Dear Selection Committee,

This PDF file contains all required application materials, including my curriculum vitae, cover letter, and research paper draft, combined into a single document, as only one PDF file is allowed for submission.

Sincerely,

Xuelian He

Xuelian He

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Education

Swansea University, UK (Apr 2024 – Current)

PhD in Finance
Research focus: Climate finance, corporate eco-innovation, environmental regulation, corporate governance, and sustainability
Current Project: Investigating the effectiveness of environmental regulation in promoting corporate eco-innovation in China

Swansea University, UK (Oct 2022- Dec 2023)
MSc, Economics
Core modules: Microeconomics, Macroeconomics, Econometrics, Research methods, Labor economics.
Trained in quantitative modeling and policy evaluation techniques

Zhengzhou College of Finance and Economics, China (Sep 2018- June 2022)
BSc, Finance
Dissertation: Research on the development of intermediary business of China Construction Bank
Key modules: Commercial bank operation and management, Securities investment, Insurance, Financial engineering, financial marketing

Conference

FHSS Postgraduate Research Conference 2025, Swansea University, UK ***May 2025***

Presentation: The Role of Environmental Regulation in Driving Corporate Eco-innovation in China
Presented empirical evidence on the ER–CEI link using firm-level panel data; highlighted the moderating effects of capital constraints, market forces, and cultural norms

Activities

Three Minutes Thesis (3MT) Competition, Swansea University, UK ***May* 2025**

Finalist: effectively communicated technical research on environmental policy and corporate eco-innovation to non-specialist audiences

Technical Skills

Stata: Advanced proficiency in panel data econometrics, fixed effects models, policy impact evaluation, and diagnostic testing
Python: Working knowledge in data manipulation (pandas), visualization (matplotlib, seaborn)
R / RStudio: Applied in statistical computing, graphical presentation, and preliminary econometric modelling.
Research Workflow: Skilled in constructing large-scale firm-level datasets and conducting empirical analysis on climate-related financial issues
Continuous Development: Actively improving coding and data science skills to support robust and reproducible research in environmental and financial economics

Profile

I am a second-year PhD student in Finance at Swansea University, with a strong research focus on climate finance, environmental regulation, and corporate eco-innovation in emerging markets. My empirical work combines panel econometrics and institutional perspectives to explore the factors that could shape firms' environmental innovation responses. I aim to produce research that contributes to policy design and sustainable financial systems.

Application for NBER PhD Student Workshop on Climate Finance

Dear Members of the Selection Committee,

I hope you are well.

My name is Xuelian He, and I am writing to express my strong interest in participating in the PhD Student Workshop on Climate Finance, hosted by the National Bureau of Economic Research on October 9, 2025, in Cambridge, MA. I am currently a second-year PhD candidate in Finance at Swansea University (UK). My research focuses on climate finance, corporate eco-innovation, environmental regulation, and corporate governance. I believe that this workshop would offer a unique opportunity to receive constructive feedback, engage in scholarly dialogue, and deepen my understanding of cutting-edge research in the field of climate finance.

My current research investigates how different types of environmental regulation influence corporate environmental innovation in China, particularly in the context of emerging market dynamics and institutional frictions. My empirical approach integrates panel data econometrics with theoretical insights from sustainability transitions and policy uncertainty. This work aims to shed light on the effectiveness of regulatory instruments in aligning corporate eco-innovation strategies with broader climate objectives.

I am submitting a working paper entitled “The Role of Environmental Regulation in Driving Corporate Eco-innovation in China”, which represents a core component of my doctoral research. The paper examines the heterogeneous effects of command-and-control versus market-based environmental policies on corporate eco-innovation and explores the mediating roles of financial constraints and corporate governance mechanisms. I am seeking constructive feedback to refine the identification strategy and improve the interpretation of results, particularly regarding firm heterogeneity and long-term environmental impacts.

Participating in this NBER workshop would be a highly valuable opportunity to engage with leading scholars and fellow PhD students working on climate-related financial topics. The event’s focus on how climate risks interact with financial markets, asset valuation, and policy frameworks aligns closely with the objectives of my doctoral research. I am particularly interested in learning from other attendees working on the financing of climate adaptation and transition pathways, and I hope to contribute perspectives from an emerging market context.

My expected PhD completion date is March 2027. My academic advisers are Dr. Mohamed Elmagrhi, Dr. Fangzhou Huang, and Dr. Giulia Fantini, who are available to provide a reference upon request.

Thank you very much for considering my application. I look forward to the opportunity to participate in this intellectually enriching event.

Yours sincerely,
Xuelian He

The Role of Environmental Regulations in Driving Corporate Eco-Innovation in China

Xuelian He

Faculty of Humanities and Social Sciences

School of Management

Swansea University

Supervisors:

Dr. Mohamed Elmagrhi

Dr. Fangzhou Huang

Dr. Giulia Fantini

1. Background and Introduction

1.1 Background

Since the economic reforms and opening-up in 1978, China's gross domestic product (GDP) has maintained an average annual growth rate of nearly 10% (World Bank, 2022). This economic growth has been accompanied by a substantial increase in resource consumption. In 2022, China's electricity consumption reached 29.12 exajoules, firmly establishing the country as the global leader. This trend continued into 2023, with China's primary energy consumption totalling 170.74 exajoules, once again securing the top position worldwide. Notably, China's energy consumption is approximately double that of the second-largest consumer, the United States, which stands at 94.28 exajoules (Energy Institute, 2024). This data not only reflects the expansion of China's economic scale and the intensity of its industrial activities but also underscores the country's significant role in the global energy market.

However, this rapid development comes at the cost of environmental degradation. For example, in 2019, China accounted for 27% of global greenhouse gas emissions, with its emissions surpassing the combined total of all developed nations (BBC News, 2021). This development strategy, which is often oriented towards short-term benefits, can pose a severe challenge to the Earth's ecological system. As noted by Nilashi et al. (2019), economic development models that neglect environmental protection struggle to achieve sustainability. The continuous increase in greenhouse gas emissions has become a major issue that countries worldwide urgently need to address (Kuramochi et al., 2020; Wils et al., 2025; Xiang & Xiao, 2025). Environmental pollution has triggered frequent extreme natural disasters, which pose a serious threat to human survival and development (Lin et al., 2022; Naderi et al., 2025; Xu & Ren, 2025). For example, natural disasters such as frequent typhoons, tsunamis, droughts, and soil desertification around the world are direct consequences of environmental degradation (Manisalidis et al., 2020; Mello & Jalles, 2025; Zandalinas et al., 2021). Extreme weather events and climate-related disasters have caused substantial economic losses on a global scale, with cumulative damages reaching nearly $1.5 trillion in the decade leading up to 2019 (World Economic Forum's Global Risks Report, 2023). In China, natural disasters in 2024—including torrential rainfall, landslides, hailstorms, and typhoons—resulted in direct economic losses exceeding USD 55.6 billion (Ministry of Emergency Management of the People's Republic of China, 2025).

In response to these threats, governments around the world have been compelled to implement measures for environmental management and to guide enterprises towards green development. The international community has made numerous efforts to reduce carbon emissions and achieve sustainable development. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) provided a legal and institutional framework for global climate change policy. The Kyoto Protocol of 1997 further committed to achieving greenhouse gas reduction targets by 2020. The Paris Agreement of 2015 established goals to limit global warming to well below 2 degrees Celsius, with efforts to restrict it to 1.5 degrees Celsius. In alignment with this framework, participating countries have engaged in reporting their progress in emission reduction and enhancing their capabilities to address and adapt to climate change.

However, even if all countries strictly adhere to the provisions of the Paris Agreement and make their own contributions to energy conservation and emission reduction, global temperatures could still rise by 3°C (Hansen et al., 2006; Lindsey & Dahlman, 2020; Wei et al., 2018). To achieve the 1.5°C target set by the Paris Agreement, global carbon emissions must be reduced by 7.6% annually between 2020 and 2030; to meet the 2°C target, emissions need to decrease by 2.7% per year (Rogelj et al., 2018; Tanaka & O'Neill, 2018; Zhao et al., 2022). These requirements underscore the urgency of intensifying emission reduction efforts, and the substantial commitment needed from countries worldwide to address climate change.

China's situation is particularly pronounced, as it is not only the largest emerging market in the world, but also the second-largest economy globally (Nguyen et al., 2021). As a key participant in the global response to climate change, China holds significant influence in formulating and implementing climate policies. Therefore, China's role in addressing global climate change is of paramount importance (Liu et al., 2022; Nilashi et al., 2019). In response to this, the Chinese government has actively engaged with international calls for action, committed to promoting green transformation and optimizing energy structure. This effort not only stems from a profound recognition of the limitations of the traditional "high-investment, high-consumption, high-pollution" development model but also reflects the urgency for China to transition to sustainable development in the context of the new era. By actively implementing environmental protection policies and exploring green development pathways, China aims to mitigate the negative impacts of climate change and contribute to global climate governance (Sun & Zhou, 2024). And the green transition is predominantly led by China, with the country manufacturing eight out of every ten solar panels globally (Financial Times, 2024). China is

responsible for producing at least three-quarters of the world's lithium batteries and holds over 60% of the global electric vehicle market (BBC News, 2024).

At the 19th National Congress of the Communist Party of China in 2017, strategic objectives were explicitly set forth to '*accelerate the reform of the ecological civilization system*' and '*build a green technology innovation system*' to better meet the growing demands of the people for a better life. This policy direction not only fosters domestic green innovation and energy-saving environmental protection but also demonstrates China's commitment to fulfilling global emission reduction responsibilities, reflecting a steadfast belief in the concept of a *'community with a shared future for mankind'*. In 2020, at the 75th United Nations General Assembly, President Xi Jinping further clarified China's climate commitments by announcing the goal of reaching *'carbon peak'* by 2030, which means carbon dioxide emissions will reach their peak and then gradually decrease. While the Chinese government has not publicly specified an exact emissions cap, various academic and institutional forecasts estimate that China's carbon dioxide emissions may peak at around 10.4 to 11.8 billion tons by 2030, depending on policy implementation and technological progress (Chen & Zhang, 2022; Li et al., 2023). More importantly, China has also set an ambitious target to achieve *'carbon neutrality'* by 2060, committing to a series of comprehensive measures to reach net-zero carbon dioxide emissions. Through these policies, China has not only achieved significant results in domestic environmental protection, but also played a crucial role in global climate governance, actively contributing to climate change mitigation (Chen & Lin, 2021). As of 2020, China's carbon intensity had decreased by 48.4% compared to 2005, surpassing the previously pledged reduction target of 40-45% to the international community (Liu et al., 2022). However, according to data from the Ministry of Energy of China, carbon dioxide emissions in the country increased by 5.2% in 2023. In order to meet the government's carbon intensity target for 2025, it is imperative that carbon emissions are reduced by 46% (Carbon Belief, 2024). This underscores the significant challenge China faces in balancing economic growth with environmental sustainability, highlighting the need for effective policies and strategies to achieve its climate goals.

To better promote green transformation and optimise energy structures, the Chinese government has not only actively responded to international calls at the national level but has also driven corporate-level changes through policies and actions. The government recognises that the urgency of transitioning to sustainable development is not only reflected in macro-level policy formulation and goal setting but also requires active participation and implementation

by enterprises at the micro level. Concurrently, as crucial market participants and key implementers of national policies, enterprises are increasingly integrating environmental, social, and governance (ESG) performance into their operational strategies (Zhou et al., 2023). This shift reflects an enhanced awareness of environmental protection among businesses and indicates that investors and consumers are considering a range of performance metrics, beyond just financial performance, in their decision-making processes.

However, voluntary measures alone are insufficient to ensure that enterprises genuinely pursue innovation (Cheng & Courtenay, 2006; P. Li et al., 2024). As an external constraint mechanism, environmental regulations (ER) are increasingly viewed as a key tool for accelerating corporate green transformation. By enforcing stringent ER regulations, the government can effectively guide enterprises to prioritise environmental protection alongside economic benefits. This approach not only helps achieve national emission reduction targets but also fosters progress in technological innovation and resource efficiency among enterprises, thereby providing them with a competitive advantage in the long term. Consequently, the relationship between ER and corporate eco-innovation (CEI) has become a prominent topic in environmental economics and corporate finance, sparking extensive interdisciplinary research (Dang et al., 2022; Zeng et al., 2024). Therefore, this study seeks to examine the impact of ER on substantive and symbolic eco-innovation, as well as the moderating roles of corporate financial constraints, market competitiveness, and Confucian culture in the ER–CEI nexus. It further explores whether ER indirectly influence corporate eco-innovation through the mediating channels of R&D investment and analyst attention.

1.2 Research motivations

The motivation for this study stems from several reasons. Firstly, corporate eco-innovation, which promotes the development of environmentally friendly products, plays a crucial role in reducing environmental burdens and is widely regarded as a key pathway to sustainable development (Cui et al., 2022; Wei et al., 2025). In this context, ER is essential for driving CEI (Fan et al., 2025; Jaffe & Palmer, 1997). It establishes clear compliance requirements, imposing mandatory limits on pollution emissions while offering incentives for CEI through policies such as tax reductions and carbon trading. On one hand, ER set clear emission reduction targets, communicated from central to local governments and to enterprises, compelling firms to reduce pollution during their development (Li & Lin, 2025; Lv et al., 2021).

By increasing pollution costs, these regulations encourage companies to seek innovative solutions, fostering the development of green technologies (Song et al., 2024). On the other hand, the implementation of carbon emission quotas and trading systems incentivizes firms to adopt innovative measures to reduce emissions, avoiding the additional costs of purchasing surplus quotas (Peng & Wang, 2021).

However, existing research on the impact of ER on CEI remains inconclusive. Some researches highlight its positive role, arguing that appropriate ER can enhance financial performance and stimulate innovation technologies, aligning economic growth with environmental goals (Farooq et al., 2024; Jaffe & Palmer, 1997; Yan et al., 2024). For example, the Porter hypothesis suggests that well-designed ER foster CEI by encouraging firms to improve efficiency (Porter & Linde, 1995). Costantini and Mazzanti (2012) provide empirical evidence supporting this perspective, demonstrating that ER can enhance firms' international competitiveness by stimulating technological innovation and advancement. Additionally, the carbon trading system serves as a positive signal of corporate environmental compliance, thereby enhancing investor confidence and alleviating the financial constraints faced by firms in pursuing CEI (Sun et al., 2017). Conversely, other studies argue that ER can suppress CEI, particularly when increased compliance costs reduce firms' cash flow and investment capacity (Bhattacharya et al., 2017). They suggest that ER may divert resources away from R&D, hindering CEI (Chen et al., 2024; Chen et al., 2021). The mixed impact of ER-CEI nexus underscores the complexity of their relationship, thereby highlighting the practical significance and theoretical value of this study. By conducting a quantitative analysis, this research aims to provide robust empirical evidence and theoretical insights into the influence of ER on CEI.

Secondly, ER is generally categorized into two main types: command-and-control (CAC) ER, which are imposed through mandatory directives by administrative authorities; market-based (MB) ER, which rely on economic incentives (Ji et al., 2025; Y. Li et al., 2025). These regulatory approaches differ substantially in their effects on CEI (Brown et al., 2022; Wang et al., 2022; Xie et al., 2017). As discussed earlier, existing studies have reported mixed findings regarding the ER–CEI nexus. However, the extant literature has predominantly focused on the effects of CAC ER, with limited attention given to MB regulatory instruments (Boubaker et al., 2024; Brown et al., 2022; Martinsson et al., 2024). For example, Liu et al. (2021) find that the implementation of China’s New Environmental Protection Law significantly increased firms’ applications for environmental patents, with a more pronounced effect among state-owned enterprises. Zhao and Zhao (2025) utilize panel data of Chinese listed

companies from 2002 to 2022 and adopt the establishment of environmental courts in China as a quasi-natural experiment to examine the causal impact of the ecological rule of law on corporate green innovation. Their study stated that the ecological rule of law significantly promotes green innovation by intensifying officials' performance pressure and strengthening environmental governance from both the public and the government. Wang and Zhang (2018) argue that CAC ER provide clear directives and enforceable standards, ensuring compliance but may lack the flexibility required to foster continuous innovation.

However, these studies largely focus on CAC ER, which presents certain limitations in capturing the broader regulatory landscape (J. Li et al., 2024; Tang et al., 2020). Specifically, CAC regulations are primarily designed to reduce pollutant emissions through uniform administrative mandates and compulsory standards (Li & Lin, 2025). While effective in enforcing compliance, such regulations often lack flexibility and thus may be insufficient in stimulating proactive CEI. In addition, as CAC regulations are typically implemented uniformly at the national level, they tend to overlook firm-level heterogeneity in size, technological capabilities, and the varying levels of regional economic development, thereby limiting their effectiveness in diverse contexts. Moreover, a focus on CAC regulations tends to overemphasize the role of government in environmental governance, while neglecting the contributions of market forces and public participation

Thirdly, as previously discussed, existing literature has primarily concentrated on the effects of CAC ER on CEI, while relatively little attention has been paid to the relationship between MB ER and CEI. Nevertheless, the significance of MB ER in reducing carbon emissions and improving total factor productivity has been well documented(Peng et al., 2021; Wu & Yu, 2025). For example, Albrizio et al. (2017) examine OECD countries and find that MB ER offer greater flexibility in emissions control compared to CAC regulations. Specifically, MB regulations enable polluters to adjust the timing and select the most appropriate technologies for emission control (Guo et al., 2021). This flexibility of MB regulations is also substantiated in the Chinese context. Drawing on data from Chinese industrial enterprises during the period 1998–2007, Peng et al. (2021) show that China's SO_2 Emissions Trading Pilot significantly enhances productivity and fosters more flexible mechanisms for technological innovation.

Despite the pivotal role of MB ER in mitigating carbon emission intensity, promoting low-carbon transitions, and improving energy efficiency, empirical research on the relationship

between MB ER and CEI remains relatively scarce (Li & Li, 2023; Wang et al., 2025; Wu & Yu, 2025). Although several studies have begun to explore this nexus (Li & Gao, 2022; Wei et al., 2024; Yang et al., 2024), the existing literature is limited in scope and generalizability.

For instance, Wei et al. (2024) analyse a sample of Chinese A-share listed firms from 2008 to 2021 and find that MB ER significantly enhance technological innovation. However, their sample is restricted to 746 firms after excluding those in the financial and real estate sectors and removing observations with missing data. Given that these sectors typically account for approximately 15–20% of all listed firms, the resulting sample size may lead to a considerable loss of observations, potentially introducing selection bias and limiting the robustness and generalizability of the findings. Similarly, Yang et al. (2024) provide evidence of a positive association between MB ER and green technology innovation within the manufacturing sector. Yet, given the sector-specific focus, the applicability of their conclusions to other industries remains uncertain, particularly considering the heterogeneous implementation of MB ER across regions and sectors. In a theoretical contribution, Li and Gao (2022) employ evolutionary game theory to examine the influence of MB ER on green innovation. However, their framework does not fully incorporate established theoretical perspectives such as the Porter Hypothesis or signalling theory, which may constrain the explanatory depth and theoretical integration of their analysis.

Finally, as discussed above, the existing literature adopts varying approaches to measuring ER, with some studies focusing on CAC instruments and others emphasizing MB mechanisms. This divergence in measurement has contributed to mixed and often inconclusive findings regarding the relationship between ER and CEI. To address these limitations, the present study incorporates both CAC and MB ER, aiming to offer a more comprehensive understanding of how different regulatory approaches influence CEI.

The inclusion of both regulatory types is theoretically and empirically justified. CAC and MB ER possess distinct advantages and limitations and may function complementarily in mitigating corporate environmental pollution and promoting CEI. Focusing exclusively on one type of ER may underestimate the overall effectiveness of environmental policy frameworks (Pan et al., 2024; Sun & Zhou, 2024). For example, CAC ER impose explicit pollution standards, which can be effective in achieving short-term emission reductions. However, their rigid structure may not incentivize long-term innovation or efficiency improvements (Tang et al., 2020). In contrast, MB ER offer greater flexibility and are more conducive to innovation-

driven responses, yet their effectiveness may be constrained by institutional factors such as underdeveloped carbon markets (Fang & Shao, 2022).

Much of the existing literature tends to examine a single regulatory approach, thereby overlooking potential interactions and complementarities between CAC and MB ERs. Moreover, given the heterogeneity in firms' resources, technological capabilities, and market environments, a uniform regulatory approach is unlikely to be universally effective (Tödtling & Trippl, 2005). Different types of ERs may be required to address the diverse innovation needs and environmental challenges faced by firms across sectors and regions.

Furthermore, the distinct objectives of CAC and MB ER—where the former primarily targets emission control and the latter emphasizes innovation—suggest that their impacts on CEI may differ not only in magnitude but also in mechanism. Understanding these differences can provide valuable insights into how firms balance short-term compliance with long-term sustainability goals (Ni et al., 2023; Yin et al., 2019).

Importantly, the nature and intensity of regulatory pressure can shape firms' innovation motivations, leading to divergent technological (Hyatt & Berente, 2017; Meng et al., 2019; Wang & Tang, 2024). While some firms pursue green innovation to enhance competitiveness through product differentiation and efficiency gains (Tong et al., 2014), others may adopt eco-innovation primarily as a compliance strategy, focusing on the quantity rather than the quality of innovation outputs (Chen, 2024). Although prior research has highlighted the distinction between substantive and symbolic green innovation (Truong et al., 2021), limited attention has been paid to how different types of ERs influence these two forms of innovation. This study seeks to fill this gap by examining the heterogeneous effects of CAC and MB ERs on both substantive and symbolic green innovation.

1.3 Research Questions

Building on the above research motivations, this study aims to address the following key questions:

(1) How do different types of ER affect CEI among Chinese A-share listed non-financial firms?

(2) Do CAC and MB regulations exert same effects on substantive versus symbolic green innovation?

(3) To what extent do financial constraints, market competition, and cultural factors moderate the ER–CEI relationship?

(4) Do R&D investment and analyst attention mediate the impact of ER on CEI?

(5) Does the effect of ER vary across enterprises with different forms of state ownership?

1.4 Research structure

The remainder of this study is organized as follows. Section 2 outlines the theoretical foundations underpinning ER and CEI, serving as the basis for the development of research models and empirical strategies. Section 3 provides a critical review of the relevant empirical literature, with particular attention to the heterogeneous effects of ER across institutional contexts. This section further examines the moderating roles of financial constraints, market competition, and Confucian cultural influence, thereby broadening the analytical framework. Section 4 presents the research design, including model specification and data sources, ensuring methodological rigor and reliability. Section 5 reports the empirical results, covering baseline regressions, moderation analyses, robustness tests. Finally, Section 6 concludes by summarizing key findings, offering policy implications, and suggesting avenues for future research in the field of corporate sustainability development.

2. Theoretical Framework

This section outlines the theoretical foundations of the study. Specifically, section 2.1 elaborates on the rationale for adopting a multi-theoretical framework, which underpins the overall analytical approach. Subsections 2.2 to 2.5 provide detailed justifications for the selection of specific theories employed to examine the relationship between ER and CEI. Finally, subsection 2.6 offers a summary of the theoretical considerations discussed in this section.

2.1 Porter hypothesis

Porter hypothesis (PH) is widely regarded as a key theory in the study of corporate innovation performance (Ambec et al., 2013a; Horbach, 2008; Lanoie et al., 2011; Stylianou et al., 2025; Zhang et al., 2020). It posits that well-designed ER can not only drive technology advancement but also enhance competitiveness and productivity, achieving a "win-win" scenario for economic and sustainable development (Porter & Linde, 1995). PH provides a robust theoretical foundation for research on ER and corporate sustainable development, which has led to its widespread application in empirical studies across diverse disciplines. Following previous studies, this research adapts PH the primary theory to explain the relationship between ER and CEI.

Porter's argument is grounded in the notion that pollution constitutes a form of economic waste, reflecting the insufficient and unnecessary utilization of resources (Lanoie et al., 2008). Accordingly, they suggest that pollution reduction can enhance firms' resource efficiency. In this context, reducing pollution is often associated with improvements in productivity (Porter & Linde, 1995). Subsequent research has widely applied the PH to explore the relationship between ER and corporate green development. (Lanoie et al., 2011; Rubashkina et al., 2015). For instance, Wang and Shen (2016) provide empirical evidence supporting a positive relationship between environmental regulation (ER) and environmental productivity. Similarly, Song et al. (2021) demonstrate a significant positive correlation between ER and the upgrading of industrial structure.

However, despite PH offers valuable insights in explaining the motivation and impact of ER mechanisms on corporate green innovation, it has also been criticized for the following reasons. Firstly, while PH posits that well-designed ER can enhance firm profitability by

encouraging pollution reduction, this contradicts the assumptions of neoclassical economics (Ambec et al., 2013b). According to the neoclassical view, profit-maximizing firms would have already exploited any cost-effective opportunities to reduce pollution in the absence of regulatory intervention as there is no "low-hanging fruits" under the perfectly competitive economy (André, 2015; Ferguson, 2008). In contrast, PH assumes that firms may systematically overlook or underutilize such opportunities to improve the financial performance (Ambec et al., 2013b). Secondly, the theory's assumptions have been criticized for oversimplifying the complexities of implementing ER and their heterogeneous effects on different types of firms (Lodi & Bertarelli, 2023). For example, it overlooks the high costs and uncertainties associated with the innovation process, which may offset the benefits of ER, leading to disputes about its incentivizing effect on innovation (Jaffe & Palmer, 1997). Finally, the Porter Hypothesis has been supported by empirical findings from specific firm-level cases, it has been subject to criticism due to concerns regarding its generalizability, given that much of the evidence is based on limited and potentially non-representative samples (Lanoie et al., 2011).

2.2 Legitimacy Theory

Legitimacy theory (LT) is among the most widely applied frameworks for explaining the relationship between ER and CEI (Mousa & Hassan, 2015). The definition of LT is "*Legitimacy is a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions*" (Suchman, 1995). Based on this definition, legitimacy theory posits that in a dynamic society—where institutional power sources and service demands are constantly evolving—institutions must continuously satisfy the dual criteria of legitimacy and relevance by demonstrating societal need for their services and securing social approval from beneficiary communities (Chelli et al., 2014). This suggests that firm survival is contingent upon the legitimacy of their operations and stakeholder acceptance (Guthrie & Parker, 1989).

From the perspective of LT, ER functions as a legitimacy-enhancing mechanism through which governments influence corporate production behaviour. ER represents an institutional embodiment of societal expectations regarding environmental protection, reflecting the demands of stakeholders such as the public, NGOs, and investors. LT posits that firms must align with prevailing social norms to maintain legitimacy. Accordingly, ER

requirements—such as mandatory disclosure of pollution data and penalties for excessive emissions—exert external pressure on firms to increase investment in pollution control and green innovation to preserve their legitimacy and ensure long-term viability (Bansal, 2005). LT further posits that organizations may engage in environmental protection and green innovation initiatives as strategic responses to gain, maintain, or restore their legitimacy. Such efforts enable firms to meet stakeholder expectations, enhance their public image, and ultimately secure reputational and competitive advantages in the market (Crossley et al., 2021).

Despite LT provides valuable insights into the relationship between ER and CEI, it has been subject to several criticisms. One major limitation is its predominantly descriptive nature, offering post hoc explanations without strong predictive capacity (Gray et al., 1995). Moreover, LT has been criticised for oversimplifying the ER–CEI nexus, as sustainable development involves not only external legitimacy pressures but also internal strategic considerations and innovation dynamics (Suchman, 1995). To address these limitations, this study also draws on stakeholder theory, which is elaborated in the following subsection

2.3 Stakeholder theory

Stakeholder theory (SHT) is a another theory used in corporate business ethics and organizational management, has been widely applied in research related to corporate governance, environmental performance, and green development (Schaltegger et al., 2019; Zhang & Zhu, 2019). Stakeholders refer to any individuals or groups with a direct or indirect relationship to an organization (Mahajan et al., 2023). Direct stakeholders include shareholders, suppliers, and employees, while indirect stakeholders encompass broader social groups, government bodies, or communities affected by corporate activities (Freeman & Reed, 1983; Phillips et al., 2003). The core tenet of SHT is that while corporate interests may sometimes conflict with broader societal interests, businesses should balance these competing interests in their decision-making processes to create value for both stakeholders and shareholders (Gibson, 2000).

The origins of SHT can be traced back to the 1960s when the concept of stakeholders was first introduced by the Stanford Research Institute (Mahajan et al., 2023). The theory emphasizes that a firm's long-term survival and prosperity depend not only on the support of shareholders but on collaboration with multiple stakeholder groups. Therefore, while profit

maximizing shareholder value remains a primary objective, corporations should also address the needs of other stakeholders.

SHT has been extensively employed in environmental research, providing evidence of the critical role diverse stakeholders play in influencing corporate sustainability and ecological responsiveness. For instance, pressures from competitors and employee behaviour have significant positive effects on CEI practices (Weng et al., 2015). Similarly, stakeholders substantially shape firms' environmental responses and are positively correlated with environmental patent innovation (Murillo-Luna et al., 2008). Moreover, green supply chain integration can enhance information sharing among partners and reduce the uncertainty associated with green product and process innovations (Seman et al., 2019). Stakeholders' personal experiences (e.g., education level, international exposure, and connections with government agencies) and the degree of trust external investors place in the company greatly influence the development of CEI (Huang et al., 2023; Quan et al., 2021).

In summary, SHT extends the PH by emphasizing the pivotal role of diverse stakeholders in promoting CEI. Broader community governance intensifies pressure on firms to comply with environmental regulations and pursue sustainable development, aligning corporate actions with shareholder expectations and enhancing long-term value (Naranjo Tuesta et al., 2021). MB ER, including emissions trading, pollution levies, and subsidies, leverage economic incentives to shape corporate environmental behaviour. By engaging a wider network of stakeholders—such as suppliers and customers—these mechanisms strengthen external oversight (Wu & Yu, 2025). For instance, emissions trading systems require firms to disclose emissions data, improving transparency and encouraging environmentally responsible practices to meet stakeholder demands.

Although SHT offers valuable insights into the relationship between ER and CEI, including the potential mechanisms through which ER influences CEI, it has been critiqued for its firm-centric orientation (Friedman & Miles, 2002). This perspective tends to place the organization at the centre of analysis, potentially overlooking the autonomy and agency of stakeholders. Moreover, SHT has been limited by its insufficient attention to the interactive and reciprocal dynamics between firms and stakeholders (Key, 1999). Specifically, it falls short in fully capturing the complex and evolving relationships that link organizations to their stakeholders. To overcome these limitations, this study draws on the dynamic capabilities view, as further detailed in the next subsection.

3. Empirical Literature Review and Hypothesis Development

3.1 Command-and-control ER and CEI

Environmental pollution has increasingly become a focal point of concern for governments, media, and society at large. However, due to the limitations in public and media capabilities, such as accessing internal corporate information, supervising resource allocation, and lacking specialized knowledge (Yang et al., 2017), their supervisory capacity remains relatively constrained. In contrast, the NEPL, as a mandatory and continuously effective formal system, possesses higher systemic and enforcement capabilities, effectively addressing the shortcomings of public and media oversight and imposing sustained compliance pressure on CEI. Consequently, environmental protection regulations play an irreplaceable role in driving corporate environmental responsibility and innovation activities, far exceeding the influence of public and media supervision (Bi et al., 2024).

The earliest version of the EPL was implemented in China in 1989. While it achieved certain accomplishments in the realm of environmental protection, its legal framework exhibited significant deficiencies. Specifically, the early version failed to detail relevant regulations, resulting in numerous operational difficulties. Additionally, insufficient enforcement and limited public participation constrained the practical effectiveness of the law, leaving many areas of environmental protection with limitations. Therefore, although the early EPL laid the groundwork for environmental protection, its limitations required subsequent revisions and enhancements to address these issues.

In response to these deficiencies, China passed the revised EPL (NEPL) in 2014, which came into effect on January 1, 2015. This amendment is regarded as the most stringent environmental protection legislation in China to date, aiming to rectify the shortcomings of the earlier law. The amendment significantly improved the implementation of the law by enhancing penalties for enterprises, introducing administrative detention measures for environmental violations, mandating environmental information disclosure by enterprises, and emphasizing the environmental protection responsibilities of local governments (Bi et al., 2024; Nilashi et al., 2019; H. Yu et al., 2021). The NEPL introduced major reforms, effectively supplementing and refining the old EPL. Notably, the new law imposed stricter regulations on corporate production, including provisions for daily continuous fines and unlimited fines, significantly increasing compliance costs for enterprises.

Porter hypothesis suggests that strict but well-designed environmental regulatory policies can incentivize firms to enhance their operational efficiency through technological innovation and organizational optimization. Such regulatory pressures compel firms to explore latent opportunities for improvement within existing technologies and processes, thereby increasing resource efficiency and reducing production costs. Building on this theoretical framework, the reform of the EPL has intensified legal requirements and external pressures on firms, exerting a profound influence on corporate behaviour by encouraging greater attention to regulatory compliance, reputation management, and the maintenance of public image (DiMaggio & Powell, 1983).

As government and public attention to environmental issues continues to grow, firms may respond by reducing production scales to lower emissions and mitigate compliance costs. Simultaneously, the heightened external pressures may drive firms to adopt CEI strategies to comply with the stringent standards for pollutant emissions and energy consumption outlined in the NEPL. However, such rigorous ER also significantly elevate the compliance risks associated with green innovation. Firms failing to meet the prescribed standards risk severe consequences, including exclusion from markets, mandatory shutdowns, or substantial fines.

Dynamic capabilities view highlights that a firm's competitive advantage stems from its ability to align dynamic capabilities with the external environment. These capabilities can be categorized into three key aspects: the ability to sense opportunities and threats in the external environment, the ability to seize these opportunities and transform them into business value, and the ability to flexibly allocate and reconfigure limited resources to adapt effectively to market changes (Singh et al., 2022). Under conditions of stricter environmental regulations, firms often adopt more conservative operational strategies to ensure legality and compliance. For instance, rather than making significant investments in CEI, firms may prioritize emission reductions by scaling down production, thereby reducing compliance costs.

Moreover, stringent regulatory requirements exert profound effects on corporate resource allocation. To meet increasingly stringent compliance demands, firms tend to prioritize allocating resources to compliance management, such as expanding the budgets of environmental compliance departments. This prioritization of resource allocation inevitably diverts financial and human resources away from green innovation initiatives, thereby constraining technological advancement and the potential for sustainable development. Thus,

the effectiveness of dynamic capabilities is influenced by the intensity of ER, which shape the direction of corporate resource allocation and innovation strategies.

Existing research on the impact of the NEPL on CEI primarily explores the mechanisms from two perspectives: cost and technology (Liu et al., 2021; Song et al., 2020). First, from the cost perspective, the implementation of the NEPL has significantly increased compliance costs for firms. Stricter regulatory requirements compel companies to internalize pollution control costs, directly raising production expenses. Furthermore, policies encouraging public participation in environmental governance expose companies not only to the direct economic risks associated with environmental pollution but also to the potential loss of consumers and investors due to the failure to fulfil social responsibilities, thereby further increasing financial pressure.

From a technological perspective, the NEPL requires firms to make choices between operating in high-pollution industries and adopting green technologies, driving companies to adopt various strategies in response. Specifically, there are three common approaches. First, some firms may opt to exit high-pollution industries or cease production. However, entering a new industry often requires substantial resources to build a customer base, and this choice typically has a significant negative impact on a company's production operations and financial performance. Therefore, firms are generally reluctant to take this path unless necessary. Second, firms can acquire green technologies through mergers and acquisitions (M&A), by purchasing companies engaged in green production, thus enabling a rapid green transition (Pan et al., 2019). Although M&A allows firms to quickly access existing green technologies, this external dependency may fail to send a strong signal of environmental responsibility and internal innovation to regulators and the public. Lastly, firms may choose to promote green technological innovation through internal R&D to meet the new regulatory requirements. In this context, companies are increasingly recognizing that CEI is not only an important means of ensuring compliance but also a core strategy for maintaining long-term competitiveness. However, due to the increased compliance costs and operational pressures resulting from ER, firms tend to adopt more conservative business strategies, avoiding risks in an uncertain environment. Additionally, given their limited resources, companies often allocate most of their resources to ensuring the stability of daily operations, which may lead to a "crowding-out effect" on R&D innovation. This is particularly true for small and SMEs, for which the high costs of compliance and CEI may become burdensome, making it difficult for them to afford the necessary financial and resource investments for sustainable innovation in the short term.

Moreover, some firms may opt for short-term compliance strategies to avoid heavy fines and regulatory penalties, rather than investing in long-term CEI, potentially limiting technological breakthroughs and sustainable development. Building on the above analysis, the following hypotheses are proposed:

H1. NEPL has a significant negative impact on the development of corporate CEI.

3.2 Market-based ER and CEI

CETP represents a practical application of stakeholder theory, which posits that firms should consider not only the interests of shareholders but also the needs of various stakeholders, such as suppliers, employees, and investors, in their decision-making processes. The implementation of CETP requires firms to disclose environmental information, prompting widespread attention from the media, analysts, and the public, thereby increasing external scrutiny of the company's production and business activities. This policy not only enhances transparency regarding environmental compliance but also subjects firms to greater external oversight.

As consumer awareness of environmental issues grows, consumers are increasingly inclined to purchase eco-friendly products and show a preference for companies that actively fulfil their social responsibilities and focus on sustainable development. This shift encourages a more active interaction between firms and their stakeholders. In response to the social, environmental, and economic considerations of these stakeholders, companies are more likely to increase their investment in green technological innovation to meet expectations and enhance their market competitiveness.

Signalling Theory further suggests that in situations of market information asymmetry, firms can send green signals to the market, government, and consumers through investments in green innovation, the launch of eco-friendly products, and the implementation of energy-saving and emission-reducing measures. These actions allow companies to demonstrate their environmental commitment, enhance their reputation, and establish themselves as leaders in green innovation. Additionally, such signals can attract investor attention and secure financial support. Not only do these signals enhance the company's sense of corporate social responsibility, but they also contribute to its long-term potential for sustainable development.

In recent years, the ETS as a flexible and market-oriented environmental regulatory tool, has emerged on a global scale, becoming a critical policy measure driving corporate sustainability. It has garnered extensive attention from both the academic community and policymakers (Chen et al., 2024). The system's flexibility and market-driven characteristics provide businesses with diverse avenues for compliance, incentivizing them to reduce carbon emissions through market mechanisms while also fostering innovation through the allocation and trading of emission permits. Against the backdrop of globalization, the widespread application of ETS allows different countries and regions to effectively leverage this mechanism to achieve the dual goals of environmental protection and economic development.

From an international perspective, the early implementation of ETS can be traced back to the EU. As one of the most prominent carbons trading markets globally, the EU ETS has achieved significant success in reducing carbon dioxide emissions since its establishment, setting an example for other countries. This system has not only demonstrated its efficiency as an environmental protection tool but also showcased its adaptability to different economic environments and industrial characteristics across countries and regions (Deng et al., 2023; Duan & Hu, 2014; Jiang et al., 2016). Through the market-based trading of carbon allowances, EU member states can meet their collective climate goals while allowing for the trading of permits based on their specific needs, thus achieving overall reductions in carbon emissions.

Further academic research has highlighted that the EU ETS is not solely about reducing emissions but also plays a pivotal role in driving the development of low-carbon technologies and accelerating the transition of firms toward a green economy (Jia et al., 2024; Teixidó et al., 2019). For instance, studies show that the system has greatly promoted the development and utilization of low-carbon energy, significantly enhancing firms' internationalization potential through the synergy of policy and market forces (Hong et al., 2022). This internationalization is reflected not only in increased technology exports but also in the growing global competitiveness and influence of firms, with the system being highly coordinated with other environmental policies (Chen et al., 2021; Li et al., 2016). This trend is particularly evident in developed countries, where many firms participating in ETS have contributed to environmental protection while also achieving successful green transitions through technological innovation and industrial upgrading.

For example, Borghesi et al. (2015) conducted an empirical study on Italy’s manufacturing sector, finding that industries participating in ETS showed significantly higher

technological innovation capabilities compared to non-participating industries. This result suggests that ETS not only provides economic incentives for businesses but also, through the market-driven supply-demand mechanism, pushes firms to continuously seek innovative breakthroughs in response to increasingly stringent ER. The commodification of carbon allowances and their price fluctuations further influence corporate decision-making through market forces, compelling firms to focus more on technological advancements and innovation during their green transitions.

Moreover, beyond its successful application in Europe, countries such as the United States, Japan, and South Korea have also established their own carbon trading systems. The experiences of these countries demonstrate that ETS, as a market-oriented environmental regulatory policy, not only helps reduce carbon emissions but also drives progress in CEI and sustainable development through economic incentives (Zeng et al., 2024). For instance, carbon trading policies in certain U.S. states and regions have effectively encouraged companies to develop clean energy technologies, fostering green technology innovation and application, while simultaneously allowing firms to remain profitable while complying with emission regulations. Similarly, South Korea's ETS, through a combination of economic penalties and incentives, has driven companies to optimize their energy structures and upgrade technologies to address global climate challenges. The success of these countries indicates that ETS is not only an environmental policy but also a market mechanism that stimulates the intrinsic innovation potential of firms (Feng et al., 2024; Jia et al., 2024; Zhang & Xi, 2024).

However, China's carbon emissions trading system started relatively late. In October 2011, the National Development and Reform Commission (NDRC) issued a notice on conducting pilot projects for carbon emissions trading, marking the initial launch of China's ETS. According to the notice, the first batch of pilot cities or regions established their carbon trading systems in 2013, including Shenzhen, Shanghai, Beijing, Guangdong, and Tianjin. These pilots aimed to explore and accumulate experience for the future establishment of a nationwide ETS. Subsequently, Hubei and Chongqing launched their pilots in 2014, with Fujian following in 2016. As these pilot programs progressed, the Chinese government announced in 2017 that the national ETS would officially launch in 2021, marking a significant step forward in China's efforts to reduce carbon emissions.

Although China's ETS was implemented later than in other countries, it has gradually become an important tool for driving CEI as a market-oriented environmental regulatory policy.

With the implementation of ETS, scholars have extensively discussed its impact on the green economy, covering regulatory authorities, corporate responses, financial performance improvements, and policy effectiveness. For example, based on data from 136 Chinese power companies, Pu and Ouyang (2023) found that CETP policy significantly promoted CEI activities. However, the study also indicated that when firms faced operational difficulties, the positive effects of the policy diminished, highlighting the role of a company's financial health in its response to carbon regulations. Similarly, Yang et al. (2023) found that the carbon trading pilot policy significantly improved corporate profitability through the attraction of research talent and increased R&D investment, ultimately fostering the development of CEI.

Based on the existing body of research, this study posits the following hypothesis:

H2. The impletion of CETP policy have a significant positive effect on the development of corporate CEI.

3.3 Moderating effect analysis

As mentioned earlier, most past studies have only examined the direct effects of financial capabilities, market competition, and cultural factors on CEI, without considering their potential moderating roles in the relationship between ER and CEI (Dang et al., 2022; Duanmu et al., 2018; Huang et al., 2024). Therefore, this study attempts to extend and contribute to the extant CEI literature by investigating whether financial constraints, market competition, and Confucian culture moderate the association between ER and CEI. There are several theoretical and empirical motivations for investigating the moderating roles of these variables on the association between the ER and CEI.

First, from a theoretical perspective, the resource-based view and institutional theory jointly suggest that corporate resources and market structures are critical determinants of competitive advantage and innovation capacity (Dubey et al., 2019; Khanra et al., 2022). Confucian culture, as an institutional factor, may further shape corporate responses to environmental regulation by reinforcing values such as social responsibility and long-term orientation (Li & Yao, 2024).

Second, in terms of practical significance, financial constraints can hinder firms' ability to invest in green innovation initiatives (C.-H. Yu et al., 2021), while market competition may either stimulate or suppress innovation depending on the intensity of competitive pressure (Ma & Li, 2025; Xu et al., 2024). Confucian culture, which is particularly salient in East Asian

economies, may encourage firms to exceed regulatory requirements or, alternatively, lead them to adopt a minimalist compliance approach, depending on how cultural norms interact with institutional expectations (Chao et al., 2023).

Third, with respect to the research gap, prior studies have predominantly focused on financial and market factors, with limited attention to the role of cultural context (Qiu et al., 2025; Wang & Zhang, 2025). By integrating internal, external, and cultural dimensions, this study contributes to a more comprehensive understanding of the mechanisms through which environmental regulation affects corporate green innovation.

Finally, from a policy perspective, the findings have important implications. For example, if financial constraints are found to be a significant barrier, governments may consider implementing green credit programs and targeted financial subsidies. If market competition is a key driver, regulatory frameworks should be designed to balance competitive dynamics with innovation incentives. If Confucian culture significantly shapes corporate environmental behaviour, policymakers should incorporate cultural considerations into regulatory design and leverage social norms and reputational mechanisms to enhance policy effectiveness.

3.3.1 Moderating effect of financial constraints

A substantial body of research has demonstrated a close relationship between CEI and their financing capabilities, as well as financial constraints, a connection that has been extensively validated in numerous academic studies (Ayyagari et al., 2011; Brown et al., 2009; Jin et al., 2019). As a crucial strategic response to environmental challenges, CEI typically requires firms to invest significant time and financial resources in areas such as technological research and development and production process improvements, making them highly dependent on internal resources. However, innovative firms often face more severe financial constraints alongside increasing capital demands, which not only limit their ability to acquire resources but also hinder their R&D intensity and innovation performance (Santos & Cincera, 2022; Tang et al., 2023). Therefore, sufficient financial support, particularly through internal financing and external funding channels, is essential for firms to successfully advance CEI and enhance their innovation outputs.

Studies indicate that firms with strong external financing channels and fewer financial constraints are generally able to achieve higher R&D output (Brown et al., 2012). The

flexibility afforded by free-flowing capital enables these firms to adjust resource allocations in response to market fluctuations and technological uncertainties, ensuring the smooth progression of R&D projects (Lin et al., 2024). For instance, empirical research conducted by C.-H. Yu et al. (2021) on Chinese firms found that enterprises facing significant financial constraints exhibited considerably lower levels of CEI output compared to their financially robust counterparts. This finding further highlights that financial constraints not only restrict firms' R&D capacity but also directly impact their overall performance in CEI. Consequently, firms' financing capabilities act as a moderating factor in the CEI process, where adequate capital allows companies to better manage the uncertainties and risks associated with R&D, ultimately improving innovation outcomes.

Moreover, the impact of financial constraints on firms' environmental innovation capacity has garnered extensive attention across multiple domains. Ghisetti et al. (2015), using survey data from European SMEs, revealed that firms' perception of financial barriers often impedes the development of environmental innovation, with such negative effects being especially pronounced when financial constraints are high. As a result, researchers have emphasized that expanding access to credit and financing channels can effectively promote environmental innovation, mitigating the tendency of firms to adopt conservative approaches to technological innovation due to insufficient funding (Guney et al., 2017). Firms facing financial constraints tend to pursue more conservative investment strategies, avoiding green technologies and sustainable development strategies due to the high uncertainty and substantial cost associated with CEI, which often exceeds the financial risk these firms can bear (Boubakri et al., 2013; Fogel et al., 2008; C.-H. Yu et al., 2021).

Noailly and Smeets (2016) conducted an extensive analysis of data from 1,300 European companies, revealing that financial constraints play a critical role in innovation activities related to renewable energy and fossil fuel technologies. Their study indicates that a firm's financing capacity directly determines its ability to initiate innovation projects, particularly in high-risk, high-reward areas such as green technology innovation. This finding suggests that, when deciding whether to pursue CEI, firms must consider not only technological and market factors but also the availability of financial resources as a key decision variable.

Moreover, the influence of a firm's financing capacity varies across different stages of the innovation project lifecycle. García-Quevedo et al. (2018) examined the likelihood of project abandonment by Spanish firms facing financial constraints and found that financing

capacity not only affects innovation decisions but also directly impacts the level of innovation outcomes. More importantly, their study highlights that the role of financing varies by project stage: during the design phase, firms rely more on internal financial resources as funding needs are primarily focused on research and early-stage planning; whereas, in the execution phase, firms become more dependent on external financing to meet the larger capital demands associated with production and market deployment.

Financial constraints have a profound impact not only on a firm's innovation capacity but also on its ability to respond to ER, playing a critical moderating role in this context (Lin et al., 2024). Externally, the pressure of ER is often accompanied by increased market demand for green technologies and products. When client firms, driven by regulatory policies, increase their demand for green technologies and products, supplier firms with sufficient financial support can swiftly adjust their product offerings and production processes to meet this demand, thereby maintaining long-term business relationships and enhancing their market competitiveness. Conversely, supplier firms facing financing constraints and insufficient capital will experience limitations in their ability to respond effectively to clients' green demands, which not only weakens their market competitiveness but also risks the loss of key clients, severely affecting their financial performance and market standing. Therefore, by alleviating dependence on financial resources, financing capacity enhances firms' ability to respond to market demands and maintain client relationships under the pressure of ER.

Internally, a firm's strong financing capacity can bolster its innovation enthusiasm and resilience in the face of stringent ER. Research shows that well-financed firms generally possess greater financial stability, enabling them to invest more resources into green technology R&D, despite the higher risks and uncertainties associated with such projects (Kunieda & Takashima, 2024). This sustained financial support not only helps improve a CEI capability but also aids in shaping and strengthening its "green image," thus enhancing its reputation and sustainable competitive advantage in the marketplace. By continuously improving CEI, firms can better adapt to evolving ER and secure a favourable position in the increasingly competitive green economy. Therefore, financing capacity not only moderates a firm's responsiveness to external regulatory pressures but also promotes internal green technology innovation, boosting its sustainable competitiveness.

In summary, financing capacity plays a pivotal moderating role in CEI. It not only directly influences a firm's innovation capacity and outcomes but also enhances its ability to

cope with ER and shifts in market demand by alleviating financial constraints. As ER become increasingly stringent, financing capacity will emerge as a core driver of firms' green transitions, helping them remain competitive in the wave of the green economy and achieve sustainable development. Based on the above analysis, the following hypotheses are proposed:

H3. The firm's financing constraints negatively moderate the ER-CEI relationship.

3.3.2 Moderating effect of market competitiveness

The market competitiveness of enterprises plays a significant moderating role in the relationship between ER and CEI. This moderating effect is reflected not only in how market competitiveness influences corporate decision-making and performance regarding CEI, but also in its impact on overall environmental performance. However, the existing literature presents differing views on the influence of market competitiveness on corporate environmental performance.

On one hand, some studies suggest that a highly competitive environment has adverse effects on corporate innovation (Duanmu et al., 2018; Guo et al., 2022). Under the competitiveness environment, enterprises may prioritize short-term gains over long-term CEI due to significant market pressures. This short-sighted behaviour can lead to insufficient investment in environmental protection and sustainable development and may even result in a disregard for compliance with ER, ultimately affecting overall environmental performance. For instance, Duanmu et al. (2018) found that intensified market competition has a significant negative impact on the environmental performance of manufacturing enterprises in China, particularly for those adopting cost-leadership strategies, where the negative effects are more pronounced compared to firms following differentiation strategies. Similarly, Guo et al. (2022) reached a comparable conclusion in their analysis of publicly listed manufacturing companies in China, indicating that fierce market competition may suppress the capacity for CEI among enterprises. This suppressive effect partially stems from the existence of technology spillover effects. In an intensely competitive market environment, the profits and patent prices for innovators are often suppressed, leading enterprises to view innovation activities as non-profit-maximizing endeavours, thus diminishing the motivation for entrepreneurs to integrate innovation into the long-term strategy of the enterprise (Nie et al., 2022).

Furthermore, research indicates that firms in highly competitive industries may strategically limit the disclosure of information to reduce the opportunity for competitors to

access critical data. This is particularly true in high-investment areas such as technology and R&D, where firms are more likely to treat such information as proprietary and confidential to safeguard their competitive advantage (Rahman et al., 2024). Importantly, the pressure of market competition also moderates the relationship between ER and CEI in terms of resource allocation. In a highly competitive market, resources for enterprises are often constrained. Under these circumstances, companies may be more inclined to focus on short-term profits, allocating more resources towards enhancing production efficiency and reducing costs rather than investing in long-term technological innovation and green development strategies. This bias in resource allocation further influences the moderating role of market competitiveness in the relationship between ER and CEI.

Another set of research posits that a highly competitive market environment can encourage corporate managers to focus more on innovation, particularly in the realm of CEI (Nesta et al., 2014; Yalabik & Fairchild, 2011). Driven by competitive pressures, enterprises are compelled to seek new methods to enhance efficiency, reduce costs, and comply with increasingly stringent ER. In this context, corporate managers are often more proactive in investing in sustainable technologies and innovations to maintain their competitive edge. A prominent study by Arrow (1972) exemplifies the notion that market competition has a positive effect on CEI. He argued that in monopolistic markets, the interests of monopolies diminish the incentive for innovation, leading to managerial complacency. However, when enterprises operate in a highly competitive environment, managers are incentivized to innovate by reducing production costs and obtaining profits from innovation.

Additionally, Carlin et al. (2004) found that a fierce competitive environment not only promotes the innovative capacity of enterprises but also enhances their production efficiency. Javeed et al. (2020) introduced the concept of an incentive mechanism whereby market competition moderates the relationship between ER and CEI. They argued that in a fiercely competitive market, enterprises often increase their investment in CEI to sustain and enhance their competitiveness. Such investments not only bolster the market position of the enterprise but also enable it to demonstrate a proactive response to ER through CEI, thereby establishing a positive corporate image. Intense market competition thus encourages enterprises to make greater efforts in CEI, which, in turn, strengthens the role of ER in promoting such innovations.

Simultaneously, when facing intensified market competition, enterprises typically adopt appropriate strategic adjustments to maintain or enhance their competitive advantages.

For instance, they may prioritize the adoption of CEI technologies and production methods that comply with ER. This approach not only helps enterprises align with environmental policies but also showcases their commitment and capability regarding environmental protection, further enhancing their competitiveness. In this context, market competition does not undermine the positive effects of ER; rather, it may facilitate a more pronounced impact of ER on CEI. Such strategic adjustments may involve increasing research and development investments, improving production processes, and acquiring green certifications, all of which can help enterprises gain advantages and enhance their environmental performance in a competitive market.

In summary, the influence of market competitiveness on the relationship between ER and CEI is complex, serving both suppressive and incentivizing roles. The former is primarily manifested in the short-term orientation of resource allocation and strategic decision-making, while the latter is reflected in the increased investment in CEI aimed at enhancing competitiveness, thereby promoting the positive effects of ER. This incentive mechanism encourages enterprises to consider the requirements of ER more prominently in their strategic development, thereby achieving sustainable development goals and standing out in a highly competitive market environment. Thus, the moderating role of market competition in the relationship between ER and CEI is not one-dimensional but may embody a complex dual effect. Based on this analysis, this study proposes the following hypotheses to further explore the different moderating effects of market competitiveness in this relationship:

H4. Market competitiveness significantly moderates the ER-CEI relationship, enhancing ER impact on CEI.

3.3.3 Moderating effect of Confucian culture

Confucian culture has profoundly shaped social values and ethical systems in East Asia, particularly in China. Numerous scholars argue that Chinese business ethics are significantly influenced by Confucian culture, which plays a critical role in shaping corporate governance models and decision-making logic (Du, 2015). As cultural carriers, individuals' behaviours reflect the deep impact of culture on organizational decision-making (Huang et al., 2024; Wang & Juslin, 2009).

Specifically, Confucian culture emphasizes the concept of “the unity of heaven and humanity” (tiān rén hé yī), which advocates for individuals and organizations to conform to

natural laws and achieve harmonious coexistence with the environment (Y. Zeng et al., 2024). Through its influence on corporate leadership, this philosophy encourages firms to undertake social responsibilities and prioritize environmental protection. Consequently, in regions where Confucian culture exerts a strong influence, firms are more likely to proactively accept and internalize command-and-control environmental regulations, adjusting their business strategies to enhance environmental performance. For instance, firms may actively upgrade production technologies, improve resource utilization efficiency, and increase investment in green technology research and development to achieve pollution reduction at its source, rather than merely complying with regulations to avoid penalties. Furthermore, Confucian culture advocates the value of "righteousness" (yì), which emphasizes adherence to moral norms and social responsibilities, promotes fairness and integrity, and prioritizes public interest over individual gains (Liu, 1998; Xu et al., 2019). Under this value system, corporate compliance is driven not only by external regulatory constraints but also by an intrinsic sense of social responsibility. This awareness encourages firms to exceed minimum legal requirements, foster constructive interactions with the government, and voluntarily enhance environmental standards, thereby strengthening corporate social reputation and potentially securing policy incentives or governmental support (M. Zhao et al., 2024).

Additionally, Confucian culture embodies the principle of "harmony in diversity" (hé ér bù tóng), which underscores the importance of collaboration and coordination among society, organizations, and the state (Fu et al., 2022). While respecting individual and organizational differences, this principal advocates for maintaining overall harmony and fostering cooperative governance. As a result, firms are more likely to engage in cross-organizational collaborations, jointly develop green technologies, optimize resource allocation, and share innovative outcomes, thereby promoting sustainability at the industry level. Lastly, the Confucian concept of "integration of family and state" suggests that firms should be perceived as an integral part of the nation and society rather than as isolated economic entities (Xu et al., 2019) This perspective motivates firms to align their strategic adjustments with national policies, reducing resistance to environmental regulations, enhancing compliance willingness, and fostering a broader transition toward green and sustainable development. Building on the theoretical framework outlined above, this study hypothesizes:

H5. Confucian culture significantly and positively moderates the relationship between ER-CEI, with a more pronounced effect of ER on CEI in regions with strong Confucian cultural values.

4. Data and Methodology

4.1 Data Selection

The initial sample of this study encompasses the annual data of all non-financial Chinese A-share companies listed on the Shanghai and Shenzhen Stock Exchange from 2004 to 2022. Considering the stringent regulations on environmental information disclosure enforced by the Shanghai and Shenzhen A-share markets, they provide a robust and reliable empirical sample for this study. Moreover, these markets serve as key focal points for both domestic and international investors (Yang et al., 2024). Thus, examining these markets can offer more effective decision-making support for investors.

On October 29, 2011, the Office of the NDRC announced the launch of carbon emissions trading pilots in seven regions, including Beijing, Tianjin, Shanghai, Chongqing, Hubei Province, Guangdong Province, and Shenzhen. However, since the carbon emissions trading market was still in its early stages, with management systems and concepts still unclear and underdeveloped, the 2011 pilot policy had a limited impact on overall carbon emissions and corporate green innovation performance (Chen et al., 2021). As China's carbon emissions trading system gradually matured, from 2014 onwards, all seven pilot regions launched online trading and public service platforms. The volume and value of carbon trading increased steadily, and an increasing number of companies voluntarily joined the carbon market, making China's emissions trading system the world's second largest, following the EU ETS (Zhou et al., 2020).

Moreover, China's NEPL was fully implemented in 2015, further supporting the development of the carbon emissions trading market. Given that the transition from an exploratory phase to a mature market takes time, and considering the inherent lag in corporate innovation, this study deliberately sets the sample period from 2004 to 2022 to capture both pre- and post-policy periods. This timeframe allows for a comprehensive assessment of the impact of these policies on corporate behaviour and performance.

To ensure the integrity and reliability of the data, a series of systematic data processing steps were undertaken. First, financial companies were excluded due to their distinct regulatory requirements, which make their financial statements non-comparable to those of non-financial firms. Second, companies labelled as ST, PT, and ST* were excluded from the sample, as these firms face financial distress, delisting risk or special transfer, and are subject to special regulatory supervision, which may introduce bias into the empirical analysis (Yang et al., 2024). To further enhance data quality, all observations with missing values were removed to ensure

the analysis was based on a complete and consistent dataset. Additionally, to mitigate the influence of outliers on the regression results, all continuous variables were winsorized at the 1% and 99% percentiles to reduce the impact of extreme values. Finally, in the regression analysis, we controlled for year and industry fixed effects to eliminate potential confounding effects from temporal and sector-specific factors, ensuring the robustness and scientific rigor of the research findings.

The sample selection procedure is detailed in panel A of Table 1. Following the above steps, the final dataset comprises 3,096 publicly listed firms, yielding a total of 30,322 firm-year observations. Annual financial data were obtained from the China Stock Market and Accounting Research (CSMAR) database, while patent-related information was sourced from the China Research Data Service Platform (CNRDS). CNRDS is a national-level research database in China, sponsored by the Chinese Academy of Social Sciences and relevant government departments. Most of the data provided by CNRDS is sourced from China's government statistical departments (such as the National Bureau of Statistics and various industry regulators), and has undergone rigorous review and verification, ensuring high accuracy and credibility. Panel B of Table 1 reports the annual distribution of firm-year observations over the sample period.

Table 1. Sample selection and year distribution

Panel A Sample selection			
			Obs.
Total number of firm-year observations from 2004-2022.			53,731
Less: exclude sample data from the financial and insurance sectors.			3,323
Less: exclude sample data labelled as ST, ST*or PT.			2,353
Less: missing values for CGI performance and control variables in this study.			17,733
Final sample			30,322
Number of firms			3,096
Panel B Sample distribution by year			
Year	Freq.	Percent	Cum.
2004	729	2.40	2.40
2005	798	2.63	5.04
2006	787	2.60	7.63
2007	828	2.73	10.36
2008	931	3.07	13.43
2009	971	3.20	16.63
2010	1,064	3.51	20.14
2011	1,336	4.41	24.55
2012	1,540	5.08	29.63
2013	1,660	5.47	35.10
2014	1,685	5.56	40.66
2015	1,750	5.77	46.43
2016	1,864	6.15	52.58
2017	2,036	6.71	59.29
2018	2,266	7.47	66.77
2019	2,278	7.51	74.28
2020	2,352	7.76	82.04
2021	2,624	8.65	90.69
2022	2,823	9.31	100.00
Total	30,322	100.00	

Note: The detailed variable definitions are presented in the appendix A.

4.2 Variable descriptions

4.2.1 Dependent variable

This study utilises CEI as the core dependent variable for in-depth analysis. However, the intangible nature of technological innovation increases the difficulty of quantifying corporate green innovation, and there is no unified proxy indicator for eco-innovation in the existing literature. The main indicators currently used to measure eco-innovation include R&D expenditure, green human resource, and number of patent applications (Chen et al., 2021; Pan et al., 2021; Peng & Liu, 2016; Rodriguez & Wiengarten, 2017). Since most firms consider R&D and innovation to be their core competitive advantages, they are typically reluctant to disclose related data. Patent data are classified according to technical fields, with each patent application assigned a corresponding International Patent Classification (IPC) number, allowing patents to be further subdivided into specific technical subcategories. Therefore, it is easier to identify corporate eco-innovation activities based on the IPC classification and analyse more detailed technical fields. Based on this, the number of patent applications by firms serves as a relatively robust indicator for measuring CEI performance, and green patent counts are widely regarded as a reliable proxy for assessing CEI activities (Berrone et al., 2013; Pan et al., 2021; Ullah et al., 2024). Building on the previous research (Amore & Bennedsen, 2016; Cui et al., 2022; Zhou et al., 2023), this study adopts the natural logarithm of the number of green patents plus one as the primary measure of CEI.

Moreover, given the potential heterogeneity in the impact of different types of ER on CEI, this study draws on previous research to categorize green innovation based on technological complexity into symbolic and substantive green innovation (Hyatt & Berente, 2017; Meng et al., 2019; Truong et al., 2021). Symbolic green innovation is represented by the natural logarithm of one plus the total number of utility model patents, while substantive green innovation is measured by the natural logarithm of one plus the total number of invention patents.

4.2.2 Independent variables

This study employs a two-stage difference-in-differences (DID) approach to systematically examine the effects of two distinct environmental regulatory policies, namely the New Environmental Protection Law (NEPL) and the Carbon Emission Trading Pilot Policy (CETP) on CEI, thereby enabling a comparative assessment of their relative effectiveness.

NEPL was implemented nationwide in 2018, making 2018 the designated year of policy implementation. Therefore, 2018 and subsequent years are coded as 1 ($Post = 1$), while the years preceding implementation are coded as 0 ($Post = 0$). Following the methodology of Fang et al. (2021) and Yu (2008), sample firms are divided based on their pollution levels, with heavily polluting firms classified as the treatment group ($Treat = 1$) and non-polluting firms as the control group ($Treat = 0$). Accordingly, NEPL is calculated as NEPL = $Treat * Post$, allowing an assessment of the NEPL's impact on CEI across different types of firms.

The implementation of the Carbon Emission Trading Pilot Policy (CETP) has followed a phased regional rollout: in 2011, the policy was initiated in Beijing, Shanghai, Tianjin, and Guangdong; in 2014, Chengdu and Hubei were incorporated into the pilot program; and in 2016, Fujian Province was subsequently added as a pilot region. Therefore, this study considers firms located in these pilot regions, the year of policy implementation and subsequent years are coded as 1 ($post = 1$), while the years prior to implementation are coded as 0 ($post = 0$). According to prior research (Pan et al., 2022; Wu, 2022), regions that implemented the CETP policy are designated as the treatment group ($treat = 1$), while non-implementation regions serve as the control group ($treat = 0$). Thus, the core variable CETP is calculated as CETP = $treat * post$ to examine the effects of policy implementation timing and region on CEI.

4.2.3 Moderating variables

4.2.3.1 Financial constraints

The financial constraints of a firm cannot be directly observed through its annual reports (Farre-Mensa & Ljungqvist, 2016; Tang & Zhang, 2022). However, based on the research by Hadlock and Pierce (2010), financial constraints are closely related to a firm's size and age. The study adopts their formula for measuring financial constraints: $SA = -0.737size + 0.043size^2 - 0.04age$, where $size$ refers to the logarithm of the firm's total number of employees, and age represents the number of years since the firm's establishment. A higher SA value indicates lower financial constraints, suggesting greater flexibility and operational capacity in the firm's financing activities.

4.2.3.2 Market competitiveness

According to the study by Zou et al. (2015), the Herfindahl-Hirschman Index (HHI) is regarded as the optimal method for calculating a firm's market competitiveness. Accordingly, the Herfindahl-Hirschman Index (HHI) is employed as a proxy for market competitiveness. The HHI value ranges from 0 to 1: when a market is completely monopolized by a single firm, the HHI value equals 1; conversely, when there are numerous small firms in the market, the HHI value approaches 0. This indicates that the more intense the market competition, the smaller the HHI value, reflecting the degree of dispersion among market participants and the level of competitive activity.

The calculation formula for HHI is as follows:

$$HHI = \sum_{i=1}^{n} {S_i}^2$$

where $s_i$represents the market share of firm i, and n denotes the total number of firms in the market.

4.2.3.3 Confucian culture

China boasts a long history and a rich cultural heritage, with Confucianism serving as a representative of its traditional culture for thousands of years (Jin et al., 2023). Throughout historical development, Confucian values have profoundly influenced people's decisions and behaviours (Zhang et al., 2025). Therefore, this study adopts Confucianism as a framework to explore the impact of cultural factors on corporate green innovation. Building on the methodology proposed by Huang et al. (2024), this study measures the extent of Confucian cultural influence by calculating the number of Confucian temples within different radius around a firm’s registered address (100 km and 300 km, denoted as r_100 and r_300, respectively). To address potential discrepancies arising from dimensional differences, these values are normalized by dividing them by 100.

4.2.4 Control variables

Based on previous literature on the antecedents of CEI, this study has incorporated several key firm level control variables that help explain variations in CEI performance. This

study aims to ensure the accuracy and robustness of the analytical results by controlling for factors that could potentially confound the relationship with ER.

First, existing research has demonstrated that a firm's age and size significantly impact its CEI performance (Atkin et al., 2012; Slawinski & Bansal, 2015). Larger and older firms typically possess greater resources and capabilities to manage the risks and costs associated with CEI (Martínez-Ros & Kunapatarawong, 2019). Building on this framework, firm size ($FirmSize$) and age ($FirmAge$) are included as control variables, with size measured by the natural logarithm of total assets and age defined as the number of years since the firm's establishment.

Second, this study introduced several financial variables, derived from the firm's financial statements, to reflect its specific financial conditions. Specifically, this study included return on assets (ROA), sales growth ($Growth$) and current ratio ($CurrentRatio$), as these indicators are widely recognized to have a significant impact on a CEI performance (Gao et al., 2024; Jacob & Zerwer, 2024). Moreover, the effect of debt levels on R&D investment cannot be overlooked. Prior studies indicate that firms with higher leverage tend to invest more in CEI to better meet stakeholders' sustainability expectations, compared to those with lower leverage (Li et al., 2018). However, Therefore, this study also controlled for leverage ($Leverage$), defined as the ratio of total debt to total assets.

Third, the composition of the board of directors is also crucial in shaping corporate decision-making. Studies have found that firms with a higher proportion of female board members tend to exhibit better CEI performance (He & Jiang, 2019). Accordingly, this study included the proportion of female board members ($Female$) as a control variable to examine its influence on CEI. In terms of corporate leadership structure, previous literature suggests CEO simultaneously serves as the chairman of the board my inhibit CEI performance (Xue et al., 2024). This study used the dummy variable $Dual$, which takes the value of 1 if the CEO also serves as the chairman, and 0 otherwise. In addition, this study controlled for additional board characteristics that might affect CEI, including the proportion of independent directors ($Independent$), the shareholding ratio of the largest shareholder ($Top1$), state ownership ratio ($StateOwn$) and the institutional ownership ratio ($Institutional$).

Finally, this study controlled for variables such as the foreign investor's shareholding ratio ($ForeignOwn$), bank loan ratio ($BankLoan$), and tax burden ($TaxBurden$) to more comprehensively assess the firm's external financing capacity, as well as the potential impact

of its financial structure and tax burden on corporate operations. A detailed description of these variables and their calculations is provided in Appendix A.1.

4.3 Model specification

In this section, this study employs both ordinary difference-in-differences (DID) analysis and stacked difference-in-differences analysis to compare the impacts of the new Environmental Protection Law (NEPL) and the Carbon Emission Trading Pilot policy (CETP) on CEI in China. Through this analysis, this study aims to explore the potential differences in the effects of the NEPL and the CETP on the CEI activities of publicly listed companies. Consistent with prior studies employing the DID approach (He & Qiu, 2025), the regression model of this study is specified as follows:

$$lnCEI_{it} = \alpha_0 + \alpha_1 NEPL_{it}(Treat_i * Post_t) + \alpha_i X_{it} + \delta_t + \delta_{ind} + \varepsilon_{it} \quad \textbf{(1)}$$

$$lnCEI_{it} = \beta_0 + \beta_1 CETP_{it}\,(treat_i * post_t) + \beta_i X_{it} + \delta_t + \delta_{ind} + \varphi_{it} \quad \textbf{(2)}$$

To examine the moderating effects, this study adds the moderating variables to the baseline model, incorporating interaction terms between the moderating variables, NEPL, and CETP in models (1) and (2), resulting in models (3) and (4):

$$lnCEI_{it} = \alpha_0 + \alpha_1 NEPL_{it}(Treat_i * Post_t) + \alpha_2 Moderators_{it} + \alpha_3 NEPL_{it} * Moderators_{it} + \alpha_i X_{it} + \delta_t + \delta_{ind} + \varepsilon_{it} \quad \textbf{(3)}$$

$$lnCEI_{it} = \beta_0 + \beta_1 CETP_{it}\,(treat_i * post_t) + \alpha_2 Moderators_{it} + \alpha_3 CETP_{it} * Moderators_{it} + \beta_i X_{it} + \delta_t + \delta_{ind} + \varphi_{it} \quad \textbf{(4)}$$

The dependent variable $lnCEI_{it}$ represents the innovation performance of company i at time t. The key independent variables $NEPL_{it}$ and $CETP_{it}$ correspond to the new Environmental Protection Law and the carbon emission trading pilot policy, respectively. Following the methodology proposed by Boubaker et al. (2024), this study constructs NEPL as a binary dummy variable composed of two components: $Post$ and $Treat$.

To account for the staggered implementation of the CETP Policy across different times and regions, this study adopts the methodology utilized by Wu (2022) to construct another

multi-period binary dummy variable($CETP_{it}$), which also consists of the components $post$ and $treat$. X_{it} represents the set of control variables. Fixed effects for year (δ_t) and industry （δ_{ind}）are also incorporated into the model. The terms ε_{it} and φ_{it} represent the error terms for the two models, respectively.

5. Empirical Results

5.1 Descriptive statistics

Table 2 presents a statistical summary of the key variables in this study, offering insights into the performance of CEI. These figures indicate that, on average, firms in the sample allocate relatively limited resources to green innovation, reflecting a generally insufficient commitment to environmental innovation initiatives. Nevertheless, the average number of substantive green innovation patent applications exceeds that of symbolic green innovation by 0.05, suggesting that under external pressures, firms may prioritize substantive innovation efforts over symbolic ones.

This slightly different may be driven by the characteristics of symbolic and substantive green innovation. Symbolic green innovation typically involves actions that are more about signalling environmental responsibility or enhancing corporate reputation rather than creating substantial environmental impact. Such initiatives may include marketing campaigns, certifications, or minor modifications to products that convey a "green" image to consumers, but they often require lower levels of investment and carry less risk. Consequently, firms might engage in symbolic green innovation as a cost-effective strategy to comply with regulations or enhance their public image without significant changes to their operations or products.

In contrast, substantive green innovation involves more substantial investments in technologies, processes, or products that genuinely contribute to environmental sustainability. These innovations may include the development of energy-efficient technologies, the reduction of waste through advanced production methods, or the creation of entirely new environmentally friendly products. Although these efforts can yield long-term environmental benefits, they require higher upfront costs, greater expertise, and longer implementation periods. As a result, companies may be more cautious about committing resources to substantive green innovation unless they are under significant external pressure from regulations or market forces.

Consequently, the variation in patenting activity across the two types of green innovation can be ascribed to the distinct underlying attributes that differentiate symbolic from substantive innovation. Firms might be more inclined to pursue substantive green innovation patents as they signal a higher level of technological achievement and can offer a competitive advantage in the market. Meanwhile, symbolic innovation, which typically does not lead to the development of new technologies or products, may be less likely to result in patent applications.

Firm-level control variables such as $FirmSize$ and $FirmAge$ exhibit moderate variation, while financial variables like $Leverage$, ROA, and $Growth$ reflect substantial heterogeneity in capital structure and performance across firms. The $CurrentRatio$ shows a large standard deviation and an extreme maximum (190.87), suggesting the presence of a few highly liquid firms.

With respect to ownership structure, the State-owned shareholding ratio ($StateOwn$) has a low mean of 0.08, and the foreign investor shareholding ratio ($ForeignOwn$) is even lower, averaging 0.01. This indicates that most firms in the sample are neither majority state-owned nor significantly foreign owned. Ownership concentration and governance are reflected in variables like $Top1$ (mean = 0.35) and $Independent$ (mean = 0.37), consistent with patterns typically found among listed firms in China.

In sum, the dataset captures a diverse set of listed firms in China, characterized by relatively low levels of green innovation and wide variation in financial, structural, and governance attributes.

Table 2. Summary statistic of main variables

Variable	N	Mean	SD	Min	P25	P50	P75	Max
$lnCEI$	30,322	0.39	0.81	0.00	0.00	0.00	0.00	3.83
$lnSub$	30,322	0.27	0.66	0.00	0.00	0.00	0.00	3.43
$lnSym$	30,322	0.22	0.57	0.00	0.00	0.00	0.00	2.89
$RationCEI$	30,322	0.03	0.10	0.00	0.00	0.00	0.00	0.57
$NEPL$	30,322	0.32	0.47	0.00	0.00	0.00	1.00	1.00
$CETP$	30,322	0.31	0.46	0.00	0.00	0.00	1.00	1.00
$FirmSize$	30,322	22.18	1.29	19.82	21.27	22.00	22.90	26.19
$FirmAge$	30,322	2.78	0.40	1.61	2.56	2.83	3.09	3.53
$Leverage$	30,322	0.44	0.20	0.06	0.28	0.44	0.58	0.88
$Tangible$	30,322	0.93	0.09	0.52	0.91	0.96	0.98	1.00
$BankLoan$	30,322	0.17	0.15	0.00	0.03	0.14	0.27	0.59
$CurrentRatio$	30,322	2.33	3.28	0.03	1.09	1.53	2.45	190.87
$TaxBurden$	30,322	0.02	0.02	-0.03	0.00	0.01	0.02	0.12
ROA	30,322	0.04	0.06	-0.25	0.01	0.04	0.07	0.20
$Growth$	30,322	0.18	0.38	-0.51	-0.01	0.12	0.28	2.29
$Independent$	30,322	0.37	0.05	0.29	0.33	0.33	0.43	0.58
$Top1$	30,322	0.35	0.15	0.09	0.23	0.32	0.45	0.73
$Institutional$	30,322	0.46	0.24	0.00	0.28	0.49	0.66	0.92
$StateOwn$	30,322	0.08	0.18	0.00	0.00	0.00	0.00	0.70
$ForeignOwn$	30,322	0.01	0.06	0.00	0.00	0.00	0.00	0.44
$Dual$	30,322	0.26	0.44	0.00	0.00	0.00	1.00	1.00
$Female$	30,322	0.18	0.11	0.00	0.10	0.17	0.25	0.50

Note: displays summary statistics for all variables in this study, including the number of observations (N), mean (Mean), standard deviation (SD), minimum value (Min), 25th percentile (P25), median (P50), 75th percentile (P75), and maximum value (Max). All continuous variables are winsorized at the 1st and 99th percentiles. The detailed variable definitions are presented in the appendix A.

5.2 Correlation analysis

To assess the potential presence of severe multicollinearity in the model, this study calculated the correlation coefficients and variance inflation factors (VIFs) before performing the regression analyses. The results in Table 3 Panel A, show that all correlation coefficients between the variables are below 0.8, indicating that multicollinearity is not a concern at the variable level. Panel B presents the VIF values for the regression models. The first column reports the VIF for the relationship between NEPL and CEI, with a maximum value of 3.41, and the second column reports the VIF for the relationship between CETP and CEI, with a maximum value of 3.33. Generally, VIF values greater than 10 are considered indicative of severe multicollinearity, which can distort the regression results by inflating standard errors (Zhou et al., 2023). However, since the maximum VIFs in this study are well below this threshold, it suggests that multicollinearity does not pose a significant issue, and the regression estimates are reliable.

Table 3. Correlation matrix and VIF test

Panel A *Correlation matrix*

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) $lnCEI$	1.000								
(2) $NEPL$	0.020***	1.000							
(3) $CETP$	0.106***	-0.016***	1.000						
(4) $FirmSize$	0.289***	0.145***	0.099***	1.000					
(5) $FirmAge$	0.050***	0.183***	0.233***	0.232***	1.000				
(6) $Leverage$	0.100***	-0.006	-0.077***	0.405***	0.074***	1.000			
(7) $Tangible$	0.041***	-0.011*	-0.109***	-0.053***	-0.104***	0.071***	1.000		
(8) $BankLoan$	-0.050***	0.075***	-0.155***	0.242***	-0.015***	0.698***	0.001	1.000	
(9) $CurrentRatio$	-0.054***	-0.045***	0.081***	-0.297***	-0.075***	-0.673***	0.081***	-0.489***	1.000
(10) $TaxBurden$	-0.091***	0.002	-0.021***	0.031***	-0.037***	-0.276***	-0.099***	-0.171***	0.214***
(11) ROA	0.036***	0.016***	-0.030***	0.049***	-0.077***	-0.347***	0.050***	-0.323***	0.218***
(12) $Growth$	0.001	-0.001	-0.018***	0.037***	-0.092***	0.032***	-0.103***	-0.005	-0.036***
(13) $Independent$	0.030***	0.006	0.116***	0.048***	0.048***	-0.022***	-0.024***	-0.043***	0.036***
(14) $Top1$	0.024***	-0.021***	-0.047***	0.173***	-0.190***	0.030***	0.114***	-0.015**	-0.023***
(15) $Institutional$	0.048***	-0.029***	-0.125***	0.373***	-0.086***	0.183***	0.075***	0.097***	-0.161***
(16) $StateOwn$	-0.048***	-0.079***	-0.151***	0.102***	-0.251***	0.159***	0.100***	0.141***	-0.131***
(17) $ForeignOwn$	-0.029***	-0.019***	0.003	-0.062***	-0.064***	-0.080***	0.037***	-0.039***	0.079***
(18) $Dual$	0.018***	-0.014**	0.108***	-0.144***	-0.014**	-0.146***	-0.033***	-0.109***	0.147***
(19) $Female$	-0.072***	-0.013**	0.157***	-0.169***	0.153***	-0.158***	-0.063***	-0.134***	0.142***

Variables	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(10) $TaxBurden$	1.000									
(11) ROA	0.415***	1.000								
(12) $Growth$	0.089***	0.252***	1.000							
(13)$Independent$	-0.002	-0.015***	-0.017***	1.000						
(14) $Top1$	0.087***	0.141***	0.025***	0.032***	1.000					
(15)$Institutional$	0.115***	0.141***	0.059***	-0.068***	0.509***	1.000				
(16) $StateOwn$	0.022***	-0.013**	0.055***	-0.087***	0.310***	0.346***	1.000			
(17)$ForeignOwn$	0.009*	0.060***	0.019***	-0.009	0.066***	0.136***	-0.040***	1.000		
(18) $Dual$	-0.010*	0.033***	0.024***	0.111***	-0.059***	-0.202***	-0.182***	0.032***	1.000	
(19) $Female$	0.038***	0.001	-0.016***	0.071***	-0.083***	-0.180***	-0.207***	0.020***	0.146***	1.000

Panel B *Variance inflation factor (VIF) test*

	(1) VIF	(2) VIF
$NEPL$	1.08	
$CETP$		1.16
$leverage$	3.41	3.33
$BankLoan$	2.08	2.07
$CurrentRatio$	1.94	1.93
$Institutional$	1.75	1.76
$Size$	1.60	1.60
ROA	1.54	1.54
$Top1$	1.46	1.47
$StateOwn$	1.31	1.31
$TaxBurden$	1.30	1.30
Age	1.28	1.28
$Tangible$	1.13	1.13
$Female$	1.13	1.14
$Growth$	1.12	1.12
$Dual$	1.10	1.11
$ForeignOwn$	1.06	1.06
$Independent$	1.04	1.04
Mean VIF	1.49	1.49

Note: This table assesses potential multicollinearity prior to regression analysis. Panel A reports Pearson correlations among key variables, and Panel B presents Variance Inflation Factors (VIF). All correlations are below 0.8 and VIFs are under 10, indicating no multicollinearity concerns. Variable definitions are provided in Appendix A. *, *, and *** denote significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. T-statistics are shown in parentheses.

5.3 Baseline regression

Table 4 reports the empirical estimates assessing the impact of the NEPL and the CETP on CEI performance**.** Column (1) presents baseline results without the inclusion of firm-level control variables. The coefficient on the NEPL is negative and statistically significant, suggesting that the implementation of the NEPL is associated with a deterioration in CEI performance. This finding is consistent with Z. Zhao et al. (2024), who argue that stringent ER may hinder firms' green innovation activities due to increased compliance burdens. Accordingly, these results provide empirical support for Hypothesis 1.

In contrast, the CETP appears to exert a positive influence on CEI. As shown in column (3), the estimated coefficient for CETP is 0.110 and statistically significant, indicating that market-based environmental regulation enhances firms' eco-innovation capabilities. This finding lends support to Hypothesis 2.

To account for firm-level heterogeneity, columns (2) and (4) incorporate a set of control variables capturing financial performance, leverage, and ownership structure. The results remain robust: the NEPL coefficient remains negative and significant at the 1% level (−0.124), while the CETP coefficient remains positive and significant at the 1% level (0.102). These findings are in line with Wu (2024), who documents that carbon trading mechanisms significantly stimulate low-carbon patent output, particularly when firms possess executives with R&D experience.

Taken together, the empirical evidence highlights the divergent effects of command-and-control versus market-based environmental regulations on CEI. These differences can be attributed to the distinct regulatory objectives, the nature of institutional pressures imposed on firms, and the broader implications for sustainable development.

First, the NEPL relies on command-and-control instruments aimed at achieving rapid reductions in pollutant emissions through mandatory compliance (Yin et al., 2019). While effective in the short term, such regulations often impose substantial compliance costs, particularly for small and medium-sized enterprises (SMEs) with limited resources. These firms may prioritize regulatory adherence over long-term innovation investments. In contrast, the CETP leverages market mechanisms to incentivize emissions reductions, enabling firms to monetize carbon savings and reinvest in green technologies (Chen et al., 2021). By alleviating R&D financing constraints and promoting long-term sustainability, CETP aligns with the

Porter Hypothesis, which posits that well-designed environmental regulations can stimulate innovation and enhance competitiveness.

Second, the two regulatory approaches impose different types of institutional pressure. The NEPL emphasizes strict enforcement and monitoring, generating significant regulatory stress. According to stakeholder theory, firms are expected to balance the interests of diverse stakeholders; however, the compliance-centric nature of NEPL may lead firms to adopt short-term strategies, such as shutting down high-emission operations or marginally improving existing technologies which usually at the expense of transformative innovation. This behaviour contradicts the dynamic capabilities view (DCV), which emphasizes the importance of resource reconfiguration and strategic flexibility in dynamic environments. Conversely, CETP's incentive-based structure reduces regulatory stress and encourages firms to pursue innovation-driven strategies.

Finally, from the perspective of signalling theory, firms can use environmental initiatives to reduce information asymmetry and signal their commitment to sustainability. CETP facilitates this process by providing a platform for firms to demonstrate green credentials through carbon trading, thereby enhancing their reputation and competitive positioning. In contrast, the rigid enforcement associated with NEPL increases operational uncertainty and discourages high-risk, high-reward R&D investments, ultimately constraining firms' long-term innovation potential.

Table 4. The effect of environmental regulations on corporate eco-innovation

	NEPL		*CETP*	
	(1)	(2)	(3)	(4)
NEPL	**-0.126*** **	**-0.124*** **		
	(-8.43)	**(-8.72)**		
CETP			**0.110*** **	**0.102*** **
			(9.95)	**(9.71)**
Size		0.199***		0.195***
		(43.69)		(42.92)
Age		-0.138***		-0.143***
		(-9.94)		(-10.36)
Leverage		0.700***		0.725***
		(16.83)		(17.53)
Tangible		0.552***		0.541***
		(10.43)		(10.24)
BankLoan		-1.102***		-1.127***
		(-25.00)		(-25.78)
CurrentRatio		0.007**		0.007**
		(2.40)		(2.41)
TaxBurden		-3.421***		-3.386***
		(-14.99)		(-14.84)
ROA		0.577***		0.576***
		(6.85)		(6.83)
Growth		-0.042***		-0.044***
		(-3.51)		(-3.62)
Independent		-0.108		-0.129
		(-1.34)		(-1.59)
*Top*1		-0.062*		-0.073**
		(-1.76)		(-2.09)
Institutional		-0.068***		-0.050**
		(-2.90)		(-2.13)
StateOwn		-0.158***		-0.165***
		(-5.37)		(-5.61)
ForeignOwn		-0.203***		-0.219***
		(-2.98)		(-3.21)
Dual		0.046***		0.045***
		(4.50)		(4.42)
Female		-0.187***		-0.194***
		(-4.53)		(-4.68)
Constant	0.404***	-4.093***	0.353***	-4.038***
	(82.43)	(-34.95)	(61.99)	(-34.51)
Observations	30,322	30,322	30,322	30,322
R-squared	0.064	0.181	0.065	0.181
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Control	NO	YES	NO	YES
F test	71.06	257.5	98.98	258.7

Note: This table reports results from high-dimensional fixed effects regressions. Columns (1) – (2) examine the impact of the New Environmental Protection Law (NEPL) on CGI, using the log of one plus green patent applications as the dependent variable. Column (1) excludes firm-level controls, while column (2) includes them. Columns (3) – (4) assess the effect of the CETP policy on CGI using the same dependent variable, with and without firm-level controls, respectively. Across specifications, NEPL shows a significant negative effect on CGI, whereas CETP consistently exhibits a significant positive impact. All regressions control for year and industry fixed effects. Variable definitions are provided in Appendix A. *, *, and *** denote significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. T-statistics are reported in parentheses.

5.4 Moderating analysis

This study further investigates the moderating roles of both internal and external factors in shaping the relationship between ER and CEI. Given that R&D-driven innovation entails substantial financial commitments, a firm's internal financial health and access to external financing are critical determinants of its capacity to engage in CEI (L. Li et al., 2025; Liu et al., 2025). Moreover, the broader institutional context, including market competition intensity and cultural value systems, plays a critical role in shaping firms' strategic engagement with eco-innovation.

To empirically capture these moderating effects, this study incorporates three key variables. First, the SA index is employed to proxy for firms' financing constraints, reflecting their ability to mobilize capital for innovation activities. Second, the Herfindahl-Hirschman Index (HHI) is used to measure industry-level market concentration, thereby capturing the intensity of market competition. Third, cultural influence is proxied by the number of Confucian temples located within a 100 km and 300 km radius of a firm's headquarters, following prior literature that links Confucian values to long-term orientation and environmental responsibility (Huang et al., 2024; Yan et al., 2021).

Table 5 presents the moderating effects of financing constraints and market competition, as captured by the SA index and HHI, respectively. Specifically, in columns (1) and (3), the coefficients on NEPL and CETP are 0.063 and −0.280, respectively, indicating a positive association between NEPL and CEI performance, and a negative association between CETP and CEI performance under specific moderating conditions. These findings diverge from the baseline estimates reported in columns (2) and (4) of Table 4, where the NEPL coefficient is −0.124 and the CETP coefficient is 0.102, both statistically significant.

The observed shifts in the coefficients of NEPL and CETP suggest heterogeneous moderating effects under varying financial conditions. Specifically, the positive coefficient on NEPL in Table 5 implies that the previously observed negative impact of CAC regulation on CEI (as shown in Table 4) may be alleviated or even reversed when firms face lower financing constraints. This finding aligns with prior literature, which emphasizes that financially unconstrained firms are better equipped to absorb regulatory compliance costs and invest in long-term innovation (Tan & Zhu, 2022; Zhai et al., 2022).

Conversely, the negative coefficient on CETP under high financing constraints indicates that the positive effect of market-based regulation on CEI may diminish when firms lack

sufficient financial flexibility. In such cases, the economic incentives provided by CETP may be insufficient to offset the upfront costs of eco-innovation, thereby weakening its intended policy impact.

Table 5 further explores the moderating role of market competition in the relationship between ER and CEI performance. In column (2), the interaction term *NEPL*HHI* yields a coefficient of −0.084, indicating a statistically significant negative moderating effect. This suggests that the adverse impact of NEPL on eco-innovation is amplified in more competitive market environments. Under intensified competitive pressure, firms may prioritize short-term profitability and operational efficiency, thereby reducing their capacity or willingness to invest in long-term sustainability-oriented innovation.

In column (4), the coefficient for CETP is 0.097, which is slightly lower than the baseline estimate of 0.102 reported in Table 4. This attenuation implies that the positive effect of CETP on CEI may weaken when firms operate in highly competitive markets. In such contexts, firms may be less responsive to long-term incentives embedded in carbon trading schemes, as immediate market survival pressures dominate strategic decision-making. Consequently, both forms of regulation may face diminished effectiveness in promoting eco-innovation under heightened competitive conditions.

Table 6 investigates the moderating role of cultural factors in the relationship between ER and CEI. In columns (1) and (2), the coefficients on NEPL are −0.127 and −0.119, respectively, both statistically significant at the 1% level, reaffirming the baseline finding that command-and-control regulation negatively affects CEI performance. Meanwhile, the coefficients for *r_100* and *r_300*, which proxy for Confucian cultural influence, are 0.205 and 0.137, significant at the 10% and 1% levels, respectively. These results suggest that firms located in regions with stronger Confucian cultural presence tend to exhibit higher levels of innovation activities, consistent with prior literature highlighting Confucianism's role in promoting ethical behaviour and regulatory compliance (Fu et al., 2022; Li & Yao, 2024).

However, the interaction terms *NEPL*r_100 and NEPL*r_300* yield coefficients of 0.033 and −0.023, respectively, neither of which is statistically significant. This indicates that Confucian culture does not exert a meaningful moderating effect on the relationship between command-and-control regulation and CEI.

One plausible explanation lies in the rigid and punitive nature of command-and-control environmental policies. Non-compliance with NEPL may result in substantial legal liabilities,

financial penalties, or operational shutdowns. Under such mandatory enforcement regimes, firms' compliance behaviour is primarily driven by legal obligations rather than cultural norms. As a result, the influence of Confucian culture on firms' strategic responses to environmental regulation is likely overshadowed by the immediate and binding nature of regulatory mandates.

In columns (3) and (4), the coefficients of CETP are 0.224 and 0.536, both significant at the 1% level. Moreover, a comparison of the coefficients of r_100 (0.381) and r_300 (0.205) reveals spatial heterogeneity in the influence of Confucian culture on CEI performance. Specifically, the positive effect of Confucian culture on CEI is stronger in regions within a 100 km radius, whereas its influence diminishes as geographical distance increases to 300 km. This suggests that the role of Confucian culture in fostering CEI is spatially dependent, with its impact being more pronounced when firms are in closer proximity to cultural resources.

Furthermore, the interaction terms CETP*r_100 and CETP*r_300 yield coefficients of -1.767 and -1.552, respectively, indicating that Confucian culture weakens the positive effect of CETP on CEI. This suggests that in regions where Confucian cultural influence is strong, the incentive effects of market-driven ER on CEI are partially constrained. This outcome may be attributed to Confucian culture's emphasis on prudent management, long-term orientation, and risk aversion (Huang et al., 2024; Li & Yao, 2024; Zhang et al., 2025). In regions with strong Confucian cultural influence, firms tend to prioritize operational stability and avoid high-risk investments. Given that innovation often requires substantial investment, long development cycles, and involves considerable uncertainty, firms in such regions may adopt more conservative business strategies despite the economic incentives provided by market-driven ER. Under these circumstances, the effectiveness of market incentives in promoting CEI may be diminished.

The above findings provide empirical support for Hypotheses 3, 4, and 5. Specifically, financial constraints (Hypothesis 3) and market competition (Hypothesis 4) significantly moderate the relationship between ER and CEI. Firms with lower financial constraints are better positioned to absorb regulatory costs and invest in green innovation, while intensified market competition tends to amplify the adverse effects of regulation by shifting firms' focus on short-term performance.

In contrast, Hypothesis 5 receives only partial support. While Confucian cultural influence is positively associated with CEI performance, it does not significantly moderate the impact of command-and-control regulation (NEPL). However, it exerts a significant negative

moderating effect on the relationship between market-based regulation (CETP) and CEI, suggesting that cultural norms may dampen the effectiveness of incentive-driven environmental policies. This implies that in regions with strong Confucian traditions, firms may prioritize compliance and stability over market-driven innovation, thereby limiting the responsiveness to flexible regulatory instruments.

Table 5. Moderating analysis of financial constraints and market competitiveness

	$NEPL$		$CETP$	
	(1) $lnCEI_{it}$	(2) $lnCEI_{it}$	(3) $lnCEI_{it}$	(4) $lnCEI_{it}$
$NEPL$	0.063	-0.107***		
	(0.33)	(-6.03)		
$CETP$			-0.280**	0.097***
			(-2.14)	(7.30)
SA	0.653***		0.705***	
	(19.90)		(18.22)	
HHI		-0.000		-0.013
		(-0.01)		(-0.52)
$NEPL * SA$	0.052			
	(1.07)			
$NEPL * HHI$		-0.084*		
		(-1.70)		
$CETP * SA$			-0.097***	
			(-2.88)	
$CETP * HHI$				0.019
				(0.56)
Constant	-2.248***	-4.100***	-2.049***	-4.037***
	(-15.19)	(-34.98)	(-12.86)	(-34.49)
Observations	30,322	30,322	30,322	30,322
R-squared	0.193	0.181	0.193	0.181
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
F test	257.6	230.6	257.2	231.5

Note: This table examines the moderating effects of financial constraints (SA) and market competitiveness (HHI) on the relationship between NEPL/CETP and CGI. The dependent variable is $lnCEI$, with NEPL and CETP as key independent variables. Columns (1) and (3) assess the role of SA, while columns (2) and (4) focus on HHI. All regressions include industry and year fixed effects. Variable definitions are provided in Appendix A. *, *, and *** denote significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. T-statistics are reported in parentheses.

Table 6. Moderating effect of Confucian culture

	NEPL		*CETP*	
	(1)	(2)	(3)	(4)
VARIABLES	r_100	r_300	r_100	r_300
$NEPL$	-0.127***	-0.119***		
	(-5.49)	(-4.48)		
$CETP$			0.224***	0.536***
			(9.95)	(11.75)
r_100	0.205*		0.381***	
	(1.79)		(3.35)	
r_300		0.137***		0.205***
		(4.39)		(7.16)
$NEPL * r_100$	0.033			
	(0.12)			
$NEPL * r_300$		-0.023		
		(-0.33)		
$CETP * r_100$			-1.767***	
			(-6.20)	
$CETP * r_300$				-1.552***
				(-9.64)
Constant	-4.099***	-4.139***	-4.061***	-4.076***
	(-34.96)	(-35.20)	(-34.70)	(-34.79)
Observations	30,321	30,321	30,321	30,321
R-squared	0.181	0.181	0.182	0.184
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
F test	230.6	231.7	233.8	238.9

Note: This table investigates the influence of Confucian culture on firms' eco-innovation (CGI) under different types of ER. The variables *r_100* and *r_300* measure the number of Confucian temples within 100 km and 300 km of a firm's registered location (scaled by 100), capturing cultural influence at varying geographic levels. Columns (1) – (2) assess the impact under command-and-control ER, while columns (3) – (4) focus on market-based ER. The results highlight the nuanced interaction between cultural context and regulatory type in shaping CGI outcomes. All regressions include industry and year fixed effects. Variable definitions are provided in Appendix A. *, *, and *** denote significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. T-statistics are reported in parentheses.

5.5 Robustness checks

5.5.1 Dynamic treatment effects

To further mitigate concerns regarding potential violations of the parallel trends assumption, we incorporate the implementation years of the NEPL and CETP into the empirical design and employ a dynamic Difference-in-Differences (DiD) regression framework. This methodological refinement enhances the robustness of the identification strategy and allows for a more precise estimation of the temporal dynamics associated with regulatory interventions. Specifically, it facilitates the identification of the timing and persistence of the effects of environmental regulatory policies on CEI, thereby providing stronger evidence of causality.

$$lnCEI_{i,t} = \sum_{j=-5}^{5} \alpha_j Treat_{i,t} * Year_j + \delta_t + \delta_{ind} + \varepsilon_{it} \quad \textbf{(5)}$$

$$lnCEI_{i,t} = \sum_{j=-5}^{5} \beta_j treat_{i,t} * year_j + \delta_t + \delta_{ind} + \varepsilon_{it} \quad \textbf{(6)}$$

In Equation (5) and (6), $lnCEI_{i,t}$ represents the measure of CEI, while δ_t and δ_{ind} represent the industry fixed effects and year fixed effects, respectively. $Treat_{i,t}$ and $treat_{i,t}$ are two indicator variables for environmental regulation, taking the value of 1 if firm i in the given region is first formally enforced by the new environmental protection law or carbon emission trading pilot policy, and 0 otherwise. $Year_j$ and $year_j$ are a series of indicator variables, taking the value of 1 if the current observation year t is the j^{th} year relative to the enforcement year of environmental regulation, and 0 otherwise. We use the year of policy implementation (i.e., the 1st year) as the reference year.

Figures 2 and 3 present the dynamic treatment effects of the implementation of the NEPL and the CETP on firms' CEI performance, respectively. Figure 2 shows that prior to the implementation of the NEPL, there were no significant changes in CEI performance. A notable increase occurred in the first year following implementation, but the effect gradually diminished and eventually turned significantly negative. This pattern suggests that while the NEPL had a strong short-term impact, its long-term effect on CEI was adverse.

This decline in long-term effects may be attributed to several economic and structural factors. First, firms may temporarily increase innovation efforts to avoid anticipated penalties for future violations and repair reputational damage. However, the financial burden associated with sustained R&D investments may hinder their ability to maintain these levels of innovation in the long term. Second, regulatory fatigue may set in, as firms adjust to compliance

requirements and shift focus back to short-term profitability. Finally, broader industry challenges such as technological saturation, lack of supportive infrastructure, and uncertainty in environmental policy enforcement, these factors could further dampen firms' innovation capabilities.

Figure 3 shows that prior to the implementation of the CETP, the estimated values of CEI (β_j) fluctuated around zero, indicating no significant changes in CEI performance before the policy. During the implementation year, the CETP had a significantly positive effect on CEI. This result aligns with expectations, as the CETP incentivizes firms to reduce emissions through the allocation of carbon quotas and the ability to sell surplus allowances, thereby simultaneously imposing emission constraints and offering economic incentives. After policy implementation, CEI performance exhibited an initial decline followed by fluctuations. The decline may be attributed to the long-term investment requirements and financial pressures associated with green innovation, which challenge firms' capacity to sustain R&D efforts. The subsequent fluctuations might result from the evolving nature of China's carbon market, which is still in its early stages and subject to institutional uncertainties. Firms may face challenges in navigating quota allocations, price volatility, and regulatory clarity, all of which can affect their strategic commitment to innovation.

Overall, the dynamic difference in difference results confirm that treated and control firms exhibited no significant non-parallel trends prior to policy implementation, supporting the causal interpretation of the observed effects. However, the diminishing long-term impacts highlight the need for sustained policy support, financial incentives, and institutional stability to ensure that environmental regulation continues to foster innovation over time.

Fig. 1. Dynamic effect of NEPL on CEI

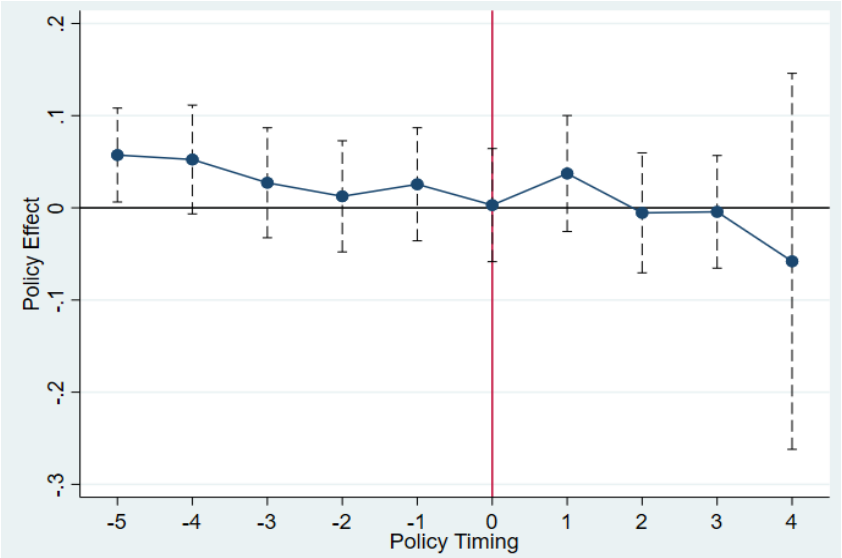
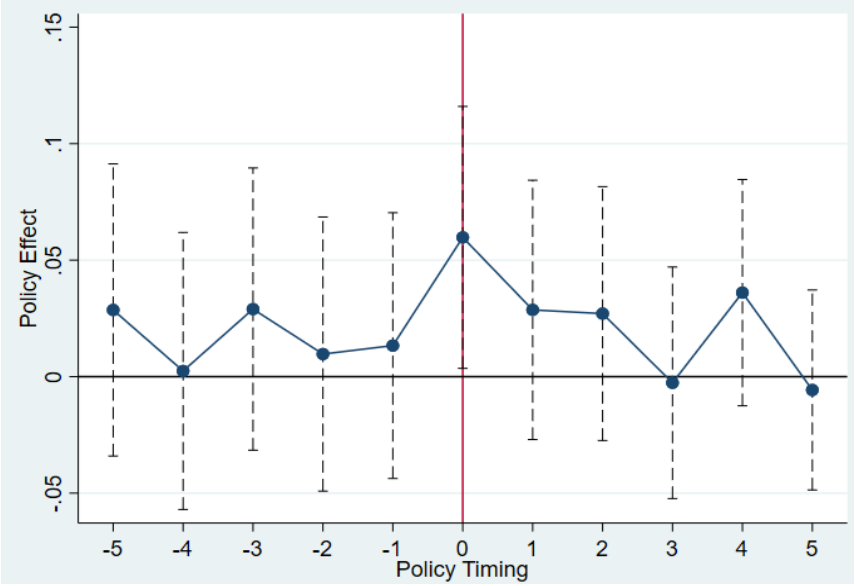


Fig. 2. Dynamic effect of CETP on CEI



5.5.2 Alternative proxy of CEI

To ensure the robustness of the empirical findings, this study adopts an alternative proxy for CEI, following the methodology of Chen et al. (2021). Specifically, this study uses the proportion of green patent applications relative to total patent applications as a measure of CEI capacity. This ratio captures the intensity of a firm's environmental innovation efforts relative to its overall innovation activity, offering a more nuanced view of its strategic orientation toward sustainability.

The regression results are reported in Table 10, where the dependent variable in all columns is the proportion of green patents. Columns (1) and (2) present the results without and with control variables, respectively. The coefficient on the NEPL variable is -0.007 and -0.006, both statistically significant at the 1% level, indicating a negative impact of command-and-control regulation on CEI intensity. Columns (3) and (4) assess the effect of CETP, with coefficients of 0.010 in both specifications, also significant at the 1% level, suggesting a positive influence of market-driven regulation.

The consistency of these results with the baseline findings reinforces the validity of the study's conclusions. By demonstrating that the effects of ER persist across different operationalizations of CEI, the analysis confirms that the observed relationships are not sensitive to the choice of measurement. Moreover, the use of a ratio-based indicator helps control for firm-level heterogeneity in overall innovation capacity, thereby strengthening the causal interpretation of the results.

Table 8. Alternative proxy of CGI

	NEPL		*CETP*	
	(1) *RatioCEI*	(2) *RatioCEI*	(3) *RatioCEI*	(4) *RatioCEI*
NEPL	**-0.007*** **	**-0.006*** **		
	(-4.07)	**(-3.44)**		
CETP			**0.010*** **	**0.010*** **
			(7.32)	**(7.21)**
Size		0.007***		0.007***
		(12.05)		(11.61)
Age		-0.013***		-0.014***
		(-7.55)		(-7.77)
Leverage		0.050***		0.051***
		(9.57)		(9.77)
Tangible		0.034***		0.034***
		(5.14)		(5.17)
BankLoan		-0.065***		-0.065***
		(-11.67)		(-11.75)
CurrentRatio		0.000		0.000
		(0.72)		(0.58)
TaxBurden		-0.203***		-0.198***
		(-7.06)		(-6.91)
ROA		0.028***		0.028***
		(2.61)		(2.67)
Growth		-0.003**		-0.003**
		(-2.15)		(-2.20)
Independent		-0.043***		-0.046***
		(-4.23)		(-4.49)
*Top*1		0.002		0.001
		(0.46)		(0.22)
Institutional		-0.008***		-0.006**
		(-2.65)		(-2.14)
StateOwn		-0.013***		-0.013***
		(-3.49)		(-3.64)
ForeignOwn		-0.009		-0.011
		(-1.09)		(-1.30)
Dual		0.001		0.000
		(0.51)		(0.33)
Female		-0.010*		-0.011**
		(-1.84)		(-2.07)
Constant	0.035***	-0.100***	0.031***	-0.097***
	(59.56)	(-6.81)	(45.38)	(-6.58)
Observations	30,322	30,322	30,322	30,322
R-squared	0.038	0.057	0.039	0.058
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
F test	16.53	37.36	53.61	39.77

Note: This table presents the results of measuring performance using an alternative variable, specifically the proportion of green patent applications to total patent applications. Columns (1) and (2) reflect the impact of the NEPL on CGI, while columns (3) and (4) illustrate the influence of the CETP on CGI performance. Variable definitions are provided in Appendix A. *, *, *and* *** *denote significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. T-statistics are reported in parentheses.*

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Appendix A.

A.1. Variable definition

Variables	Definition	Data Source
Dependent variables		
$lnCEI$	Natural logarithm of the number of total green patents the firm applied in a year plus one.	CNRDS
$RatioCEI$	The ratio of green patent applications to total patent applications.	CNRDS
Independent variables		
$NEPL$	A dummy variable that equals to one if the firm belongs to a high-polluting industry in 2015 or subsequently, otherwise it equals to zero.	CSMAR Hand-collected
$CETP$	The dummy variable equals one if the firm is in Beijing, Shanghai, Tianjin, Shenzhen city, or Guangdong province in 2013 or later; in Chengdu city or Hubei province in 2014 or later; or in Fujian province in 2014 or later; otherwise, it equals zero.	CSMAR Hand-collected
Control variables		
$FirmSize$	The natural logarithm of the total assets	CSMAR
$FirmAge$	Natural logarithm of firm age since establishment.	CSMAR
$Leverage$	The ratio of total liabilities to total assets.	CSMAR
$Tangible$	The tangible assets ratio is calculated as the ratio of the difference between total assets and the sum of net intangible assets and net goodwill to total assets.	CSMAR
$BankLoan$	The bank loan ratio is calculated as the sum of short-term loans, non-current liabilities due within one year, and long-term loans divided by total assets.	CSMAR
$CurrentRatio$	The current ratio is defined as the ratio of current assets to current liabilities.	CSMAR
$TaxBurden$	The tax burden is defined as the ratio of income tax to operating revenue.	CSMAR
ROA	Return on assets, calculated as net profit over total assets.	CSMAR
BM	The book-to-market ratio is calculated as the ratio of total assets to market value.	CSMAR
$Growth$	Sales growth is defined as the percentage growth rate of total sales.	CSMAR
$Operating$	Operating cost confirmed by the enterprise.	CSMAR
$Independent$	The ratio of independent directors over the number of directors.	CSMAR
$Top1$	Shareholding ratio of the first largest shareholder.	CSMAR
$Institutional$	Institutional investor's shareholding ratio	CSMAR
$Stateown$	State-owned shareholding ratio.	CSMAR
$Foreign$	Foreign Investor's Shareholding Ratio	CSMAR
$Dual$	A dummy variable that equals one if the chairman and general manager are the same person; otherwise, it equals zero.	CSMAR
$Female$	The proportion of female directors, supervisors and senior executives to the total.	CSMAR
Variables for moderation analyses		
SA	The financial constraint index, measured by the SA index, is calculated as: $SA\ index = -0.737 * Size + 0.043 * Size^2 - 0.040 * Age$, where size represents the firm's total assets and age is the number of years since the firm's establishment.	CSMAR
HHI	The Herfindahl–Hirschman Index, calculated as the sum of the squared shares of all firms operating in the same industry based on total sales.	CSMAR
r_{100}	The number of Confucian temples within a radius of 100 kilometres.	CNRDS
r_{300}	The number of Confucian temples within a radius of 300 kilometres.	CNRDS
SOE	State ownership is represented by a dummy variable that equals one if the firm is ultimately controlled by the government, and zero otherwise.	CSMAR
$CloseSOE$	A dummy variable that equals one if the firm is ultimately controlled by the government and its shareholding concentration is greater than industry-year median. Shareholding concentration is measured by the Herfindahl– Hirschman Index, which is calculated as the sum of squares of percentage of the largest shareholder.	CSMAR
$lnSub$	Natural logarithm of the number of green innovations patents the firm applied in a year plus one.	CNRDS

$lnSym$	Natural logarithm of the number of green utility model patents the firm applied in a year plus one.	CNRDS
Fixed variables		
$Industry$	Dummy variables that represent different types of industry.	CSMAR
$Year$	Dummy variables that represent different types of calendar year.	CSMAR