies supporting green initiatives

We use province- and city-level re-lending policies issued by the local government to proxy for green finance supporting policies. In August 2016, the People's Bank of China and seven other ministries jointly released *the Guiding Opinions on Building a Green Financial System*, proposing exploration of measures such as re-lending to support the development of green credit. Subsequently, various provinces and cities gradually introduced specific measures. Re-lending is a proactive quantitative monetary policy tool: the central bank provides credit loans to commercial banks, which to some extent can function as a macroeconomic regulation tool within monetary policy. Due to the longer repayment cycles of central bank re-lending, the targeted support for green project financing can address the mismatch between traditional commercial bank credit tools and the operational timelines of green projects. This aligns with the characteristics of green projects, such as their long implementation periods and positive externalities, thereby motivating commercial banks in developing green credit. The development of green credit provides substantial financial support for firms' emission reduction projects in the region.

We obtain the re-lending policy data from the 2020 and 2021 Annual Report on the Development of Local Green Finance in China. The report is authored by scholars from the International Institute of Green Finance at the Central University of Finance and Economics. It summarizes the regional re-lending policies supporting green initiatives since 2010. The report has been cited by the China Regional Financial Operations Report released by the People's Bank of China.

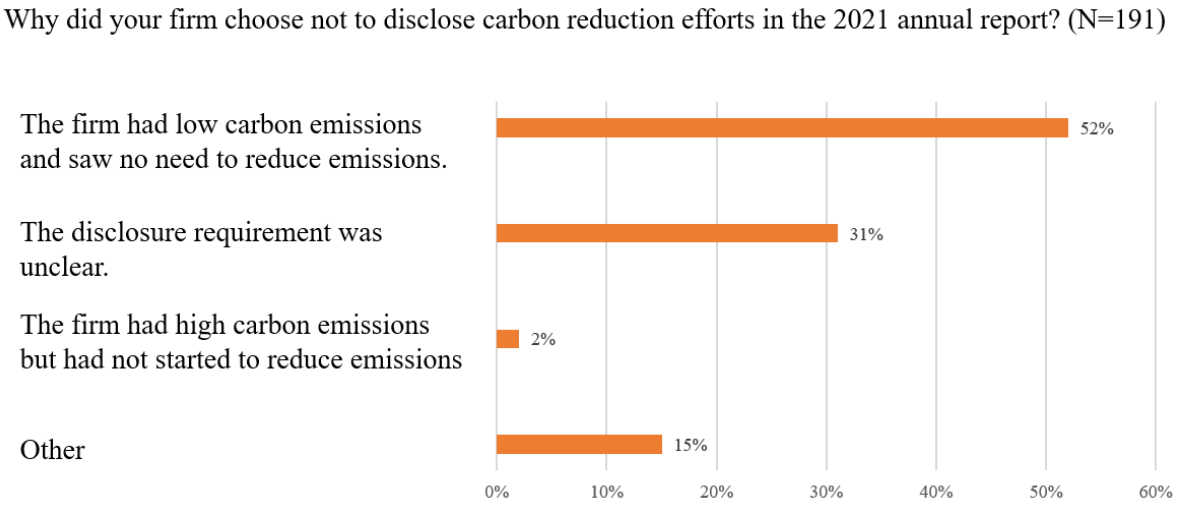
The following are some examples of re-lending policies supporting green initiatives.

Region	Policy name	Year	Related measures
Chongqing	Green Finance Development Plan of Chongqing (2017-2020)	2017	Explore the use of policy tools such as re-lending and re-discounting to support the development of green credit.
Gansu	Office of the People's Government of Gansu Province on Building a Green Financial System	2018	Fully utilize re-lending to encourage and support banks and other financial institutions to increase credit support for green enterprises and green projects.
Sichuan	Green Finance Development Plan of Sichuan Province	2018	For banking financial institutions that meet the conditions for re-lending applications and actively provide green credit, prioritize re-lending support.
Yangzhou	Implementation Details of Guiding Opinions on Building a Green Financial System	2021	Utilize targeted re-lending and re-discounting to support the precise development of the green industry.

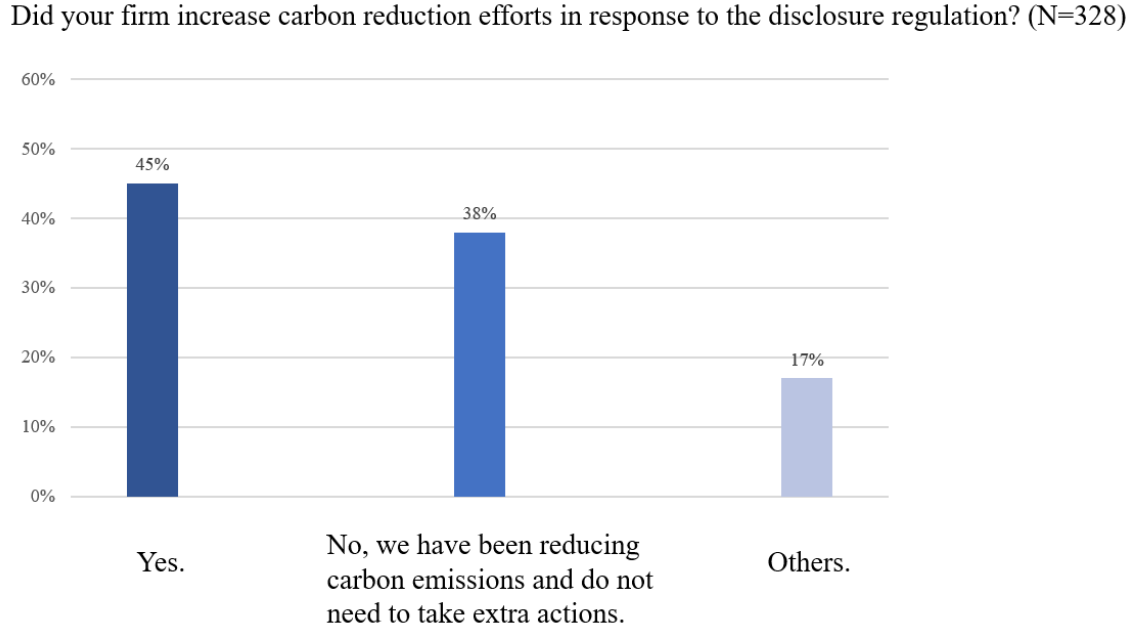
Figure 1. Survey results

Panel A summarizes the responses to the survey question regarding the reasons for non-disclosure. Respondents who had not disclosed their carbon reduction measures and effects in response to the 2021 carbon disclosure provision were asked to choose a reason for their non-disclosure. Panel B summarizes the responses to the survey question concerning whether firms chose to increase their carbon reduction efforts in response to the 2021 carbon disclosure provision. Panel C focuses on the firms that disclosed and chose to increase their carbon reduction efforts and summarizes the reasons for their decisions. Each panel displays the corresponding options provided for each survey question and the percentages of respondents who selected each option.

Panel A. Reasons for non-disclosure



Panel B. Firms' response to the disclosure regulation



Panel C. Reasons for firms' decision to reduce carbon emissions

Why did your firm increase carbon reduction efforts in response to the disclosure regulation? (N=146)

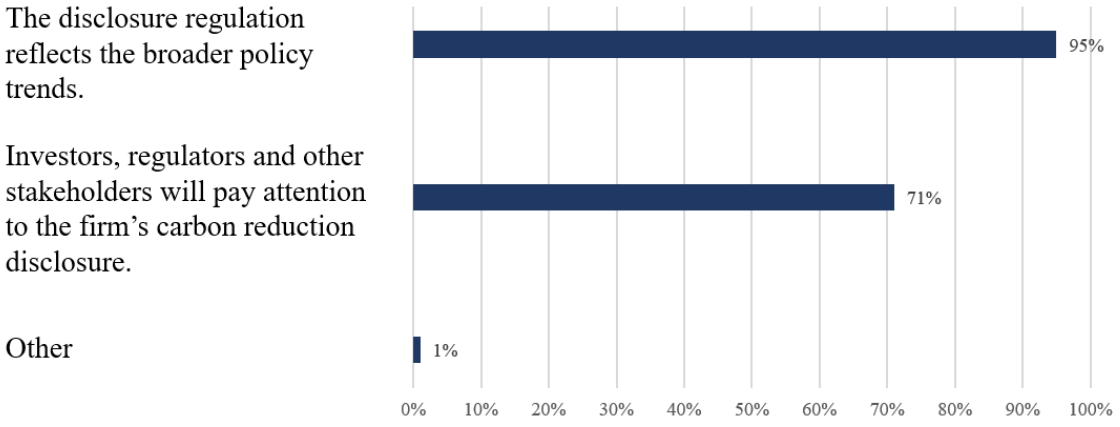


Figure 2. Carbon intensity and emissions for treatment and control firms

This figure shows the trends in average carbon intensity (emission) of CEM-matched treatment and control firms from 2018 to 2021. We use CEM to match treatment firms to control firms based on their carbon emission level and intensity measured in year 2018. The Y-axis indicates the natural logarithm of carbon emissions scaled by sales (the natural logarithm of carbon emissions).

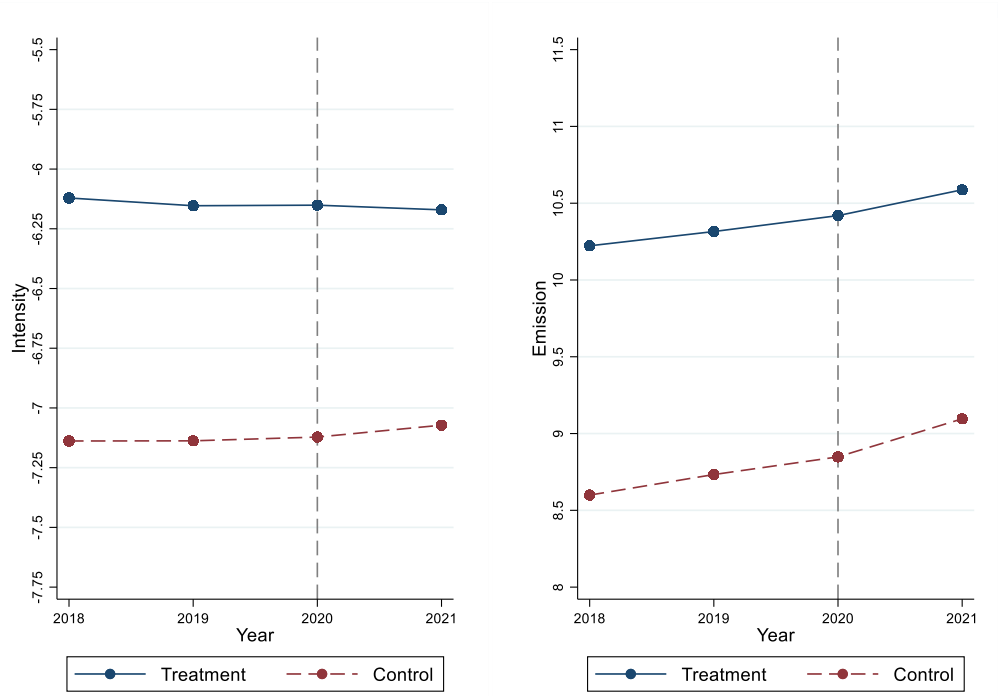


Table 1. Determinants of carbon reduction disclosure

Panel A reports the percentage of listed firms that complied with the 2021 disclosure regulation in each industry. The industries are defined based on CSRC classification. The first column lists the industry names, the second column computes the percentage of disclosing firms within each industry, while the third column presents the number of disclosing firms in each industry. Panel B presents the results of a logistic regression using the CSI 800 firms, which is the subsample with carbon emissions data. The dependent variable is *Treat*, an indicator variable equal to one if a firm choose to disclose its carbon reduction efforts and results in its 2021 annual report and equal to zero otherwise. Among the independent variables, current firm characteristics are measured as of year 2021. Historical environmental awareness, reporting quality and carbon emission are measured as of year 2020. All variables are defined in Appendix A, and all continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on robust standard errors, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Industry distribution of the disclosing firms

Industry	% Disclose	# Disclose
Ferrous metal smelting and processing	78%	25
Accommodation and food services	67%	6
Mining	66%	51
Chemical fiber manufacturing	64%	18
Paper and paper products manufacturing	64%	23
Non-ferrous metal smelting and processing	63%	51
Non-metallic mineral product manufacturing	62%	64
Transportation equipment manufacturing	59%	44
Energy and water production and supply	58%	75
Transportation, warehousing, and postal services	57%	62
Alcoholic beverages, beverages, and refined tea production	54%	26
Furniture manufacturing	54%	14
Chemical raw materials and product manufacturing	52%	162
Financial services	52%	66
Food production	51%	35
Leather, fur, feather, and footwear production	50%	6
Wood processing and products manufacturing	50%	4
Textile and apparel manufacturing	48%	20
Automobile manufacturing	47%	73
Rubber and plastic product manufacturing	46%	50
Miscellaneous	46%	6
Pharmaceutical manufacturing	45%	129
Construction	44%	48
Electrical machinery and equipment manufacturing	43%	128
Textile manufacturing	42%	20
Water management, environmental services, and public facilities	42%	37
Instrumentation manufacturing	41%	29
General equipment manufacturing	40%	67
Specialized equipment manufacturing	39%	123
Metal products manufacturing	39%	34

Agricultural and food processing	38%	21
Other manufacturing	38%	6
Petroleum refining, coking, and nuclear fuel processing	38%	6
Waste resource recycling	36%	4
Wholesale and retail	35%	65
Computer, communication, and other electronic equipment manufacturing	35%	168
Scientific research and technical services	32%	28
Health and social work	27%	4
Real estate	26%	30
Agriculture, forestry, animal husbandry, and fisheries	23%	11
Information transmission, software, and IT services	23%	88
Printing and media reproduction	21%	3
Leasing and business services	18%	12
Culture, sports, and entertainment	18%	11
Education	17%	2
Cultural, educational, art, sports, and entertainment goods manufacturing	14%	3
Residential services, repair, and others	0%	0

Panel B: Logistic regression

	CSI 800 sample *Treat*
Current firm characteristics	
Size	.359**
	(2.442)
ROA	3.306
	(1.464)
PB	-.072**
	(-2.184)
SOE	.1
	(.421)
InstHolding	.029
	(1.287)
Oversea	-.392
	(-.658)
AnalystCov	.044
	(.324)
Historical environmental awareness and reporting quality	
ESG	.113
	(.792)
CSRReport	.274
	(1.029)
MDA2020	.377
	(1.138)
RepQuality	-.177
	(-.919)
Historical carbon emission	
EmissionPCA	.483***
	(3.531)
Industry fixed effects	Yes
Constant	-9.296**
	(-2.555)
Observations	573
Pseudo R^2	.205

Table 2. Sample selection

This table delineates the sample selection procedure. We start from CSI 800 firms for which carbon emissions data are available between 2018-2021. We first exclude firm-years that are missing data required for control variables in Eq. (1). We also exclude firms that do not have at least one observation each in the periods before and after the implementation of the disclosure regulation in 2021. Next, we exclude a firm from our sample if its year-over-year change in carbon intensity ranks among the top or bottom 1% in the sample period. Our manual reading of the firms' annual reports suggests that such drastic changes in carbon emission nearly all result from endogenous changes in the scope of measurement (e.g., including more segments in the measurement process) or data errors. By this step, we have a sample of 633 unique firms and 2380 firm-years (CSI 800 sample). In the last step, we use coarsened exact matching (CEM) to match treatment and control firms. Specifically, we coarsen our sample into 50 CEM strata[15] based on the firms' carbon emissions and intensity measured as of 2018. The CEM method drops observations that lack common support (i.e., firms in strata without both a treatment and control observation), and that gives us a final sample of 492 unique firms and 1961 firm-year observations.

Step	Firm years	Unique firms
CSI 800 firms with non-missing carbon emissions data between 2018-2021	2750	768
Less: firm-years with missing control data	(122)	(2)
Less: firms without at least one observation before and after implementation of the disclosure regulation	(114)	(98)
Less: firms with drastic changes in carbon intensity	(134)	(35)
CSI 800 sample	2380	633
Less: firms that cannot be matched in CEM	(419)	(141)
Final sample	1961	492

[15] We use Sturge's rule to specify the number of equally sized bins. Each CEM variable is coarsened using 11 equally spaced cutpoints, leading to 50 strata.

Table 3. Summary statistics

This table shows the descriptive statistics for all variables used in the main regressions. Panel A reports summary statistics for CSI 800 firms. Panel B reports the summary statistics for the CEM-matched sample used in our analysis. Panel C shows the difference in means between the treatment and control groups before and after coarsened exact matching (CEM). Panel D shows the Pearson correlations of the variables. All variables are defined in Appendix A. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Summary statistics for the CSI 800 sample

	N	Mean	SD	Min	p25	Median	p75	Max
Intensity	2380	-6.322	2.282	-11.074	-7.975	-6.468	-4.814	-.052
Emissions	2380	10.132	3.044	3.841	8.018	9.875	12.032	18.463
Treat	2380	.655	0.476	0	0	1	1	1
Size	2380	17.302	0.935	15.675	16.625	17.104	17.773	20.323
AssetIntensity	2380	.195	0.179	.001	.05	.144	.302	.715
PB	2380	3.371	3.715	.272	1.023	1.967	4.132	20.328
Leverage	2380	.495	0.212	.067	.335	.499	.65	.929

Panel B: Summary statistics for CEM-matched sample

	N	Mean	SD	Min	p25	Median	p75	Max
Intensity	1961	-6.514	2.148	-11.074	-7.996	-6.711	-5.209	-.052
Emissions	1961	9.819	2.730	3.841	7.985	9.692	11.531	18.463
Treat	1961	.629	0.483	0	0	1	1	1
Size	1961	17.189	0.878	15.675	16.567	17.019	17.597	20.323
AssetIntensity	1961	.192	0.177	.001	.05	.141	.295	.715
PB	1961	3.11	3.185	.276	1.078	1.948	3.866	17.332
Leverage	1961	.49	0.206	.067	.334	.492	.639	.929

Panel C: Mean differences between treatment and control firms

	Before matching			After matching		
	Treatment mean	Control mean	Difference	Treatment mean (weighted)	Control mean (weighted)	Difference (weighted)
Intensity	-5.867	-7.184	1.317***	-6.168	-6.125	-0.043
Emissions	10.891	8.694	2.197***	10.386	10.312	0.074
Size	17.404	17.108	0.296***	17.253	17.084	0.169**
AssetIntensity	0.227	0.135	0.092***	0.223	0.174	0.048***
PB	2.946	4.176	-1.230***	2.728	2.858	-0.130
Leverage	0.516	0.455	0.061***	0.512	0.493	0.020

Panel D: Pearson correlation for CEM-matched sample

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) *Intensity*	1.000						
(2) *Emissions*	0.891***	1.000					
(3) *Treat*	0.210***	0.271***	1.000				
(4) *Size*	-0.033	0.186***	0.095***	1.000			
(5) *AssetIntensity*	0.555***	0.475***	0.221***	-0.173***	1.000		
(6) *PB*	-0.134***	-0.272***	-0.156***	0.287***	-0.113***	1.000	
(7) *Leverage*	-0.088***	0.169***	0.141***	0.201***	-0.172***	-0.317***	1.000

Table 4. The effect of disclosure regulation on carbon intensity and emissions

This table presents results from the estimation of Eq. (1). Columns (1) and (2) reports the results obtained after coarsened exact matching (CEM). Columns (3) and (4) reports same regressions using the CSI 800 sample, which include all listed firms for which carbon emissions data are available. The dependent variables in columns (1) and (3) are the natural logarithm of annual carbon emissions scaled by sales. The dependent variables in columns (2) and (4) are the natural logarithm of annual carbon emissions. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	CEM-matched sample		CSI 800 sample	
	Intensity	*Emissions*	*Intensity*	*Emissions*
	(1)	(2)	(3)	(4)
Treat × *Post*	-.078**	-.09*	-.071**	-.097**
	(-2.008)	(-1.888)	(-2.25)	(-2.554)
Size	-.013	.463***	-.021	.484***
	(-.318)	(5.987)	(-.596)	(7.361)
AssetIntensity	.08	.391	.023	.392
	(.3)	(1.071)	(.115)	(1.495)
PB	-.002	-.061***	.001	-.051***
	(-.281)	(-4.186)	(.225)	(-3.884)
Leverage	-.187	.802**	.019	.887***
	(-.83)	(2.32)	(.114)	(3.821)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Constant	-5.845***	2.02	-5.971***	1.352
	(-7.632)	(1.447)	(-9.657)	(1.178)
Observations	1961	1961	2380	2380
R^2	.008	.3	.005	.328

Table 5. The effect of disclosure regulation with vs without institutional support

Panel A presents results from estimating Eq. (2) using the CEM-matched sample. The dependent variable in column (1) is carbon intensity, defined as the natural logarithm of annual carbon emissions scaled by sales. The dependent variable in column (2) is the natural logarithm of annual carbon emissions. *PolicySupport* equals the number of distinct types of supportive policies within the region where firm i is headquartered. In this paper we investigate two specific types of policy support: *Personnel* and *GreenFinance*. In Panel B, we individually examine the effects of the two policy types. The *Personnel* score is computed as the number of authorized verification agencies in the region in 2021 scaled by the corresponding regional GDP (in trillion RMB). *GreenFinance* is an indicator variable equal to 1 if a region has refinancing support for green projects by the end of 2021, and equal to 0 otherwise. Because *Personnel* is a continuous variable, we count it as 1 in the calculation of *PolicySupport* if *Personnel* is above the sample median. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Overall institutional support

	Intensity	*Emissions*
	(1)	(2)
Treat × *Post* × *PolicySupport*	-.119**	-.123**
	(-2.571)	(-2.085)
Treat × *Post*	.07	.064
	(1.143)	(.834)
Post × *PolicySupport*	.082**	.087*
	(2.306)	(1.717)
Size	-.011	.466***
	(-.269)	(6.053)
AssetIntensity	.083	.395
	(.302)	(1.066)
PB	-.003	-.061***
	(-.35)	(-4.214)
Leverage	-.162	.828**
	(-.736)	(2.455)
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Constant	-5.892***	1.966
	(-7.712)	(1.42)
Observations	1961	1961
R^2	.016	.304

Panel B: Personnel and green finance

	Intensity (1)	*Emissions* (2)	*Intensity* (3)	*Emissions* (4)
Treat × *Post* × *Personnel*	-.032**	-.036**		
	(-2.261)	(-2.353)		
Treat × *Post* × *GreenFinance*			-.216***	-.211**
			(-2.926)	(-2.199)
Treat × *Post*	.042	.046	.085	.072
	(.666)	(.59)	(1.421)	(.921)
Post × *Personnel*	.019	.022*		
	(1.631)	(1.728)		
Post × *GreenFinance*			.168***	.186**
			(3.213)	(2.279)
Size	-.017	.459***	-.011	.467***
	(-.399)	(5.927)	(-.257)	(6.03)
AssetIntensity	.056	.365	.103	.421
	(.21)	(.995)	(.381)	(1.136)
PB	-.001	-.06***	-.002	-.061***
	(-.192)	(-4.138)	(-.346)	(-4.207)
Leverage	-.191	.799**	-.159	.83**
	(-.852)	(2.317)	(-.711)	(2.433)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Constant	-5.78***	2.09	-5.907***	1.942
	(-7.487)	(1.494)	(-7.731)	(1.393)
Observations	1961	1961	1961	1961
R^2	.014	.304	.016	.304

Table 6. Excluding the power sector

This table presents results from the estimation of Eq. (1) using the CEM-matched sample, with the exclusion of firms operating in electricity, heat production and supply industry (CSRC industry classification code D44). The dependent variable in column (1) is the natural logarithm of annual carbon emissions scaled by sales. The dependent variable in column (2) is the natural logarithm of annual carbon emissions. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	Intensity	*Emissions*
	(1)	(2)
Treat × *Post*	-.072*	-.07
	(-1.931)	(-1.571)
Size	.001	.476***
	(.022)	(6.538)
AssetIntensity	.02	.164
	(.072)	(.438)
PB	-.003	-.058***
	(-.454)	(-4.358)
Leverage	-.024	1.058***
	(-.141)	(3.798)
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Constant	-6.314***	1.567
	(-8.983)	(1.204)
Observations	1909	1909
R^2	.007	.315

Table 7. Falsification tests

Panel A: Response to the "dual carbon" policy announcement

This table presents results from estimating a modified version of Eq. (1) using the CEM-matched sample, replacing the *Treat* variable with *MDA2020*. *MDA2020* is an indicator variable equal to 1 if the firm mentioned "carbon peak", "carbon neutrality", or "dual carbon" in the Management Discussion and Analysis section of its annual report for 2020, and 0 otherwise. *Post* is an indicator variable equal to 1 for fiscal year 2021, and 0 otherwise. The dependent variable in column (1) is the natural logarithm of annual carbon emissions scaled by sales. The dependent variable in column (2) is the natural logarithm of annual carbon emissions. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	Intensity	*Emissions*
	(1)	(2)
MDA2020 × *Post*	.012	.033
	(.25)	(.65)
Size	-.047	.407***
	(-.816)	(7.499)
AssetIntensity	.145	.573***
	(.622)	(2.629)
PB	.007	-.045***
	(.783)	(-4.03)
Leverage	-.085	.38*
	(-.374)	(1.758)
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Constant	-4.12***	4.682***
	(-4.258)	(4.797)
Observations	1556	1556
R^2	.01	.317

Panel B: Political pressure to reduce emissions

This table presents the results from estimating a modified version of Eq. (2) using the CEM-matched sample, replacing the *PolicySupport* variable with *Target*. The dependent variables in columns (1) and (3) are carbon intensity, defined as the natural logarithm of annual carbon emissions scaled by sales. The dependent variables in columns (2) and (4) are the natural logarithm of annual carbon emissions. *Target* is defined as the intended percentage of reduction in greenhouse gas emissions in a region during the 13th Five-Year Plan (2016-2020), as stipulated by the central government's emission reduction objectives. *PolicySupport* equals the number of distinct types of supportive policies within the region where firm i is headquartered. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)
	Intensity	*Emissions*	*Intensity*	*Emissions*
Treat × *Post* × *Target*	-.007	.033	.018	.063
	(-.309)	(.71)	(.897)	(1.429)
Treat × *Post* × *PolicySupport*			-.127***	-.148**
			(-2.649)	(-2.549)
Treat × *Post*	.064	-.754	-.274	-1.167
	(.15)	(-.804)	(-.735)	(-1.328)
Post × *Target*	.015	-.022	-.005	-.048
	(.803)	(-.512)	(-.354)	(-1.188)
Post × *PolicySupport*			.084**	.105**
			(2.33)	(2.129)
Size	-.012	.464***	-.01	.467***
	(-.278)	(6.026)	(-.241)	(6.045)
AssetIntensity	.079	.378	.071	.372
	(.296)	(1.041)	(.259)	(1.012)
PB	-.002	-.061***	-.003	-.062***
	(-.297)	(-4.188)	(-.371)	(-4.209)
Leverage	-.187	.794**	-.166	.819**
	(-.832)	(2.271)	(-.753)	(2.387)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Constant	-5.874***	2.015	-5.907***	1.961
	(-7.677)	(1.449)	(-7.705)	(1.41)
Observations	1961	1961	1961	1961
R^2	.009	.301	.017	.307

Table 8. Carbon reduction experience

This table presents the results from estimating the modified version of Eq. (2) in two subsamples. We split the CSI 800 sample based on firms' carbon reduction experience and then perform CEM within each subsample. Firms' carbon reduction experience is identified by their participation in carbon emission trading systems (ETS). The dependent variables in columns (1) and (3) are carbon intensity, defined as the natural logarithm of annual carbon emissions scaled by sales. The dependent variables in columns (2) and (4) are the natural logarithm of annual carbon emissions. Panel A shows the effects of *Personnel* score for firms with and without carbon reduction experience. Panel B shows the effects of *Greenfinance*. The *Personnel* score is calculated as the number of authorized verification agencies in the region in 2021 scaled by the corresponding regional GDP (in trillion RMB). *GreenFinance* is an indicator variable equal to 1 if a region has refinancing support for green projects by the end of 2021, and equal to 0 otherwise. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Personnel

	Experienced		*Inexperienced*	
	Intensity	*Emissions*	*Intensity*	*Emissions*
	(1)	(2)	(3)	(4)
Treat × *Post* × *Personnel*	-.032	.01	-.053***	-.061***
	(-.824)	(.192)	(-2.769)	(-2.686)
Treat × *Post*	-.074	-.42	.146**	.219**
	(-.298)	(-1.149)	(2.09)	(2.416)
Post × *Personnel*	.016	-.022	.036**	.047**
	(.438)	(-.455)	(2.14)	(2.264)
Size	.027	.342*	.001	.514***
	(.205)	(1.742)	(.011)	(5.71)
AssetIntensity	-.135	.547*	.011	.062
	(-.343)	(1.737)	(.03)	(.133)
PB	-.01	-.044	-.004	-.066***
	(-.434)	(-1.353)	(-.492)	(-4.099)
Leverage	-.687	-.862	.109	1.317***
	(-.953)	(-.898)	(.554)	(4.466)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Constant	-5.255**	5.941	-6.441***	.687
	(-2.088)	(1.654)	(-7.743)	(.429)
Observations	320	320	1593	1593
R^2	.091	.349	.021	.324

Panel B: Green finance

	Experienced		Inexperienced	
	Intensity	*Emissions*	*Intensity*	*Emissions*
	(1)	(2)	(3)	(4)
Treat × *Post* × *GreenFinance*	-.338**	-.549***	-.196**	-.169
	(-2.339)	(-2.78)	(-2.342)	(-1.336)
Treat × *Post*	.024	.036	.095	.127
	(.245)	(.246)	(1.563)	(1.201)
Post × *GreenFinance*	.303**	.459**	.106*	.144
	(2.469)	(2.481)	(1.779)	(1.298)
Size	.042	.367*	.007	.52***
	(.328)	(1.931)	(.143)	(5.749)
AssetIntensity	-.121	.511	.051	.1
	(-.31)	(1.55)	(.14)	(.209)
PB	-.011	-.046	-.006	-.068***
	(-.476)	(-1.501)	(-.713)	(-4.178)
Leverage	-.602	-.669	.131	1.328***
	(-.871)	(-.723)	(.648)	(4.413)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Constant	-5.548**	5.441	-6.56***	.569
	(-2.288)	(1.566)	(-7.833)	(.354)
Observations	320	320	1593	1593
R^2	.101	.363	.012	.314

Table 9. Ex-post policy support

This table presents the results from estimating a modified version of Eq. (2), replacing the *PolicySupport* variable with *Reward*. Columns (1) and (2) report the results using the CEM-matched sample. Columns (3) and (4) report the same regressions using the CEM-matched subsample of experienced firms. Columns (5) and (6) report the results using the CEM-matched subsample of inexperienced firms. Firms' carbon reduction experience is identified by their participation in carbon emission trading systems (ETS). The dependent variables in columns (1), (3), and (5) are carbon intensity, defined as the natural logarithm of annual carbon emissions scaled by sales. The dependent variables in columns (2), (4), and (6) are the natural logarithm of annual carbon emissions. *Reward* is an indicator variable equal to 1 if a regional government offers rewards or subsidies for carbon reductions, and 0 otherwise. All variables are defined in Appendix A. All continuous variables are winsorized at the 1st and 99th percentiles. *t-statistics*, based on standard errors clustered by firm, are presented below the coefficient estimates. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	Full sample		Experienced		Inexperienced	
	Intensity	*Emissions*	*Intensity*	*Emissions*	*Intensity*	*Emissions*
	(1)	(2)	(3)	(4)	(5)	(6)
Treat × *Post* × *Reward*	-.074	.104	-.333**	-.181	-.049	.099
	(-1.185)	(.977)	(-2.431)	(-.829)	(-.553)	(.912)
Treat × *Post*	-.006	-.164*	.047	-.23	.012	-.059
	(-.142)	(-1.814)	(.508)	(-1.418)	(.188)	(-.728)
Post × *Reward*	.113**	-.021	.292**	.103	.109	.022
	(2.478)	(-.22)	(2.495)	(.502)	(1.53)	(.233)
Size	-.009	.466***	.041	.345*	.008	.519***
	(-.22)	(6.027)	(.321)	(1.733)	(.175)	(5.782)
AssetIntensity	.098	.382	-.117	.521	.022	.032
	(.366)	(1.043)	(-.296)	(1.629)	(.06)	(.067)
PB	-.003	-.061***	-.015	-.045	-.006	-.067***
	(-.353)	(-4.196)	(-.724)	(-1.324)	(-.701)	(-4.163)
Leverage	-.186	.787**	-.637	-.802	.11	1.308***
	(-.832)	(2.262)	(-.916)	(-.851)	(.55)	(4.289)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-5.919***	1.986	-5.509**	5.871	-6.569***	.61
	(-7.773)	(1.425)	(-2.269)	(1.618)	(-7.927)	(.381)
Observations	1961	1961	320	320	1593	1593
R^2	.011	.302	.096	.349	.009	.315