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Innovation with ecological sustainability: Does corporate environmental responsibility matter in green innovation?

Xiaoli Hao [a, b], Wenqian Fu [c], Khaldoon Albitar [d, *]

[a] *School of Economics and Management, Xinjiang University, Urumqi, China*

[b] *Center for Innovation Management Research, Xinjiang University, Urumqi, China*

[c] *China Economics and Management Academy, Central University of Finance and Economics, Beijing, China*

[d] *Faculty of Business and Law, University of Portsmouth, Portsmouth, United Kingdom*

ABSTRACT

Green innovation, driven by China's new development concept, plays a crucial role in high-quality economic development. In line with the green development trend, businesses increasingly prioritize whether their corporate environmental responsibilities (CER) can effectively enhance corporate green innovation (CGI) levels. This paper examines the influence and mechanism of CER on CGI using a dynamic perspective, drawing from 1,640 manually-collected panel data of Shanghai and Shenzhen A-share listed companies between 2010 and 2017. The primary findings indicate that the impact of CER on CGI possesses phase-specific characteristics and a dual effect of "crowding in" and "crowding out." The current phase of CER negatively affects green innovation, while the lag phase has a positive effect. CER's impact on various CGI types is heterogeneous: specifically, it follows an "inverted-N" trajectory (inhibition-promotion-inhibition) for "strategic green innovation" and has a promotional effect on "substantive green innovation," which is stronger and has a longer time lag. The mechanism analysis reveals that financing constraints play a critical mediating role. A heterogeneity analysis based on multiple dimensions (ownership, industry, and location) suggests that CER has a more significant driving force for CGI among state-owned firms, high-polluting industries, and enterprises in inland areas. Finally, the paper presents corresponding suggestions for government and corporate entities.

KEYWORDS

Corporate environmental responsibility; Corporate green innovation; the Inverted N-shaped curve; Mediating effect; Heterogeneity analysis

* Corresponding author: Khaldoon Albitar
E-mail address: khaldoon.albitar@port.ac.uk

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1. Introduction

The Chinese economy is currently transitioning from rapid expansion to high-quality development, facing challenges such as accelerating innovation-driven growth, strengthening environmental protection, and upgrading industrial structures (Wu et al., 2020; Hao et al., 2022). Green innovation, a combination of green and innovation-driven development, is key to resolving the tension between economic growth and environmental degradation (Zhang and Zhu, 2019). Under the new development concept of "innovation, coordination, green, openness, and sharing," China supports green, low-carbon, cyclic development, and innovation-driven policies. The 19th National Congress also advocated for a market-driven green technology innovation system. Green innovation will become a focal point of China's economic development, promoting "green" growth (Pan et al., 2021; Ren et al., 2022). However, China's technical support for green development is limited: according to SIPO data [1], only four enterprises ranked among the top 20 applicants for green patent applications in China between 2014 and 2017, with the remainder being non-enterprise R&D bodies such as universities. Enhancing corporate green innovation is a pressing issue.

Despite China's remarkable economic success, the country faces severe environmental challenges. As the world's largest carbon dioxide emitter and energy consumer, China accounted for 28.8% of global CO2 emissions in 2019, surpassing both the European Union and the United States combined [2]. In 2019, China led the world in overall energy consumption, using 4.86 billion tons of conventional coal [3]. Energy resource restrictions and environmental degradation have become impediments to China's economy (Chen et al., 2021; Wu et al., 2019; Hao et al., 2022). Enterprises, especially industrial ones, are expected to protect the environment as major producers and emitters of pollutants (Huang et al., 2021; Chai et al., 2021). Strengthening corporate environmental responsibility (CER) is crucial to addressing pollution at its source. CER, a unique and essential aspect of corporate social responsibility (Rahman and Post, 2012), encompasses various business environmental management activities aimed at reducing ecological footprints and environmental impacts (Bansal and Roth, 2000). Fulfilling CER not only increases long-term enterprise value (Ren et al., 2020; Qian et al., 2021; Xu et al., 2020) but also improves environmental performance (Chuang and Huang, 2018), establishes a green corporate image (Qian et al., 2021), and helps firms gain green competitive advantages (Hadj, 2000).

Corporate green innovation (CGI) involves enterprises improving or innovating technologies, processes, products, and related systems to enhance resource utilization and reduce pollution (Kemp and Foxon, 2007). Enterprises can obtain a competitive advantage through green product innovation and secure the pioneering advantage of industry leaders via green process innovation (Zhang and Ma, 2021). CGI is also crucial for the coordinated development of energy-economy-environment systems (Yuan and Xiang, 2018). Theoretically, integrating environmental responsibility consciousness into production and operation should improve production technology, inspire green innovation, and produce green commodities, thereby cultivating responsible competitiveness (Su and Chen, 2015; Hadj, 2020). However, whether CER can drive green innovation in practice remains questionable. Can businesses effectively foster CGI by fulfilling their environmental responsibilities? What is its action mechanism? Does CER have heterogeneous effects on substantive and strategic green innovation activities? How do CER's impacts on CGI vary across firm types? Answering these questions is vital for enhancing CER, promoting corporate green transformation, and achieving sustainable economic and social development.

Academics have extensively studied the relationship between corporate social responsibility and technological innovation (Kraus et al., 2020; Liu et al., 2021; Su et al., 2018). However, the impact of CER, a critical component of social responsibility, on technological innovation remains underexplored. Additionally, regarding the drivers of green innovation, existing literature primarily focuses on macro and meso-level factors, such as environmental

[1] State Intellectual Property Office: China Green Patent Statistical Report (2014-2017).
[2] BP World Energy Statistics Yearbook (2020).
[3] Statistical Communiqué of the People's Republic of China on the 2019 National Economic and Social Development.

regulation and market competition (Yuan and Xiang, 2018; Wang et al., 2019; Cai et al., 2020; Song et al., 2020), with few studies examining the influence of CER behavior on green innovation at the micro-enterprise level. This research uses manually-collected data of listed companies from 2010 to 2017 to investigate the effect and mechanism of CER on green innovation. Moreover, green innovation is divided into substantive and strategic innovation, enabling in-depth examination of CER's varying effects on different types of green innovation. Furthermore, the research considers the heterogeneous effects from multiple dimensions of corporate property rights, industry, and regional diversity.

This paper's marginal contributions are as follows: First, it empirically investigates the phased influence of CER on green innovation from a dynamic perspective at the micro-enterprise level. Second, it explores the potential mechanism of financing constraints in the process, clarifying the relationship between CER and green innovation. Third, by deconstructing green innovation into strategic and substantive perspectives, the paper examines the heterogeneous effects of CER on various forms of green innovation, enabling organizations to optimally allocate innovation resources, establish short-term and long-term green innovation plans, and effectively enhance green innovation performance. Finally, the research investigates the differentiated impact of CER on corporate green innovation under different corporate ownerships, industries, and locations, providing a reference for Chinese companies to accurately implement green innovation strategies based on their unique characteristics.

2. Literature review

2.1. Economic and social benefits of corporate environmental responsibility

In recent years, as environmental pollution has worsened and societal environmental awareness has risen, the environmental dimension of corporate social responsibility has gained academic attention. According to most scholars, CER is crucial for companies to achieve competitive advantage and long-term growth (Chuang and Huang, 2018; Xu et al., 2020; Qian et al., 2021). Hu et al. (2018) suggest that environmental engagement can be used as a strategic tool to reduce agency costs, improve corporate governance, and enhance enterprises' operating performance and market value. Active CER and information disclosure can help alleviate financing constraints, improve stock liquidity, lower transaction costs, and enhance long-term enterprise valuation (Zhao et al., 2021). In addition to economic benefits, CER can convey a positive corporate image of actively responding to environmental protection policies (Chuang and Huang, 2018), increase enterprises' visibility and favorable impressions (Zhang and Ouyang, 2021), and have a positive social impact. Companies' commitment to environmental protection can help achieve integrated economic, social, and ecological development by reducing negative externalities to the environment (Qian et al., 2021).

2.2. Drivers of corporate green innovation

Green innovation prioritizes environmental benefits, and its most notable distinction from conventional innovation is its "double externality" (Rennings, 2000). This implies that green innovation provides positive externalities to the environment in addition to the positive externality of knowledge spillover from general innovation activities (Arfi et al., 2018). Moreover, green innovation requires larger resource investment, has higher market uncertainty, and has a longer R&D cycle. Most companies lack motivation to engage in green innovation. Scholars have investigated various factors driving green innovation, including internal qualities and external environments of businesses. Regarding internal determinants, factors such as firm size and ownership (Bai et al., 2019), resource endowment (Wang and Jiang, 2021), intellectual capital (Wang and Juo, 2021), and organizational culture (Wang et al., 2020; Zhang et al., 2020) play significant roles. Wang et al. (2021) found that the more R&D

resources organizations invest, the greater their potential for green innovation. Chen et al. (2018) argued that redundant organizational resources help companies seize market opportunities and promote green innovation. In addition to firm-level characteristics, managers' attributes can also play a crucial role in green innovation. Executives with higher environmental knowledge are more likely to enable companies to implement proactive environmental policies and foster green innovation through internal resource allocation (Chuang and Huang, 2018; Singh et al., 2020).

Concerning external factors, research focuses on environmental regulations and policies. However, the effect of environmental regulations on corporate green innovation remains uncertain, and current scholarly perspectives can be categorized into three groups: (1) Based on neoclassical economic theory, environmental regulations force companies to internalize the externalities of environmental pollution, increase pollution control costs, compress R&D time, and produce a "crowding-out effect" on firms' innovation resources, thus inhibiting green innovation (Palmer et al., 1995; Kemp and Pontoglio, 2011). (2) Based on the Porter hypothesis, appropriate environmental regulations will "push" enterprises to engage in green innovation, thereby increasing profits to compensate for increased compliance costs caused by environmental laws (Porter and Van, 1995; Cai et al., 2020; Liu et al., 2021). Empirical research has shown that market-driven environmental policies, such as green credit policy and emissions trading, can stimulate CGI (Zhu et al., 2019; Chen et al., 2021). Command-and-control structured environmental regulations, such as the new Environmental Protection Law, are also favorable to CGI, with the effect being greater for state-owned enterprises and concentrated industries (Liu et al., 2021). Li and Xiao (2020) further demonstrate that only R&D-intensive and technologically advanced industries or enterprises can realize the green innovation promotion impact of environmental regulations, thus validating the conditions of the Porter hypothesis (Li and Xiao, 2020). (3) There are non-linear relationships between environmental regulation and green innovation, such as U-shaped and threshold relationships (Wang et al., 2019; Song et al., 2020). The impact varies when the type of environmental regulation instrument and the intensity of environmental regulation are different. In addition, research analyzing informal environmental regulation suggests that public attention and media monitoring can be equally effective in encouraging enterprises to adopt green innovation strategies (Chen et al., 2020; Wang et al., 2021; Huang et al., 2021; Zhang et al., 2022).

In summary, scholars have conducted extensive research on the economic and social benefits of CER and the driving factors of CGI. However, further improvements are needed in the following aspects: First, the research on the relationship between CER and CGI is relatively limited and cannot effectively reveal the interaction between the two. Research on green innovation is often analyzed at macro and meso levels, such as environmental regulation and industry competition, but there are fewer studies exploring the drivers of green innovation from micro corporate behavior. Second, few literatures integrate corporate environmental responsibility, financing constraints, and technological innovation into the research framework to analyze the transmission mechanism between CER and CGI. Third, the impact of CER on CGI from a dynamic perspective lacks due attention. Due to the time lag in the signaling of corporate environmental responsibility and the long R&D cycle and high technological complexity of green innovation, the current and lagging periods of corporate environmental responsibility may have different impacts on green innovation. Fourth, the specific heterogeneous impacts of CER on CGI from multi-dimensional perspectives needs to be supplemented. The effect of CER on CGI may vary depending on the companies' ownerships, industries, and locations.

3. Theoretical analysis and research assumptions

3.1. The direct impact of corporate environmental responsibility (CER) on corporate green innovation (CGI)

The dual effects of "extrusion" and "incentive" of CER on CGI involve products, processes, organizations, and management. CER may have both positive and negative effects on CGI at different phases. According to stakeholder theory, fulfilling CER satisfies stakeholders' expectations for companies to protect the environment, which benefits the company by gaining stakeholder support and trust, ensuring safe operation, and creating conditions for green innovation (Benlemlih et al., 2018). First, enterprises that actively fulfill their environmental responsibilities can project an eco-friendly "corporate citizen" image, gaining favor from consumers and environmental protection organizations while maintaining good social relations with stakeholders. This not only expands access to information but also fosters the exchange and sharing of internal and external knowledge, helping businesses identify potential for green innovation. Second, companies actively engaging in environmental responsibility are more likely to be recognized by the government, which is favorable for obtaining financial support such as tax incentives and R&D subsidies (Bai et al., 2019). This offsets the loss of green innovation externalities and effectively boosts enterprises' green innovation vitality. Third, active performance of CER not only reduces companies' environmental risks but also signals a commitment to green and sustainable development, making it easier to gain investors' trust and helping businesses secure external financing for green innovation projects (El Ghoul et al., 2018).

In addition, from the standpoint of resource-based theory, CER assists enterprises in integrating their own advantageous resources and strengthening their core competencies, laying the groundwork for CGI. First, CER will boost the demand for CGI. CER implies that companies need to modify or innovate existing technologies and processes to achieve energy-saving production processes and green products. Secondly, a series of environmental management practices within the company, such as environmental education for employees and adoption of an eco-friendly philosophy, are conducive to cultivating a green corporate culture and laying the knowledge foundation for green innovation. Moreover, highly qualified and innovative talents are more likely to be drawn to organizations that actively fulfill their environmental responsibilities and participate in their technical innovation projects (Chuang and Huang, 2018), producing a favorable innovation atmosphere within the company. Lastly, enterprises with active CER focus on their long-term growth, and CGI also plays a significant role in the sustainable growth of businesses. Therefore, companies that actively undertake environmental responsibility will tend to incorporate green innovation into their long-term development strategies and acquire green competitive advantages by developing green products and technologies for sustainable development (Latupeirissa and Adhariani, 2020).

Neoclassical economists, on the other hand, argue that CER will crowd out green R&D investment. First, CER may result in resource misallocation and crowd out resources that should be invested in innovation activities, stifling green innovation. Second, implementing environmental management practices in the organization and changing the original production and management model will inevitably have an impact on the organization's coordination ability and productivity, which will impede the enterprise's green innovation. Third, businesses' efforts to conserve resources and protect the environment may be symbolic. Firms may engage in low-cost but highly publicized environmental activities to enhance their reputation or deflect public and media attention from their environmental issues (Meng et al., 2019). Fourth, due to the principal-agent problem, enterprise managers may speculatively participate in environmental protection activities to obtain private interests or enhance job security, resulting in the internal "interception" of innovation resources and the interruption of green innovation (Ren et al., 2020).

In conclusion, the relationship between CER and CGI is the result of both the "extrusion effect" and the "incentive effect". Thus, the following hypotheses are proposed:

H1: Corporate environmental responsibility has both “extrusion” and “incentive” effects on green innovation.

The phased effect of corporate environmental responsibility on corporate green innovation.

It is worth noting that CER's "extrusion" and "incentive" effects on CGI are not in sync. In the short term, businesses will choose to increase pollution control investments to quickly alleviate external regulatory pressure, which will inevitably crowd out resources for R&D and innovation, creating an "extrusion effect" on green innovation. CER's "incentive effect" on CGI will take some time to manifest (shown in Fig. 1). The reasons may be that, first, due to the inefficiency of the real market, it is difficult for stakeholders to understand the situation of CER in a timely manner, preventing them from providing positive feedback on the environmentally-friendly behaviors of enterprises. Second, CER is a systemic project that encompasses products, processes, organization, and management, and it necessitates continuous adjustment over time to appropriately reallocate resources and thus contribute to green innovation. Lastly, green innovation is characterized by its high technical complexity and lengthy R&D cycle, and it takes time to demonstrate its effectiveness. As a result, the "extrusion effect" of CER on CGI often occurs in the current period, whereas the "incentive effect" takes longer. Accordingly, the following hypotheses are proposed:

H1a: The current period of CER will have an “extrusion effect” on CGI.

H1b: The lagging period of CER will have an “incentive effect” on CGI.

3.2. The mediating effect of financing constraints

CGI is characterized by high investment, high risk, and a long return cycle, implying that green innovation practices require a significant amount of financial support (Zhao et al., 2021). However, depending entirely on internal resources to progress green technology R&D activities is insufficient, thus external funding is required for green innovation activities to run smoothly (Yu et al., 2021). In a capital market that prioritizes short-term profits, green innovation initiatives are unpopular with investors, and the prevalence of information asymmetry and principal-agent issues makes external funding for green innovation much more difficult. Firms will reduce green R&D investment or even abandon green innovation projects if they face higher financing constraints and lower risk resilience (Zhang and Vigne, 2021). As a result, the financing constraints will limit the progress of green innovation capabilities.

Existing research has found that corporate social responsibility can help companies overcome financing constraints (Benlemlih and Bitar, 2018). Companies that meet environmental standards and actively embrace environmental responsibility could gain financial support from the government, easing the financing pressure for green innovation activities (Jiang et al., 2018). According to the signaling theory, companies that actively fulfill their environmental responsibilities release signals of environmental protection and green development to the outside world through information disclosure, which alleviates the problem of information asymmetry between companies and investors. The supplementary information offered by the company can enable investors with limited information to make more accurate assessments of the company's long-term development and investment value to minimize investment risk. According to the reputation theory, businesses that take on environmental obligations can build a favorable societal image, earn a green reputation, and improve their green competitive advantage. This would not only draw the attention of more investors but would also increase their confidence, which is advantageous to firms obtaining more investment from the capital market and financial institutions. As a result of signal transmission and reputation impacts, CER can effectively boost firms' external financing capacity and eventually support green innovation activities (Ball et al., 2018) (shown in Fig. 1). Accordingly, this paper proposes the following hypotheses:

H2: Financing constraints mediate the process of CER promoting CGI.

3.3. The impact of CER on different types of CGI

Although green innovation can help enterprises obtain economic benefits and establish competitive advantages, they may be limited by internal resources and capabilities, leading them to adopt different green innovation strategies for various motivations. Existing research has demonstrated that a business's patent output may be a strategic method for acquiring external resources but has no significant impact on enhancing enterprise value. According to different motivations for innovation, Li and Zheng (2017) divided enterprise innovation activities into substantive innovation and strategic innovation. They believe that substantive innovation is high-quality innovation that seeks to improve the technological level and gain a competitive advantage, whereas strategic innovation seeks "quantity" rather than "quality" in order to gain certain benefits. Green innovation efforts inspired by CER may also be motivated by strategic objectives to obtain other benefits rather than truly advancing green technology. Under the strain of existing environmental regulations, companies may prioritize strategic green innovation activities with a quick R&D cycle and many outputs to comply with government legislation and obtain market recognition, thereby collecting external resources (Wang and Yang, 2018). With the strengthening of environmental responsibility and the accumulation of enterprise innovation resources, enterprises will shift the emphasis of green innovation to substantive green innovation projects which can effectively improve green technology and realize the transformation of production methods. Furthermore, in the context of high-quality economic development, environmental obligations have become an indispensable aspect of a company's long-term development, which is consistent with the objective of green innovation. As a result, exercising environmental responsibility will encourage businesses to make more significant green innovation successes in the long run, enhancing their sustainable competitiveness. Accordingly, this paper presents the following hypotheses:

H3: There are differences in the effects of CER on different types of CGI.

H3a: The “incentive effect” of CER acts on strategic green innovation first.

H3b: The “incentive effect” of CER on substantive green innovation is greater and has a stronger lag.

The mechanism analysis is shown in Fig. 1. The main hypotheses are presented in Fig. 2.

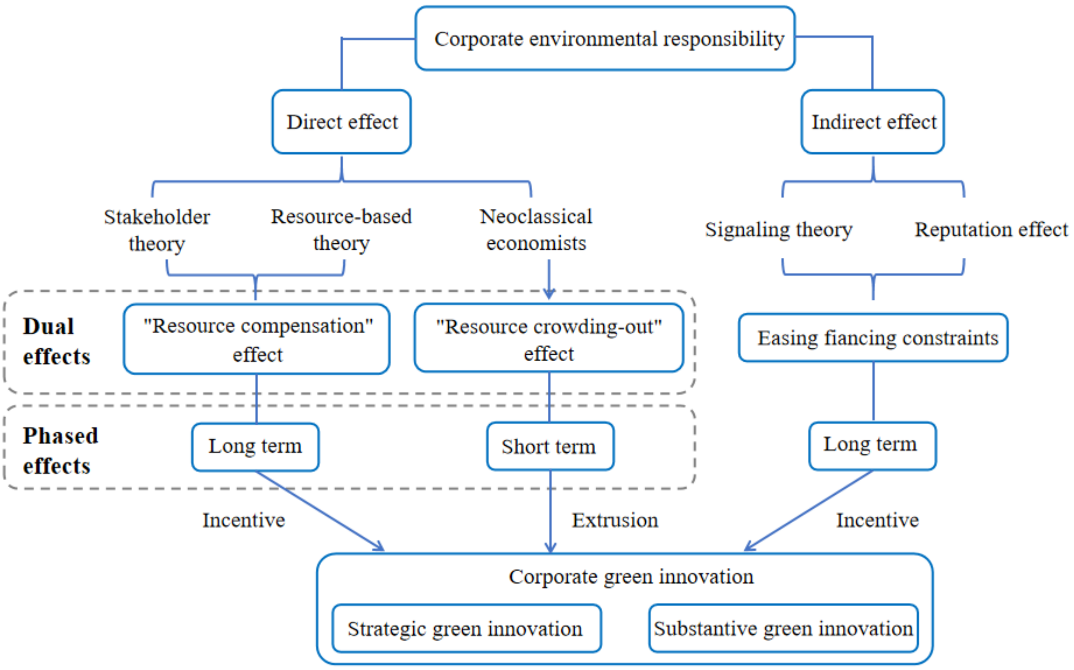

Figure 1. Mechanism analysis of corporate environmental responsibility and corporate green innovation.

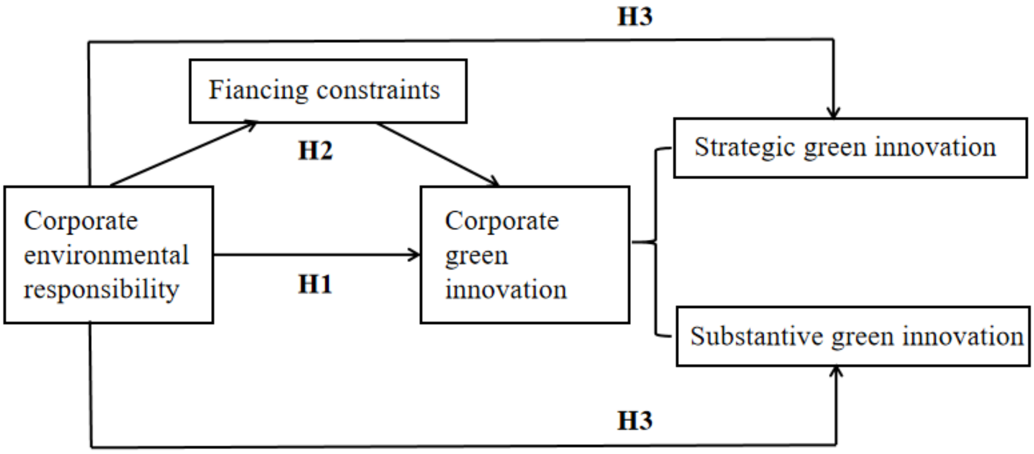

Figure 2. Conceptual research model.

4. Research design

4.1. Sampling and data

This report uses A-share listed companies in Shenzhen and Shanghai from 2010 to 2017 as a sample to empirically examine the effect of CER on CGI. The initial sample is processed as follows: (1) Exclude companies listed after 2010; (2) Exclude ST, *ST, and delisted companies; (3) Exclude companies with missing data on the primary research variables; and (4) Winsorize the 1% and 99% quantiles of all continuous variables to limit the impact of outliers on the research results. A total of 205 listed companies and 1,640 "enterprise-year" observation samples were obtained after screening and matching (shown in Table 2).

The data sources of this paper are mainly divided into the following parts: (1) the corporate environmental responsibility data is collected manually from the evaluation index of social responsibility reports of listed companies on Hexun.com; (2) the corporate green patent data is retrieved and collected manually from the State Intellectual Property Office (SIPO) according to the IPC classification list of green patents released by the World Intellectual Property Organization in 2010; (3) the corporate financial data comes from the China Stock Market and Accounting Research Database (CSMAR) and the annual reports of listed companies disclosed by the Shanghai and Shenzhen Stock Exchanges.

4.2. Basic model settings

4.2.1. Benchmark model

To test the direct impact of CER on CGI, the following benchmark model (1) is developed.

$$GI_{i,t} = \beta_0 + \beta_1 CER_{i,t} + \sum A_i\, Firm_{Controls_{i,t}} + \mu_i + \varepsilon_{i,t} \tag{1}$$

where, $GI_{i,t}$ is the explanatory variable, representing the level of green innovation of firm i in year t; $CER_{i,t}$ is the explanatory variable, representing the degree of environmental responsibility fulfillment of firm i in year t; $Firm\_Controls_{i,t}$ contains all the control variables mentioned above for firm i in year t; μ_i is the individual fixed effect; and $\varepsilon_{i,t}$ is the random error term.

In order to investigate *the* dynamic effect of CER on CGI, the current period indicator of CER in the benchmark model (1) $CER_{i,t}$ is substituted by the lagged one-period term and the lagged two-period term of CER indicators in models (2) and (3).

$$GI_{i,t} = \beta_0 + \beta_1 CER_{i,t-1} + \sum B_i \, Firm_{Controls_{i,t-1}} + \mu_i + \varepsilon_{i,t} \quad (2)$$

$$GI_{i,t} = \beta_0 + \beta_1 CER_{i,t-2} + \sum C_i \, Firm_{Controls_{i,t-2}} + \mu_i + \varepsilon_{i,t} \quad (3)$$

4.2.2. The mediating role of financing constraints

The mediating effect of financing constraints is investigated to examine the probable indirect influence mechanism of CER on CGI. The following mediation model (4) is based on the mediation effect analysis given by Baron and Kenny (1986).

$$FC_{i,t} = \alpha_0 + \alpha_1 CER_{i,t} + \sum D_i \, Firm\_Controls_{i,t} + \mu_i + \varepsilon_{i,t}$$

$$GI_{i,t} = \gamma_0 + \gamma_1 CER_{i,t_{-2}} + \gamma_2 FC_{i,t_{-2}} + \sum E_i \, Firm_{Controls_{i,t-2}} + \mu_i + \varepsilon_{i,t} \quad (4)$$

where, $FC_{i,t}$ represents the degree of financing constraint of firm i in year t, which is measured by the SA index in this paper.

4.2.3. The influence of GER on different types of CGI

Finally, considering the disparities in difficulty and value of different green innovation types, models (5) and (6) are developed to investigate the heterogeneous effects of CER on substantive and strategic green innovation.

$$GI_{inv_{i,t}} = \theta_0 + \theta_1 CER_{i,t_{-j}} + \sum F_i \, Firm_{Controls_{i,t-j}} + \mu_i + \varepsilon_{i,t} \quad (5)$$

$$GI_{uti_{i,t}} = \lambda_0 + \lambda_1 CER_{i,t_{-j}} + \sum G_i \, Firm_{Controls_{i,t-j}} + \mu_i + \varepsilon_{i,t} \quad (6)$$

where, $GI_{inv_{i,t}}$ denotes the level of substantive green innovation of firm i in year t, $GI_{uti_{i,t}}$ denotes the level of strategic green innovation of firm i in year t; j represents the lag period, $j = 0,1,2$.

4.3. Variable definition and measurement

4.3.1. Explained variable: corporate green innovation (CGI)

Most previous studies use R&D input and innovation output (number of new products or patents) to quantify corporate green innovation capability (Costantini et al., 2017; Liu et al., 2021). Innovation patents are commonly used to analyze company innovation performance because of their standardized and detailed information (Aguilera-Caracuel et al., 2013). This work draws on the research of Xiang et al. (2020) and Zhang et al. (2022) to measure the level of corporate green innovation each year based on the number of green patents granted. Meanwhile, the number of green patent applications is employed in the robustness test.

Substantive green innovation (GI_inv) and strategic green innovation (GI_uti): according to SIPO patent data, green patents are more prevalent in invention patents and utility patents. The technology level and complexity of invention patents are regarded to be higher than those of utility patents. Considering the differences in the difficulty and innovation of the two types of patents, this paper further examines the heterogeneity of green innovation. Referring to the studies of Yuan and Xiang (2018) and Zhang et al. (2022), this paper uses the number of green invention patents granted to measure substantive green innovation (GI_inv) and the number of green utility grants to measure strategic green innovation (GI_uti).

4.3.2. Explanatory variable: corporate environmental responsibility (CER)

The approaches of content analysis (Liu et al., 2021; Zhang and Ouyang, 2021), reputation index (Chuang and Huang, 2018), and third-party evaluation index (Hu et al., 2018) are commonly used to evaluate CER. Considering the objectivity, comprehensiveness, and authority of CER measurement, this paper selects the evaluation index of the corporate social responsibility report of Hexun.com. Hexun.com's evaluation system includes five aspects: shareholder responsibility, supplier and customer rights responsibility, employee responsibility, environmental responsibility and social responsibility. This paper selects the environmental responsibility score as an indicator of CER.

4.3.3. Mediating variable: financing constraints (FC)

The KZ index (Lamont et al., 2001) and WW index (Toni et al., 2006) are representative indices for measuring financial restrictions in the existing literature. However, the calculation of the above index involves many company-level characteristic indicators, and there is a strong endogeneity between them and financing constraints, which may bias the results. Hadlock and Pierce (2010) employed two exogenous variables of firm size and firm age to create the SA index, which is simple to calculate and reasonably robust. Therefore, the SA index is chosen to quantify the financing constraints. $SA = -0.737 \times Size + 0.043 \times Size2 - 0.04 \times Age$, where Size is the natural logarithm of the company's total assets and Age is the company's age. The larger the index value, the greater the enterprise's financing constraints.

4.3.4. Control variables

(1) Firm profitability (*Profit*). Profitable businesses have more resources to dedicate to research and development.

(2) Firm leverage ($Debt$). A moderate amount of debt can compensate for a lack of corporate capital, allowing more funds to be allocated to green innovation.

(3) Firm growth (*Grow*). The faster the enterprise develops, the greater the impetus for the enterprise to carry out technological innovation.

(4) Ownership concentration (*Top*). The concentration of ownership will have a significant impact on how enterprises make technological innovation decisions.

(5) Firm scale (*lnTA*). In general, the larger an organization's scale, the greater its innovation capability and rate of success.

Table 1 shows the definitions of the main variables, and the summary statistics are presented in Table 2.

The descriptive statistics indicate that the mean value of *GI* of the sample enterprises is 0.463, indicating that most of enterprises have a low level of *GI*, and the standard deviation of 0.672 is relatively large, indicating that there is a significant heterogeneity in the green innovation level of different enterprises. The sample enterprises' environmental responsibility rating (CER) ranges from 0 to 30, with a mean of 5.268 and a standard deviation of 8.103, showing that the sample enterprises' environmental responsibility is generally low and considerably different. The mean value of finance constraint (*FC*) is -3.536, with a standard deviation of 0.465, indicating that the overall distribution of financing constraint is relatively stable. Compared to other control variables, the business scale and the concentration of equity in the total sample differed more.

Table 1. Definitions of the main variables.

Variable name	Variable Definition	Reference
Corporate green innovation (CGI)	Ln (green patent granted + 1)	Xiang et al. (2020); Zhang et al. (2022)
Corporate environmental responsibility (CER)	Corporate environmental responsibility score of Hexun.com	Hu et al. (2018); Liu et al. (2021)
Financing constraints (FC)	SA index	Zhou et al. (2022)
Firm profitability (Profit)	Net Profit/total assets	Bai et al. (2018)
Firm leverage (Debt)	Total debts/Total Assets	Xiang et al. (2020)
Firm growth (Grow)	(Total $assets_t$ -Total $assets_{t-1}$) / Total $assets_t$	Wang and Yang (2018)
Ownership concentration (Top)	Percentage of equity share of the biggest shareholder.	Zhao et al. (2021)
Firm size (lnTA)	Ln (total assets)	Pan et al. (2021)

Table 2. Results of descriptive statistics.

Variable	N	Mean	S.D.	Min.	Max.
GI	1640	0.463	0.672	0	4.700
CER	1640	5.268	8.103	0	30
FC	1640	-3.536	0.465	-4.338	-1.366
Profit	1640	0.0432	0.0476	-0.129	0.187
Debt	1640	0.540	0.199	0.0684	0.939
Grow	1640	0.228	0.342	-0.237	2.130
Top	1640	38.88	17.67	9.330	82.51
lnTA	1640	23.51	1.933	20.02	30.31

5. Analysis of empirical results

5.1. The direct influence of CER on CGI

First, in order to assess the overall effect as well as the stage effects of CER on CGI, this paper adopts a fixed-effects regression model to perform regression analysis on the models (1)-(3). Table 3 displays the regression results. Table 3's columns (1) through (3) depict the effects of CER on CGI in the current, lag 1, and lag 2 periods, respectively. The regression coefficients of CER in the current period and lag 2 periods are both significant, but the signs of the regression coefficients are opposite, indicating that CER inhibits green innovation in the current period and only promotes it in the lag 2 periods. Therefore, the hypothesis H1 is confirmed, with CER having both "extrusion" and "incentive" impacts on green innovation.

From a dynamic perspective, the results show that CER has different effects in terms of directions and magnitude on CGI during different time periods, indicating the effects have phased properties. In the current period of CER, the increase of various costs, such as pollution control squeezes the innovation resources and hinders green innovation. However, in the long run, CER will bring various tangible and intangible benefits to enterprises, exert a "resource compensation" effect, and significantly improve the level of CGI. Therefore, the "extrusion" effect of CER on CGI is current, and the "resource compensation" effect is lagged, verifying Hypotheses H1a and H1b. Notably, the coefficient of CER in the lag 2 period ($\beta = 0.012, p < 0.01$) is greater than that in the current period ($\beta = -0.005, p < 0.05$), indicating that the lagged driving effect of CER on CGI can compensate for the inhibitory effect in the current period, which proves the effectiveness of CER in driving CGI.

Table 3. Benchmark regression results on the impact of the CER on CGI.

	(1) Current	(2) Lag 1	(3) Lag 2
CER	-0.005**	0.001	0.012***
	(-2.166)	(0.015)	(2.758)
Profit	-0.055	0.979*	0.792
	(-0.132)	(1.826)	(1.284)
Debt	-0.334*	0.232	0.303
	(-1.815)	(1.171)	(1.328)
Grow	-0.202***	-0.199***	-0.094*
	(-4.799)	(-3.396)	(-1.750)
Top	0.002	0.004	0.005
	(0.685)	(1.178)	(1.159)
lnTA	0.298***	0.250***	0.187***
	(8.348)	(5.717)	(3.266)
_cons	-6.371***	-5.630***	-4.252***
	(-7.039)	(-5.168)	(-3.070)
Obs	1,640	1,435	1,230
R2	0.111	0.069	0.042
N	205	205	205

*Note: t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1. The following tables are the same.*

5.2. The mediating effect of FC

To test the mediating effect of financing constraints between CER and CGI, this paper employs Baron and Kenny's (1986) causal stepwise regression test approach. The regression results are reported in Table 4. Column (2) shows a negative correlation between CER and financing constraints at a significant level of 1%, suggesting that excellent environmental responsibility performance can assist businesses minimize financing constraints. In column (3), the regression coefficients of CER and financing constrains are all significant, and the regression coefficient of CER ($\beta = 0.009, p < 0.01$) is smaller than that of the benchmark model in column (1) ($\beta = 0.012, p < 0.01$). The foregoing results show that financing constraints play a partially mediating role in the process of CER to encourage CGI, with a mediating effect of 0.002935, or 24.46% of the total effect. The hypothesis H2 is verified that corporate environmental responsibility effectively alleviates corporate financing constraints through signaling and reputation effects and subsequently stimulates corporate green innovation.

5.3. The influence of CER on different types of CGI

Further, this paper subdivides green patents into green invention patents and green utility patents and analyzes the specific effects of CER on different types of CGI during different time periods. The results of CER regression on the two distinct categories of green patents are presented in Table 5. To begin with, the results of strategic green innovation show that the regression coefficients of CER in the current and the lag 2 period are significantly negative, whereas they are significantly positive in the lag 1 period. CER inhibits strategic green innovation at first, then promotes it, but the effect is temporary and eventually reversed. This suggests that CER has a dual effect of "extrusion" and "incentive" on strategic green innovation. Second, for substantive green innovation, only the regression coefficient of CER in the lag 2 period is significantly positive, while the regression coefficients in the current and lag 1 periods are not significant, indicating that CER will significantly increase the output of substantive green innovation, but the lag time of the "incentive" effect is longer. In conclusion, the dual "extrusion" and "incentive" effects of CER on strategic green innovation are significant. The "crowding out" effect on substantial green innovation is negligible, whereas the "incentive" effect is stronger in the lag period. As a result, hypothesis H3 is confirmed.

Table 4. The mediating effect of financing constraints.

	(1) *GI*	(2) *FC*	(3) *GI*
CER	0.012***	-0.005**	0.009***
	(2.758)	(-2.107)	(2.812)
FC			-0.587**
			(-2.107)
Profit	0.792	0.289***	0.819
	(1.284)	(4.187)	(1.365)
Debt	0.303	0.042	0.301
	(1.328)	(1.566)	(1.351)
Grow	-0.094*	0.029***	-0.078
	(-1.750)	(4.016)	(-1.404)
Top	0.005	0.000	0.004
	(1.159)	(0.882)	(0.938)
lnTA	0.187***	-0.115***	0.094
	(3.266)	(-27.726)	(1.541)
_cons	-4.252***	-0.885***	-4.115***
	(-3.070)	(-8.923)	(-3.394)
Obs	1,230	1,640	1,230
R2	0.042	0.416	0.041
N	205	205	205

Table 5. The influence of CER on different types of CGI.

	Strategic green innovation			Substantive green innovation		
	Current	Lag 1	Lag 2	Current	Lag 1	Lag 2
CER	-0.004**	0.006***	-0.004*	0.001	-0.002	0.017***
	(-2.010)	(2.689)	(-1.748)	(0.210)	(-0.736)	(4.879)
Profit	0.004	0.015	0.050***	-0.019	0.041	-0.000
	(0.213)	(0.765)	(2.652)	(-0.755)	(1.505)	(-0.011)
Debt	-0.041	-0.069	-0.053	-0.009	0.140**	0.168**
	(-1.065)	(-1.521)	(-0.966)	(-0.182)	(2.047)	(2.073)
Grow	-0.017*	-0.029**	-0.004	-0.027*	-0.041**	-0.023
	(-1.896)	(-2.385)	(-0.303)	(-1.766)	(-2.203)	(-1.315)
Top	0.020	-0.037	-0.074	0.204**	0.253**	0.312*
	(0.286)	(-0.332)	(-0.466)	(2.452)	(2.557)	(1.920)
lnTA	0.190***	0.236***	0.223***	0.151***	0.069**	-0.008
	(9.007)	(7.199)	(5.681)	(6.756)	(2.176)	(-0.160)
_cons	-4.176***	-4.979***	-4.682***	-3.759***	-2.697***	-1.185
	(-6.807)	(-4.958)	(-3.793)	(-5.838)	(-3.023)	(-0.816)
Obs	1,370	1,206	1,044	1,370	1,206	1,044
R2	0.087	0.093	0.064	0.030	0.018	0.047
N	205	205	205	205	205	205

In terms of the stage characteristics of CER's impact on CGI, the effect of CER on strategic green innovation follows an "inverted N" influence trajectory, with current inhibition, lag-1 period promotion, and lag-2 period re-inhibition. In contrast, the short-term effect of CER on substantive green innovation is negligible, whereas the lag 2 period has a greater incentive effect on substantive green innovation. Therefore, hypothesis H3a and H3b are confirmed. This could be because, in comparison to substantive green innovation, strategic green innovation is easier to develop and less expensive to invest in. Enterprises prefer to embrace strategic green innovation behavior in the short term to comply with environmental regulations and gain government subsidies. Thus, the "incentive" effect of CER on CGI is initially applied to green innovation strategies. CGI's focus will shift once the company has exploited the external resources brought by CER and implemented an effective environmental management system. CGI will prioritize substantive green innovation since it can effectively improve green technology and increase the company's sustainable competitiveness. When enterprise resources are primarily spent on substantive green innovation, there will be a certain "crowding out" effect on strategic green innovation, resulting in a decrease in strategic innovation output. Overall, CER will contribute significantly to the actual advancement of green technology and will assist businesses in producing high-quality green innovation outputs.

5.4. Robustness test

The number of green patent applications of the sample enterprises is taken as proxy variable of CGI, referring to some studies (Xiang et al., 2020; Zhang et al., 2022). The results are shown in Table 6. CER has a certain inhibiting effect on CGI in the current period and an encouraging influence on CGI in the lag period, indicating the robustness of the basic regression results.

Table 6. Results of robustness test.

	(1) Current	(2) Lag 1	(3) Lag 2
CER	-0.005**	0.007**	0.006*
	(-2.266)	(2.592)	(1.775)
Profit	0.004	0.045*	0.020
	(0.164)	(1.857)	(0.775)
Debt	0.003	-0.026	-0.076
	(0.058)	(-0.520)	(-1.043)
Grow	-0.015	-0.020	-0.019
	(-1.014)	(-1.441)	(-0.975)
Top	0.131	-0.027	0.146
	(1.475)	(-0.189)	(0.872)
lnTA	0.184***	0.209***	0.213***
	(7.612)	(6.571)	(4.910)
_cons	-4.467***	-4.540***	-4.934***
	(-6.063)	(-4.345)	(-3.794)
Obs	1,370	1,206	1,044
R2	0.059	0.054	0.040
N	205	205	205

6. Further analysis

6.1. Ownership heterogeneity

The substantial disparities in resource endowment, economic status, and strategic objectives between state-owned and non-state-owned businesses may result in varying effects of CER on CGI. Therefore, the sample enterprises are divided into state-owned and non-state-owned groups based on the actual controllers of listed companies. Then, this research explores the heterogeneity in the impact of CER on CGI under different ownerships, as shown in Table 7.

Table 7 shows that CER by SOEs has a slight inhibitory influence on CGI in the current period, but following a two-period lag, it substantially boosts CGI. As the "spokesperson" of the government, SOEs play a critical role in advancing the process of ecological civilization creation. Consequently, they place a greater emphasis on the pursuit of comprehensive benefits, including economic, environmental, and social factors. They actively adhere to the national green development policy and engage in green innovation activities. In addition, the significant economic status of SOEs and their natural connections with the government increase their likelihood of receiving policy leaning and financial support, which provide essential resources for SOEs to invest in green innovation activities

(Bai et al., 2019). As a result, SOEs' CER will have a more visible green innovation-driving effect. In contrast, the regression coefficients of CER for all periods in the sample of non-SOEs failed the significance test, demonstrating that the CER of non-SOEs had no significant effect on the development of CGI. There are following reasons. On the one hand, non-SOEs do not have the advantage of obtaining external resources. Without sufficient support resources for high-risk and high-investment green innovation activities, non-SOEs are unable to significantly increase green innovation motivation, even when they fulfill their environmental responsibilities. On the other hand, non-SOEs mostly pursue profit maximization and may only engage in environmental responsibility to satisfy legal requirements. And it is difficult to stimulate the potential incentive effect of CER on CGI in firms that only do so passively.

Table 7. The impact of CER on CGI: an ownership heterogeneity perspective.

	SOEs			Non-SOE		
	Current	Lag 1	Lag 2	Current	Lag 1	Lag 2
CER	-0.007**	-0.002	0.014***	0.002	0.008	0.004
	(-1.999)	(-0.474)	(3.138)	(0.414)	(1.385)	(0.759)
Profit	-0.030	0.033	0.015	-0.010	0.062	0.070
	(-0.948)	(0.973)	(0.341)	(-0.247)	(1.359)	(1.611)
Debt	-0.263*	-0.127	-0.004	0.035	0.145*	0.132
	(-1.796)	(-0.710)	(-0.023)	(0.613)	(1.667)	(1.276)
Grow	-0.024	-0.046	-0.037	-0.037*	-0.073***	-0.027
	(-1.044)	(-1.606)	(-1.231)	(-1.690)	(-2.980)	(-1.044)
Top	0.383**	0.272	0.387	0.135	0.131	-0.049
	(2.398)	(1.454)	(1.540)	(1.032)	(0.818)	(-0.182)
lnTA	0.395***	0.311***	0.187*	0.285***	0.266***	0.228***
	(5.271)	(3.636)	(1.831)	(8.476)	(5.956)	(2.991)
_cons	-9.239***	-7.455***	-5.385*	-6.470***	-6.539***	-5.104**
	(-4.625)	(-3.035)	(-1.741)	(-7.152)	(-5.213)	(-2.429)
Obs	727	642	557	635	558	482
R2	0.125	0.062	0.047	0.143	0.128	0.071
N	113	113	113	94	94	94

6.2. Industry heterogeneity

Different industries have varying factor input structures, pollutant emission levels, environmental management capabilities, and technological innovation levels. Accordingly, this paper categorizes 16 types of industries as high-polluting industries and others as less-polluting industries. The results are in Table 8. [4]

The regression coefficients for the current and the lag 2 period of CER in high-polluting industries are -0.009 and 0.016, respectively, and both pass the significance test, suggesting that the CER of the high-polluting industry has an immediate inhibiting influence and a delayed encouraging effect on CGI. The results of the less-polluting industry indicate that the coefficients of CER for the current and the lag 1 period are not statistically significant, while the coefficient for the lag 2 period is 0.01 and passes the significance test at the 5% level. CER in the less-polluting industry only has a significant "incentive" effect on CGI with a time lag. The rationale for the above discrepancies could be that high-polluting industries cause significant environmental harm and have high environmental governance costs (Xu et al., 2020). Businesses must invest massive resources in order to lessen their negative external environmental impact, which will crowd out green innovation in the short term. In addition, high-

[4] Based on the "Guidelines for Environmental Information Disclosure of Listed Companies" published by the Ministry of Environmental Protection in 2010, high-polluting industries specifically include thermal power, iron and steel, cement, electrolytic aluminum, coal, metallurgy, chemical, petrochemical, building materials, paper, brewing, pharmaceutical, fermentation, textile, leather, and mining industries.

polluting enterprises will be subject to stricter government supervision and wider social attention due to the particularity of the industry (Cai et al., 2020). Only by actively fulfilling environmental responsibility and effectively enhancing the core competitiveness of green innovation can polluting enterprises achieve sustainable development. Consequently, the driving effect of CER on CGI is stronger in high-polluting industries. For the less-polluting industry, the negative impact of enterprises on the environment is limited, the cost of environmental governance is low, and the short-term inhibitory effect of environmental responsibility on green innovation is not obvious. Furthermore, less-polluting enterprises face weak environmental oversight and low environmental pressure, their haste to implement green innovation is low. Therefore, the role of CER in encouraging CGI is relatively weak.

Table 8. The impact of CER on CGI: an industry heterogeneity perspective.

	High-polluting industry			Less-polluting industry		
	Current	Lag 1	Lag 2	Current	Lag 1	Lag 2
CER	-0.009**	0.004	0.016**	-0.003	0.001	0.010**
	(-2.192)	(0.988)	(2.242)	(-0.831)	(0.259)	(2.262)
Profit	0.052	0.063	-0.006	-0.054*	0.031	0.055
	(1.359)	(1.288)	(-0.106)	(-1.775)	(0.958)	(1.396)
Debt	0.200	0.301*	0.210	-0.078	0.053	0.098
	(1.416)	(1.988)	(1.271)	(-1.200)	(0.636)	(0.980)
Grow	0.010	-0.093***	-0.045	-0.054***	-0.056**	-0.033
	(0.306)	(-2.750)	(-1.193)	(-2.900)	(-2.584)	(-1.453)
Top	-0.012	-0.661**	0.277	0.274**	0.277**	0.189
	(-0.069)	(-2.282)	(0.531)	(2.370)	(2.005)	(0.918)
lnTA	0.209***	0.107	0.071	0.354***	0.321***	0.239***
	(3.944)	(1.391)	(0.749)	(9.810)	(7.144)	(3.394)
_cons	-5.449***	-0.857	-3.041	-8.083***	-8.074***	-6.147***
	(-3.693)	(-0.402)	(-0.932)	(-8.109)	(-5.979)	(-3.083)
Obs	301	258	223	1,069	948	821
R2	0.068	0.086	0.055	0.152	0.098	0.057
N	57	56	53	160	159	159

6.3. Regional heterogeneity

China's regional economic development is uneven, with disparities in resources, policy environments, and institutional conditions across the country. The coastal areas and inland areas are divided to further investigate the heterogenous impact depending on the regions where the companies are located. Table 9 displays the results.

According to Table 9, the CER regression coefficients of coastal enterprises are positive but only significant in the lag 2 period. In inland firms, the current period of CER has a certain inhibiting influence on CGI, but this effect eventually declines, and the lag 2 period has a large encouraging effect. Thus, it is evident that CER has a driving influence on CGI in both coastal and inland enterprises, but the inhibiting effect solely exists in inland enterprises. This disparity could be due to the following factors. (1) Coastal regions have robust economic power, an abundance of human resources, and advanced technological development, so firms' green innovation activities are supported by a sufficient amount of high-quality resources. Therefore, CER has no "extrusion" effect on CGI in the current period. Besides, coastal regions have switched their development strategy towards industrial upgrading and ecological environmental management. In a context where there are stricter environmental regulations and more market competition, coastal firms tend to put more value on being environmentally responsible. This allows the "incentive" effect of CER on CGI mainfest earlier in a favarable environment for innovation. (2) Inland areas' economic development is comparatively lagging, with limited innovation resources and low levels of green innovation. As a result, there is a clear "extrusion" effect on green innovation during the current phase of CER. Furthermore, in a large number of inland areas, the phenomenon of driving economic expansion at the expense of resources and the environment still prevails, and the starting point for green development is poor (Pan et al., 2021). Facing the issues of resource depletion, pollution control, and industrial upgrading, inland firms must create green solutions to achieve energy savings, emission reduction, and green transformation. Therefore, when supported by external resources brought by CER, inland firms will expand their investments in green R and D and aggressively promote green innovation.

Table 9. The impact of CER on CGI: a regional heterogeneity perspective.

	Coastal areas			Inland areas		
	Current	Lag 1	Lag 2	Current	Lag 1	Lag 2
CER	0.002	0.006*	0.010**	-0.012**	-0.003	0.013**
	(0.699)	(1.692)	(2.112)	(-2.630)	(-0.553)	(2.343)
Profit	0.007	0.071*	0.045	-0.052	0.013	0.037
	(0.192)	(1.957)	(1.288)	(-1.574)	(0.315)	(0.661)
Debt	-0.058	0.119	0.096	0.037	0.035	0.131
	(-0.846)	(1.144)	(0.771)	(0.393)	(0.313)	(1.032)
Grow	-0.038*	-0.058***	-0.017	-0.033	-0.075**	-0.067**
	(-1.867)	(-2.641)	(-0.671)	(-1.206)	(-2.335)	(-2.114)
Top	0.134	0.194	0.149	0.481*	0.119	0.281
	(1.417)	(1.434)	(0.638)	(1.909)	(0.481)	(0.786)
lnTA	0.341***	0.310***	0.247***	0.316***	0.254***	0.173*
	(11.005)	(7.145)	(3.255)	(4.783)	(3.641)	(1.868)
_cons	-7.618***	-7.918***	-6.186***	-8.621***	-5.880***	-5.050*
	(-9.107)	(-6.153)	(-3.006)	(-4.278)	(-2.735)	(-1.684)
Obs	775	680	590	595	526	454
R2	0.134	0.107	0.065	0.136	0.075	0.049
N	117	117	117	90	90	90

7. Conclusions and implications

7.1. Conclusions

Green innovation has become an effective strategy to reconcile economic growth and environmental conservation. To achieve green transformation, businesses must alter their philosophy, reduce their environmental impact, and relentlessly pursue green innovation activities. Numerous studies have investigated the drivers of green innovation at macro and meso levels, while research at the micro-firm level is scarce. Based on manually-collected panel data from 1640 Shanghai and Shenzhen A-share listed companies from 2010-2017, this paper empirically examines the influence and mechanism of CER on CGI from a dynamic perspective. The research conclusions are as follows. (1) The influence of CER on CGI has "phase" and "dual-effect" characteristics. The expense of environmental responsibility is rising in the current period, which exerts an "extrusion effect" on innovative resources and limits CGI. The "resource compensation" effect of environmental responsibility comes to the fore with the adjustment of an enterprise's internal and external environment and plays a role in supporting CGI. As a result, CER can successfully raise CGI levels, but the incentive effect takes time. (2) Financial constraints have a significant mediating effect in the process of CER promoting CGI, implying that CER can promote CGI by removing financing constraints. (3) CER affects different types of CGI in different ways. CER has an "inverted-N" impact on strategic green innovation; CER only has an "incentive" effect on substantive green innovation, but the effect is stronger and more lagging. Overall, CER implementation is more conducive to the promotion of high-tech and high-value substantive green innovation in the long run. (4) The heterogeneity analysis based on ownership, industry, and location reveals that the "extrusion" and "incentive" effects of CER on CGI are more pronounced among state-owned enterprises, high-polluting industries, and enterprises in inland regions.

7.2. Managerial insights

Based on the above conclusions, some important managerial insights can be put forward for the promotion of corporate green innovation.

First, enterprises should incorporate environmental responsibility into their long-term development strategy. In addition, corporate managers should make precise policies and targeted efforts to fully release the incentive effect of CER on CGI according to the differentiated impact of CER on different types of CGI in different periods.

Second, enterprises should actively disclose environmental information to improve financing circumstances and alleviate financial restraints. CER can lower company financing costs through signal transmission and reputation effects, resulting in financial aid for green R&D initiatives.

Third, considering the heterogeneity of the influence of CER on CGI in different types of firms, enterprises must thoroughly analyze their resource advantages and innovation capabilities to adopt a green innovation strategy that is appropriate for their development. A reasonable long-term green innovation plan is also required to ensure that sufficient innovation resources are available in the early stages of green R&D projects and that green innovation activities proceed smoothly.

7.3. Policy implications

The findings of this study also provide the government with useful implications for the green transformation of the Chinese economy.

First, the environmental information disclosure system should be improved. It is necessary to create a scientific and quantitative system of environmental indicators, as well as a legal framework for environmental information disclosure. Departments such as security supervision, environmental protection, and law enforcement must collaborate to ensure that the system is implemented properly.

Second, diverse methods should be adopted to foster green R&D, reducing CER's instant "extrusion effect" on innovation resources and enhancing CER's lagging "incentive effect". The government may help businesses go greener by providing tax breaks and financial support. A stable supply of enterprise innovation resources can be ensured by establishing a cooperative method among enterprises, institutions, and governments. To truly foster the growth of green innovation projects with high technological substance and high R&D value, the government should refine the classification of green innovation according to the difficulty and value of patents when providing assistance.

Third, the government should speed up the process of financial marketization, expand enterprise financing channels, and lower enterprise financing costs. The government can also help enterprises overcome external funding barriers by guiding the multi-tiered capital market to support green R&D projects. Green bonds and other new financial instruments should also contribute to the CGI.

Fourth, to effectively stimulate the vitality of CGI, local governments should utilize targeted and diverse measures according to enterprise characteristics. The government can appropriately strengthen the intensity of environmental regulations and supervision for SOEs, high-polluting industries, and inland enterprises, as well as improve the incentive mechanism for them to invest more resources in CGI. As for non-SOEs, less-polluting industries, and coastal enterprises, the government should strengthen their CER, promote green innovation practices, and effectively increase their level of CGI.

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Declaration of Competing Interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

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