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Environmental Regulation and Corporate Sustainability: A Review of Green Innovation Mechanisms and Performance Outcomes

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Abstract

Purpose: To review the latest domestic and international research (past five years) on how different types of environmental regulation-command-and-control, market-based, and voluntary-affect green technological innovation and corporate sustainability, and to propose an integrated analytical framework for understanding these mechanisms. **Methodology:** This study conducts a systematic literature review, synthesizing theoretical and empirical findings related to the nonlinear, heterogeneous, and complementary effects of environmental regulation on green technology innovation and firm performance. **Findings:** Environmental regulation significantly influences green innovation through diverse and nonlinear mechanisms. Moderate regulation generates innovation compensation effects, while overly stringent enforcement may restrain R&D investment. Different regulatory tools also demonstrate complementarity. The study proposes a multi-mechanism analytical framework and identifies future research directions related to digital governance, social equity, and institutional coordination. **Research limitations:** As a literature review focused on the past five years, the findings may be constrained by the scope of available studies and the evolving nature of environmental policies. Future research should further explore cross-regional heterogeneity and long-term dynamic impacts. **Practical implications:** Insights from the review help inform China's effort to construct a balanced and efficient environmental regulatory system, offering guidance for improving green transition governance via digital tools, inclusive policy design, and coordinated institutional arrangements. **Originality:** This paper provides a comprehensive and updated synthesis of recent research, highlights the complementary mechanisms of varied regulatory tools, and introduces an integrated analytical framework that enriches the theoretical understanding of how environmental regulation shapes green innovation and corporate sustainability.

Keywords: Corporate Sustainability, Heterogeneity Effects, Innovation Compensation

Introduction

In recent years, with the continuous advancement of ecological civilization construction and the gradual implementation of the "dual carbon" goals, environmental regulation has become a crucial policy instrument for China to balance economic development and ecological sustainability. Over the past decade, the Chinese government has successively established a multidimensional environmental regulatory system integrating command-and-control measures, market-based mechanisms, and voluntary and participatory programs. This institutional evolution signifies a shift in environmental governance from traditional administrative oversight toward a more flexible and innovation-oriented policy framework (Shen et al., 2022). Under the high-quality development strategy, environmental regulation is widely regarded as a key driver of green technological innovation and corporate sustainability. Consequently, research on the related mechanisms has increasingly become a focal point in academic circles.

At the macro level, scholars worldwide generally agree that the relationship between environmental regulation(ER) and green innovation is not a simple linear correlation. Shen et al. (2022), using provincial panel data and a dynamic GMM model, demonstrated that both command-and-control(CAC) and market-based regulations exert significant but nonlinear effects on green innovation efficiency: the former exhibits an inverted N-shaped relationship, while the latter shows a U-shaped relationship. Research suggests that moderate regulatory intensity effectively stimulates corporate innovation motivation, whereas overly stringent policy constraints may reduce resource allocation efficiency. Li et al. (2022), using city-level data, similarly found a nonlinear relationship between environmental regulation and green total factor productivity (GTFP), confirming the existence of a policy threshold effect. These findings collectively support the theoretical proposition that well-designed environmental regulations facilitate the innovation compensation effect.

At the micro level, variations in firm behavior further highlight the heterogeneity of environmental regulatory instruments. Nie et al. (2022), analyzing firm-level data, found that voluntary environmental regulation significantly boosted green patent output in manufacturing firms, increasing patent grants by an average of 15%–18%. This effect primarily operates through three channels: government subsidies, public support, and external collaboration. Hu et al. (2021), examining export technology intensity, identified distinct pathways through which different regulatory tools command-and-control, market-based, and voluntary mechanisms-influence corporate innovation: command-and-control affects corporate behavior mainly through technology transfer mechanisms; market-based instruments function primarily through technological innovation mechanisms; while voluntary participation is dominated by technology adoption pathways. Furthermore, Hu et al. (2021) found that directive control tools partially restricted hybrid trade and foreign enterprise participation, whereas market-based and voluntary tools were more conducive to clean production and higher technological sophistication. This suggests that a balanced regulatory mix may outperform single policy instruments in achieving dual environmental and economic objectives.

As research deepens, scholars are expanding their focus from innovation performance to broader corporate sustainability dimensions. Liu Qingling (2025), using China's new Environmental Protection Law as a quasi-natural experiment, found that policy implementation significantly enhances corporate ESG performance. This mechanism operates by increasing institutional investor attention and reducing agency costs, although managerial short-termism may weaken this effect. Du Ke (2025) further argues that heterogeneous environmental regulation compels firms to adopt either passive compliance or proactive innovation strategies, which serve as critical mediators between policy pressure and green innovation. Meanwhile, Wang Xiaodan (2025) examines the distributional dimension, revealing that strong command-and-control regulations (e.g., the Ten Measures for Air Pollution Prevention and Control) reduce labor income shares through capital deepening and financing constraints, raising new issues concerning social equity and a just transition. This demonstrates that environmental regulations exert profound impacts not only on economic and technological outcomes but also on social distribution and equity.

At the regional level, findings from Li et al. (2022) and Shen et al. (2022) further indicate that when environmental regulatory intensity reaches a certain threshold, it significantly enhances green innovation efficiency and productivity, thereby supporting the innovation compensation hypothesis. In contrast, Nie et al. (2022) and Hu et al. (2021) emphasize the importance of voluntary and market-based regulatory tools—the former offering flexibility and incentives, and the latter strengthening firms' intrinsic motivation for innovation through market mechanisms. A synthesis of these studies reveals that the innovation effects of environmental regulation exhibit pronounced nonlinearity, heterogeneity, and context dependence. Outcomes depend on the combined influence of multiple factors, including policy design, regional economic capacity, industrial characteristics, and firm strategies.

Overall, despite substantial research progress, several issues warrant further exploration. First, significant variations in the measurement of environmental regulatory intensity across studies undermine the comparability of findings. Second, most research focuses solely on the direct effects of environmental regulation, with insufficient attention to mediating mechanisms such as managerial cognition, ESG governance, or external knowledge search. Third, there is a lack of systematic linkage between macro-level policy performance analysis and micro-level corporate strategic responses, limiting a holistic understanding of the synergistic effects among different regulatory instruments.

Based on the above research landscape, this paper aims to deepen the literature analysis in three aspects by systematically reviewing relevant domestic and international studies. First, it constructs a multi-mechanism analytical framework to reveal the intrinsic logic of three transmission pathways—technological, financial, and strategic—through which different types of environmental regulation influence green innovation and corporate performance. Second, it synthesizes empirical findings across diverse regions, industries, and firm types to explore the nonlinear and heterogeneous characteristics of policy effects, emphasizing the critical roles of policy thresholds and instrument complementarity. Third, it extends the research perspective to examine the impacts of environmental regulation on corporate sustainability and social equity, proposing that policies should balance innovation incentives with inclusivity and competitiveness to achieve a well-coordinated policy mix.

Literature Review

Review of Environmental Regulation and Green Innovation Research

The relationship between environmental regulation and green technological innovation(GTI) has become a central topic in research on sustainable economic transformation. In recent years, Chinese scholars have generally recognized that environmental regulation not only constrains pollution-intensive production activities but also promotes technological upgrading and industrial restructuring through incentive mechanisms. However, the operational mechanisms and policy effectiveness of this relationship vary significantly across different regulatory instruments, industrial contexts, and regional conditions (Shen et al., 2022; Li et al., 2022).

Early empirical studies predominantly viewed command-and-control regulation (CAC) as a compliance constraint mechanism, with policy objectives primarily focused on emission reduction and pollution abatement. As the policy toolkit diversified, market-based instruments(MBI) and voluntary environmental programs(VEP) gradually emerged as important complements to administrative control. Studies by Nie et al. (2022) and Hu et al. (2021) revealed that voluntary and market-based regulations significantly enhance corporate green patent applications, whereas CAC instruments under high-intensity enforcement may lead to delayed or even inhibitory effects. This demonstrates that environmental regulation can function both as a constraint and as an incentive, with its outcomes depending on the scientific rigor of policy design and the intensity of implementation.

Li et al. (2022) employed bibliometric methods to systematically analyze 738 international publications from 2001 to 2021, revealing the field's phased evolution—from an early exploratory stage to a phase of expansion and integration. In recent years, China has become a major contributor to global research on environmental regulation and green innovation. Research themes have expanded beyond traditional environmental economics to include innovation efficiency, regional spillover effects, and corporate ESG performance. This indicates a disciplinary shift from environmental economics toward an interdisciplinary focus on environment–management integration.

Theoretical Perspectives

At the theoretical level, scholars employ diverse explanatory frameworks to interpret the mechanisms through which environmental regulation influences green innovation and corporate performance. The Porter Hypothesis offers crucial insights. Studies by Shen et al. (2022) and Li et al. (2022) implicitly validate its core proposition: while well-designed environmental regulations initially increase compliance costs, innovation activities generate compensatory effects once firms surpass policy thresholds, achieving a win-win outcome in which regulation drives excellence.

From the perspective of stakeholder theory, corporate environmental behavior is influenced not only by policy constraints but also by external legitimacy pressures. Liu Qingling (2025) finds that institutional investor attention and public oversight jointly shape corporate decision-making regarding environmental responsibility and ESG disclosure, demonstrating that external stakeholders play a crucial motivational role in environmental governance.

Research based on the Resource-Based View (RBV) treats green technological innovation as a dynamic capability of firms. Du Ke (2025) and Qi Liyun (2025) argue that heterogeneous environmental regulation compels firms to reconfigure resources and capabilities, fostering proactive green strategies that transform external policy pressures into competitive advantages. This perspective links environmental regulation with corporate strategic behavior and provides new theoretical support for understanding the internal mechanisms of the innovation compensation effect.

Some studies also adopt institutional and evolutionary perspectives. Analyses using evolutionary game models (Huang, 2023; Xiao, 2025) reveal a continuous process of interaction and learning among government regulation, public participation, and corporate innovation. The effectiveness of environmental governance depends on the coordinated evolution of multiple actors. This perspective moves beyond traditional static analysis and emphasizes the dynamic equilibrium among policy implementation, social feedback, and corporate responses.

Classification of Environmental Regulatory Tools

Existing literature generally classifies environmental regulation into three types: Command-and-Control, Market-Based Instruments, and Voluntary Environmental Programs , each differing significantly in policy logic and incentive mechanisms.

Under command-and-control regulation, governments directly intervene in corporate behavior through administrative orders, emission standards, and enforcement inspections. Shen et al. (2022) identified an inverted N-shaped relationship between command-and-control intensity and green innovation efficiency: moderate regulation stimulates innovation vitality, whereas excessive intervention may lead to resource crowding-out effects. Wang Xiaodan (2025) notes that mandatory policies such as the Ten Measures for Air Pollution Prevention and Control may reduce labor income shares through capital deepening and financing constraints, posing distributional challenges. Du Ke (2025) further argues that CAC can still catalyze reactive technological improvements under compliance pressure, forming adaptive strategies that enable firms to cope with regulatory constraints.

In contrast, market-based instruments emphasize economic incentives and price signals. Li et al. (2022) discovered a U-shaped relationship between market-based regulation and green total factor productivity, indicating that moderate price pressures yield limited effects. However, when policy intensity surpasses a critical threshold, firms tend to lower emission reduction costs through technological innovation. Hu et al. (2021) further demonstrated that market incentives significantly increase the number of green invention and utility model patents, thereby enhancing the technological sophistication of exports. These findings suggest that market-based mechanisms can transform constraints into innovation drivers.

Voluntary environmental programs have received growing attention in recent years. Nie et al. (2022) provided robust causal evidence that voluntary participation raises firms' green patent applications by 15% to 19%, with effects arising from government recognition, public oversight, and knowledge diffusion through collaborative networks. Liu Qingling (2025) further indicates that voluntary disclosure and ESG practices mediate the influence of environmental regulation on firm performance, with information transparency and

stakeholder trust serving as essential complements to formal enforcement. Collectively, these studies outline a multidimensional environmental governance system integrating government regulation, market incentives, and social participation (Liu et al., 2024).

Mechanisms Linking Environmental Regulation to Innovation Performance

At the mechanism level, environmental regulation influences innovation and corporate performance through multiple pathways, including technological, financial, institutional, and spatial channels.

In terms of technological and financial mechanisms, although environmental regulation increases firms' pollution control costs, it also encourages them to reduce long-term expenses through cleaner production, energy efficiency improvements, and technological R&D. Market-based policy instruments such as fiscal subsidies and emissions trading can ease firms' financing constraints and promote green investment (Hu et al., 2021; Li et al., 2022).
Institutional and strategic mechanisms reflect how policy pressures drive dual strategic responses: passive compliance and proactive innovation (Du Ke, 2025). Voluntary environmental governance further enhances ESG performance by strengthening corporate legitimacy and investor confidence (Liu Qingling, 2025).

Spatial spillover effects also merit attention. Li et al. (2022) demonstrate that local environmental policies not only improve green innovation efficiency within the region but also generate positive externalities for neighboring areas through knowledge diffusion and competitive dynamics.

Moreover, multiple studies identify nonlinear and threshold effects. Shen et al. (2022) and Li et al. (2022) find that innovation compensation effects emerge only when regulatory intensity exceeds a critical threshold. This suggests that the relationship between environmental regulation and green innovation is nonlinear and jointly shaped by policy design quality, regional capabilities, and firm-specific characteristics.

Emerging Issues and Research Gaps

Despite the rapid growth of relevant literature, several research limitations persist.
At present, macro-level analyses and firm-level strategic studies remain insufficiently integrated, highlighting the need for stronger linkage across different analytical levels. Measurement standards for environmental regulatory intensity also lack consistency, with substantial variations in the proxy indicators used across studies, such as pollution fee collection, enforcement frequency, or policy dummy variables. These inconsistencies compromise the comparability of research outcomes.

Meanwhile, the emergence of digital transformation and artificial intelligence provides new opportunities for environmental governance research. Huang Lei (2023) suggests that digital and intelligent technologies can enhance regulatory efficiency through knowledge sharing and data analytics, although empirical evidence remains limited.

In addition, issues of social equity and a just transition are gaining prominence. Wang Xiaodan (2025) notes that while environmental policies promote green growth, they may also generate unintended consequences such as income inequality and declining labor shares.

This underscores the need for policymakers to balance environmental objectives with social sustainability.

Overall, future research should undertake more in-depth cross-dimensional analyses encompassing policy heterogeneity, technological capabilities, and corporate strategic governance to develop a systematic and multi-level theoretical framework. The subsequent chapters will further integrate empirical evidence to examine how environmental regulation can serve as a key driver of innovation and green transformation across different contexts.

Empirical Evidence

Research Design and Econometric Methods

Empirical studies on environmental regulation and green technological innovation in China demonstrate considerable methodological diversity, reflecting evolving policy dynamics, data availability, and the broadening of research perspectives. Overall, existing studies generally adopt three main approaches: panel data models, quasi-natural experimental designs, and efficiency analyses. Collectively, these approaches constitute the empirical exploration of ER's operational mechanisms.

At the macro level, dynamic panel models and system GMM methods are widely employed to identify policy lag effects and address endogeneity issues between ER and innovation. Shen et al. (2022) examined the impact of three regulatory instruments on green innovation efficiency using system GMM models and data from 30 provinces between 2009 and 2019. The results indicate that command-and-control regulation exhibits an inverted N-shaped relationship, market-based regulation shows a U-shaped relationship, while voluntary environmental programs demonstrate a moderate positive linear effect. Li et al. (2022) further extended this analysis using a spatial econometric framework, finding that environmental regulation not only enhances regional GIE but also generates positive spatial spillover effects on neighboring regions, thereby revealing the existence of knowledge diffusion and policy competition mechanisms.

At the same time, some scholars have employed quasi-natural experiment designs to explore the causal impacts of policy shocks. Nie et al. (2022) exploited differences in voluntary regulation implementation and applied propensity score matching combined with a difference-in-differences (PSM-DID) approach to estimate policy effects. They found that voluntary regulation significantly increased corporate green patent counts by 15% to 19% through mechanisms of public participation and government support. Liu Qingling (2025) treated the 2015 Environmental Protection Law as a natural experiment, finding that the policy heightened institutional investor attention and reduced agency costs, thereby significantly improving corporate ESG performance. Wang Xiaodan (2025), analyzing the Ten Measures for Air Pollution Prevention and Control, observed that while strengthened command-and-control regulation effectively reduced pollution levels, it also lowered labor income shares, revealing the distributional implications of stringent environmental enforcement.

In addition, studies adopting efficiency analysis and system modeling offer more nuanced assessments of regulatory performance. Du Ke (2025) combined nonparametric frontier techniques such as Super-SBM and EBM models to measure green innovation efficiency,

integrating these results with data on corporate environmental strategies. The findings reveal that heterogeneous environmental regulation can induce both reactive compliance strategies and proactive innovation behaviors, with the latter contributing more substantially to substantive innovation. Xiao Jing (2025) further expanded this perspective by proposing a dual regulatory model, arguing that the rational differentiation and combination of market-based and administrative control instruments can maximize environmental performance. This diversity of research methodologies provides a more comprehensive empirical foundation for understanding policy effects and strategic adaptation.

Measurement and Operationalization of Key Variables

Heterogeneity in variable measurement remains one of the most prominent challenges in the existing literature. Researchers typically quantify different types of environmental regulation using multiple proxy indicators.

Command-and-control regulation (CAC) is often measured by variables such as inspection frequency, pollution control investment, or dummy indicators representing major policy events (e.g., the enactment of new regulations or the implementation of the Central Environmental Protection Inspection Program, CEIP). Market-based instruments (MBI) are commonly captured through economic variables such as pollution fees, environmental tax rates, or carbon trading participation. Voluntary environmental programs are usually measured by environmental disclosure indices, levels of public participation, or the number of collaborative projects between governments and enterprises (Nie et al., 2022; Liu, 2025).
Regarding green technological innovation , most studies employ metrics such as the number of green invention and utility model patents (Hu et al., 2021; Nie et al., 2022), green innovation efficiency (Shen et al., 2022), or green total factor productivity (Li et al., 2022) as core indicators. Corporate sustainability performance is often represented by ESG ratings (Liu, 2025), green investment intensity (Qi, 2025), export technological sophistication (Hu et al., 2021), and measures of income distribution alongside environmental performance indicators (Wang, 2025; Xiao, 2025).

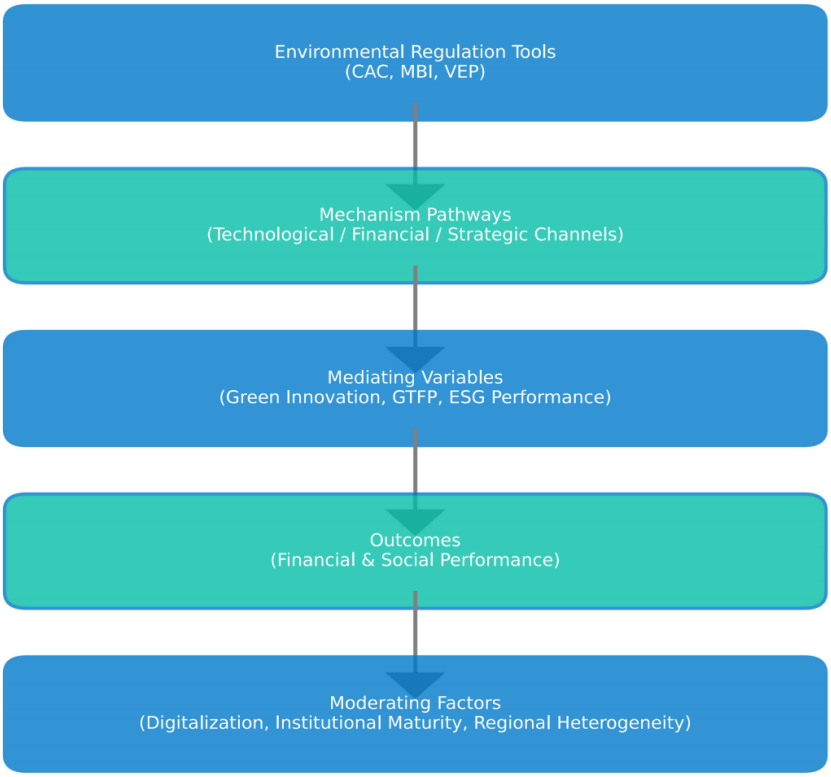
This diversity in measurement dimensions enriches the empirical literature to some extent but also weakens comparability across studies. Research based on patent data tends to emphasize the quantitative aspect of innovation, whereas studies employing efficiency measures or ESG indicators focus more on innovation quality and institutional response differences.

Mechanistic Pathways and Mediating Effects

As shown in Figure 1, environmental regulation influences green technological innovation and corporate performance through multiple interconnected pathways, including cost pressure, government support, financial channels, knowledge networks, and social mechanisms. These mechanisms jointly shape firms' green innovation outcomes, reflecting the multifaceted nature of ER's impact on corporate sustainabiliIn terms of cost and incentive mechanisms, moderate compliance costs can motivate firms to achieve innovation compensation through technological upgrading. Shen et al. (2022) found that when regulatory intensity is moderate, green innovation efficiency significantly improves, whereas excessive enforcement weakens returns, exhibiting an inverted N-shaped pattern. Hu et al. (2021) also identified a U-shaped relationship between market-based instruments (MBI) and

export technology intensity, indicating that innovation compensation effects only emerge after firms cross an adaptation threshold.

Figure 1. Framework of Environmental Regulation–Green Innovation–Corporate Performance



Government support and public participation represent equally important channels. Nie et al. (2022) found that voluntary environmental programs enhance firms' environmental legitimacy through public oversight and governmental endorsement, expanding open innovation networks and increasing green patent output. Public opinion and reputational incentives transform external constraints into internal drivers, encouraging firms to adopt green technologies more proactively.

Financial mechanisms also play a vital role. Environmental policies can improve corporate financing environments and attract institutional investor attention. Liu Qingling (2025) showed that ER indirectly enhances corporate ESG performance through investor monitoring

and reductions in agency costs. Du Ke (2025) further emphasized that heterogeneous regulation prompts firms to adopt diversified strategies, with proactive innovation strategies amplifying financial incentives in the long term and communicating sustainability commitments to external stakeholders.

With the rise of digitalization, knowledge networks and technological empowerment have become new areas of research. Huang Lei (2023) demonstrated that integrating artificial intelligence with knowledge capital strengthens the positive effect of voluntary environmental responsibility on innovation, improving firms' absorptive capacity and information efficiency.

Finally, social equity mechanisms have attracted increasing scholarly attention. Wang Xiaodan (2025) found that stringent command-and-control regulation may exacerbate social inequality by shifting income toward capital through capital-deepening effects. Although green innovation provides some buffering capacity, it cannot fully offset structural distributional imbalances. This finding underscores the need for environmental policy design to balance efficiency and equity objectives.

Analysis of Heterogeneous Characteristics

Extensive empirical research shows that the impact of environmental regulation on green technological innovation and firm performance is not uniform but varies across regions, ownership structures, industries, and time periods.

At the regional dimension, Li et al. (2022) found that the ER–GTI relationship is more pronounced in eastern regions due to their well-developed industrial bases and mature financial systems, whereas western regions display a lagging effect because of weaker innovation infrastructure.

With respect to ownership structure, Hu et al. (2021) revealed that state-owned enterprises respond more strongly to command-and-control regulation, while private firms exhibit greater innovation sensitivity under market-based and voluntary regulatory environments.
Across industries, Nie et al. (2022) observed that capital-intensive and technology-intensive sectors react more positively to voluntary environmental programs, whereas pollution-intensive industries remain characterized by passive compliance.

From a temporal perspective, Du Ke (2025) found that the long-term effects of ER outweigh its short-term impacts, as firms gradually shift from passive compliance to proactive innovation strategies through continuous adaptation.

Collectively, these findings demonstrate that the role of environmental regulation is highly context-dependent. Its effectiveness is shaped by the combined influences of institutional maturity, industrial characteristics, and firm-specific capabilities.

Synthesis and Conclusions

Synthesizing existing empirical research yields several consistent conclusions. First, a nonlinear relationship generally exists between environmental regulation and green technological innovation , with policy effects often exhibiting U-shaped or inverted N-shaped

patterns that are closely associated with regional development levels (Shen et al., 2022; Li et al., 2022).
Second, strong complementarity exists among different regulatory instruments. Integrated policy mixes that combine command-and-control measures, market-based incentives, and voluntary environmental programs enhance innovation performance more effectively than single regulatory approaches (Hu et al., 2021; Nie et al., 2022).

Third, corporate strategy functions as a crucial mediating mechanism, with ESG engagement and dual environmental behaviors serving as important bridges that transform external policy pressures into internal innovation drivers (Du, 2025; Liu, 2025).

Finally, spatial spillover effects and social distributional concerns highlight that the green transition is not merely a technological challenge but also a process requiring regional coordination and inclusive growth (Li, 2022; Wang, 2025).

As summarized in Table 1, although most studies support the innovation-stimulating effect of environmental regulation, the direction and magnitude of its impact vary across regulatory types, industrial characteristics, and methodological designs.

Table 1
Summary of Empirical Studies on Environmental Regulation and Green Innovation

Author (Year)	Sample / Context	Methodology	Main Findings	Key Implications
Shen et al. (2022)	30 Chinese provinces (2009–2019)	System GMM	CAC regulation shows an inverted N-shaped effect on green innovation efficiency; MBI shows a U-shaped relationship; VEP has a moderate positive effect.	Supports the conditional Porter Hypothesis; moderate regulation stimulates innovation.
Li et al. (2022)	Provincial spatial panel data	Spatial econometric model	Market-based regulation improves green total factor productivity (GTFP) and generates positive spatial spillover effects.	Environmental policies can diffuse innovation benefits across regions.
Nie et al. (2022)	Firm-level panel data	PSM-DID (Propensity Score Matching - Difference-in-Differences)	Voluntary environmental regulation increases green patent applications by 15–19%, mediated by government support and public participation.	Highlights the importance of stakeholder engagement and policy flexibility.
Hu et al. (2021)	Chinese manufacturing firms	Panel regression	Market-based instruments significantly enhance export technological sophistication through	Financial incentives and tradable rights can transform regulation into innovation drivers.

Author (Year)	Sample / Context	Methodology	Main Findings	Key Implications
			green invention and utility patents.	
Liu (2025)	Listed companies (post-Environmental Protection Law 2015)	DID model	Implementation of the new Environmental Protection Law significantly improves firms' ESG performance through higher investor attention and reduced agency costs.	Strengthens the link between regulation, governance, and sustainability performance.
Du (2025)	Manufacturing enterprises	Multiple regression analysis	Heterogeneous environmental regulation triggers both passive compliance and proactive innovation strategies; the latter has stronger impact on substantive innovation.	Demonstrates the dual-path mechanism between regulation pressure and innovation strategy.
Wang (2025)	Industry-level analysis	Policy evaluation model	Strong command-and-control regulation (e.g., Air Pollution Prevention Ten Measures) decreases labor income share through capital deepening and financing constraints.	Suggests that environmental policies should balance efficiency and equity.

Note: This table summarizes representative empirical studies examining the nexus between environmental regulation and green technological innovation in China

Overall, empirical evidence supports the conditional Porter Hypothesis in the Chinese context: environmental regulation serves as a positive driver of innovation and performance enhancement only when policy instruments are properly configured, the institutional environment is sufficiently mature, and enterprises possess adequate absorptive capacity. Future research should further emphasize the synergistic design of policy instruments, the role of digital empowerment, and the development of inclusive transition pathways, thereby deepening the systemic understanding of how ER fosters innovation and sustainable development.

Discussion and Future Research Directions

Integrated Understanding of Environmental Regulation and Green Innovation

Existing research indicates that China's environmental regulation system has evolved from a single-dimensional administrative oversight model to a multidimensional governance structure. Command-and-control, market-based instruments, and voluntary environmental programs) collectively shape the landscape of green technological innovation and corporate sustainability (Shen et al., 2022; Li et al., 2022). Empirical evidence consistently reveals a

conditional nonlinear relationship: moderate regulation stimulates corporate innovation, whereas excessive enforcement may crowd out R&D resources. This pattern validates the conditional Porter Hypothesis, suggesting that innovation compensation arises only when institutional, financial, and managerial capabilities reach a certain threshold, enabling firms to transform external policy pressures into innovation momentum.

At the same time, existing studies emphasize the complementarity among policy instruments. The integrated use of CAC, MBI, and VEP produces stronger synergistic effects than any single policy tool (Hu et al., 2021; Nie et al., 2022). Within this policy mix, command-and-control measures establish compliance thresholds and institutional constraints, market mechanisms introduce economic incentives and efficiency orientation, and voluntary programs enhance legitimacy and transparency through public oversight and stakeholder participation. The interaction of these three instruments forms a policy ecosystem combining both hard constraints and soft incentives, facilitating more flexible and adaptive environmental governance and promoting a robust and inclusive green transition.

Nevertheless, despite substantial consensus in current research, theoretical integration and methodological refinement remain limited. The following discussion will further examine and reflect on four dimensions: theoretical integration, methodological consistency, digitalization and strategic transformation, and inclusive and just transition.

Theoretical Integration: Bridging Macro Policies and Micro Strategies

In n recent years, Chinese scholars have made significant contributions by attempting to bridge the gap between macro-level policy effects and micro-level firm strategies. Du Ke (2025) and Qi Liyun (2025) observe that firms often respond to various types of environmental regulation through dual-track strategies of passive compliance and proactive innovation. This phenomenon illustrates that environmental policies are not merely coercive instruments but also shape firms' long-term strategic orientations. In comparison, market-based instruments and voluntary environmental programsare more likely to foster proactive innovation strategies, whereas command-and-control regulations primarily induce passive compliance (Du Ke, 2025).

Nevertheless, theoretical integration within existing research remains limited. Most empirical models treat ER as an exogenous variable, overlooking the bidirectional interactions and feedback loops between firms and government authorities. For instance, local governments may adjust enforcement intensity based on firms' innovation performance, generating a dynamic policy–response–readjustment cycle (Xiao, 2025). Future studies should incorporate institutional feedback mechanisms into analytical frameworks, integrating institutional theory, the Resource-Based View, and evolutionary game perspectives to uncover the co-evolutionary dynamics between policymakers and firms. Such an approach would enable a more systematic understanding of environmental governance processes.

Methodological Optimization and Measurement Consistency

Methodological differences and inconsistencies in variable measurement constitute another major challenge in this field. Scholars employ diverse proxy indicators to capture regulatory intensity and innovation levels, such as pollution fees, enforcement frequency, policy dummy variables, and metrics including green patent counts, efficiency indices, and ESG indicators.

While this diversity enriches research perspectives, it simultaneously weakens comparability across studies. Shen et al. (2022) and Li et al. (2022) constructed composite indices encompassing both administrative and market dimensions to assess environmental responsibility, whereas Nie et al. (2022) and Hu et al. (2021) emphasized firm-level policy response dummy variables. The absence of unified standards makes it difficult to synthesize consistent conclusions across the literature.

Future research should prioritize methodological standardization and innovation in indicator systems. Integrating quantitative and textual data-such as policy document text mining, carbon trading participation records, and patent classification databases-could facilitate the construction of dynamic indicators for a more comparable measurement of environmental regulatory intensity. Meanwhile, adopting advanced econometric approaches such as multi-period difference-in-differences, spatial dynamic panel models, and instrumental variable GMM techniques would improve causal inference accuracy and account for policy lag effects. Furthermore, machine learning methods can be utilized to analyze heterogeneity-controlled effects, uncovering micro-level variations in regulatory impacts across industries, regions, and time periods.

Digitalization, AI Applications, and Strategic Transformation

With the advancement of the digital economy, the integration of digital technologies and artificial intelligence (AI) has emerged as a new frontier in environmental governance and corporate innovation research. Huang Lei (2023) found that combining AI with knowledge capital significantly enhances firms' ability to respond to informal and voluntary environmental regulation, primarily by strengthening knowledge acquisition and environmental monitoring functions. This finding aligns with recent scholarly perspectives suggesting that digital empowerment amplifies firms' absorptive capacity, transforming compliance pressures into innovation opportunities.

Nevertheless, current empirical research has yet to fully operationalize digitalization as a moderating variable. Future studies could further examine how digital infrastructure-such as big data analytics, smart manufacturing systems, and blockchain-based traceability-mediates or moderates the relationship between corporate environmental responsibility and innovation. Digital transformation not only reduces compliance costs and improves the real-time monitoring of environmental performance but also enhances the transparency and precision of policy implementation. Moreover, digital tools facilitate information disclosure and ESG transparency, thereby attracting institutional investor attention and strengthening public trust (Liu, 2025). This intersection between digital governance and institutional pressure opens new research avenues for understanding the dynamic process of green transformation

Inclusivity, Distributional Effects, and Just Transition

Beyond economic and technological dimensions, the social and distributional effects of environmental regulation have increasingly attracted scholarly attention. Wang Xiaodan (2025) demonstrates that while mandatory carbon reduction policies effectively improve environmental quality, they may also reduce labor income shares through capital-deepening effects, revealing structural tensions between environmental improvement and social equity. Similarly, Du Ke (2025) found that intensive regulation generates more pronounced positive

effects for large resource-based enterprises but may create competitive disadvantages for small and medium-sized enterprises (SMEs), thereby exacerbating innovation inequality.
Future research should further integrate social equity and inclusivity into analytical frameworks for ER and green technological innovation. Policymakers must ensure the equitable distribution of innovation dividends and prevent transition costs from disproportionately burdening vulnerable groups. Integrating environmental economics with social policy research can help clarify the inherent trade-offs between efficiency and equity in environmental governance. By incorporating indicators such as job quality, income distribution, and community resilience, the concept of a just transition can be more systematically operationalized, fostering a virtuous cycle between corporate innovation and social welfare.

Policy Implications

Based on existing empirical evidence, several policy implications can be drawn.
First, greater emphasis should be placed on balanced policy design. Policymakers should coordinate regulatory, market-based, and voluntary instruments to leverage their complementary strengths. Studies by Hu et al. (2021) and Nie et al. (2022) indicate that market-based instruments (MBI) and voluntary environmental programs can amplify innovation incentives through flexibility and stakeholder participation, while a "combination rather than substitution" policy logic helps ensure both regulatory efficiency and innovation momentum.

Second, innovation infrastructure development must be strengthened. Li et al. (2022) found through regional heterogeneity analysis that areas with robust innovation ecosystems-including research institutions, financial services, and digital infrastructure-exhibit higher efficiency in implementing environmental regulation (ER). Thus, enhancing regional innovation capacity is crucial for narrowing gaps in the green transition.

Third, ESG governance should be more closely integrated with ER. Liu Qingling (2025) confirmed that environmental regulation improves corporate ESG performance by enhancing investor scrutiny and governance transparency. Regulators should actively promote information disclosure, green finance, and investor engagement to align corporate governance structures with environmental and sustainability objectives.

Finally, inclusive and digital governance should be pursued in tandem. The integration of digital platforms into ER can enhance policy efficiency and transparency, while complementary social policies can help mitigate transition costs (Huang, 2023; Wang, 2025). Achieving these dual objectives will enable China's green growth path to become both economically competitive and socially equitable.

Future Research Directions

Building on the preceding discussion, future research can be further deepened along several dimensions. First, cross-scale integration should be strengthened by combining macro-level policy evaluations with micro-level corporate data to reveal how policy signals propagate across hierarchical levels. Second, dynamic and nonlinear analytical models-such as system dynamics or threshold regression-should be developed to capture long-term feedback loops and complex evolutionary processes. Third, future studies should explore the synergies

among digital finance, ESG frameworks, and carbon markets to assess their role in strengthening the linkage between environmental regulation and green technological innovation. Fourth, behavioral and managerial dimensions should be broadened by examining the mediating effects of managerial cognition, risk perception, and corporate culture in compliance transformation. Finally, extending the research to other emerging economies would help validate the external applicability of China's conditional Porter Hypothesis.

Overall, future academic research should move beyond single-dimensional causal inference models by adopting a comprehensive perspective that integrates technological, financial, institutional, and social dimensions. This systemic governance approach will further clarify the innovative effects of environmental policies, thereby enriching theoretical understanding and providing practical guidance for China's transition toward a green, digital, and inclusive economy.

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