

A Literature Review on Environmental Regulation and Green Technological Innovation

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Abstract

China's rapid industrialization has generated substantial economic growth while simultaneously intensifying environmental pollution and ecological degradation, posing significant challenges to sustainable development. As a major source of emissions, the manufacturing sector is at the core of China's low-carbon transition, where green technological innovation plays a pivotal role. However, existing studies have largely examined these regulatory instruments in isolation, with limited attention to their joint effects and interactive mechanisms. This study develops an integrated analytical framework encompassing command-and-control, market-based, and public-participation environmental regulations, and employs an evolutionary game model to examine strategic interactions among governments, manufacturing enterprises, and the public. The analysis further incorporates central-local government coordination, pollution co-governance among small and medium-sized enterprises within supply chains, and the mediating role of public participation in modern environmental governance. The results indicate that appropriately designed combinations of regulatory intensity, economic incentives, and public supervision can jointly promote firms' green technological innovation, while excessive regulatory pressure may inhibit innovation by increasing compliance costs and financial constraints. Moreover, coordinated governance mechanisms and supply chain collaboration significantly enhance the effectiveness of environmental regulation in driving green transformation.

Keywords

Environmental regulation; Green technological innovation; Manufacturing sector

1. Introduction

Rapid industrialization and urbanization have substantially accelerated China's economic growth, yet they have simultaneously intensified environmental pollution and ecological degradation. The long-standing extensive development model has imposed severe pressures on ecosystems, threatening environmental security and undermining the foundations of long-term sustainable development. According to the China Ecological and Environmental Status Bulletin (2022), although overall

environmental quality has improved to some extent, ecological damage remains pronounced in several regions, with pollution still highly concentrated in key industrial areas. Consequently, environmental protection in China continues to face considerable challenges.

As a pillar of the national economy, the manufacturing sector plays a central role in this tension between growth and sustainability. Large volumes of pollutants and industrial waste generated during manufacturing processes have not only degraded natural ecosystems but have also constrained the sector's own capacity for sustainable development. In this context, promoting green transformation within manufacturing has become a critical prerequisite for advancing China's ecological civilization agenda.

To address the escalating environmental crisis, China has articulated clear long-term climate commitments. At the United Nations General Assembly in 2020, President Xi Jinping announced the "dual-carbon" goals of achieving peak carbon emissions by 2030 and carbon neutrality by 2060. Subsequent policy documents—including the Opinions on the Complete, Accurate, and Comprehensive Implementation of the New Development Philosophy to Achieve Carbon Peaking and Carbon Neutrality—identified industrial structure optimization as a core pathway toward these targets. Enterprises, as primary emission sources, are therefore positioned at the center of the low-carbon transition, with green technological innovation emerging as a key enabling mechanism.

At the same time, China's environmental governance system has undergone profound institutional evolution. Environmental regulation has shifted from a predominantly command-and-control approach toward a diversified governance framework that integrates market-based incentives and public participation. Under this modern environmental governance system, manufacturing enterprises are required not only to comply with regulatory constraints but also to proactively engage in green innovation to enhance their economic, environmental, and social performance. However, despite growing scholarly attention to environmental regulation and green innovation, limited research has systematically examined how diversified regulatory instruments jointly influence manufacturing firms' green technological innovation within the context of modern environmental governance.

Against this backdrop, this study aims to address this gap by developing an analytical framework that integrates command-and-control, market-based, and public-participation environmental regulations. By employing an evolutionary game approach, this paper investigates strategic interactions among governments, manufacturing enterprises, and the public, and explores how regulatory and incentive mechanisms can jointly promote green technological innovation. The study further examines central-local government dynamics, pollution co-governance among small and medium-sized enterprises (SMEs) within supply chains, and the role of public participation as a governance linkage. In doing so, this

research seeks to provide theoretical support for environmental tax reform and practical guidance for manufacturing firms pursuing green transformation under regulatory constraints, ultimately contributing to coordinated and sustainable development among governments, enterprises, and society.

2. Institutional Background and Policy Context

Environmental pollution issues in China emerged as early as the initial stage of industrialization. The promulgation of the first Environmental Protection Law in 1979 marked the beginning of a formal environmental regulatory system.[1] With the deepening of economic reforms and rapid industrial expansion, environmental degradation intensified, gradually attracting heightened attention from both policymakers and the public.[2]

Over time, environmental protection has been elevated to a core national development priority. The 18th and 19th National Congresses of the Communist Party of China emphasized sustainable development concepts such as “Beautiful China” and “lucid waters and lush mountains are invaluable assets,” [3] while the 20th National Congress further reinforced the importance of accelerating green development, strengthening pollution prevention and control, and steadily advancing carbon peaking and carbon neutrality.[4] These policy orientations reflect China’s transition from high-speed growth toward high-quality development, in which environmental sustainability is increasingly integrated into economic decision-making.

In support of this transition, China has introduced a series of stringent environmental regulatory instruments targeting manufacturing activities. The revised Environmental Protection Law implemented in 2015 significantly strengthened enforcement and penalties.[5] Subsequent amendments to the Air Pollution Prevention and Control Law, along with the introduction of the Environmental Protection Tax Law in 2018, further internalized environmental costs by replacing the long-standing pollutant discharge fee system.[6] Simultaneously, ecological civilization and the vision of “Beautiful China” were incorporated into the national constitution, signaling a long-term institutional commitment to environmental governance.

More importantly, environmental regulation in China has evolved beyond reliance on singular administrative controls.[7] A modern environmental governance framework has gradually taken shape, characterized by the joint participation of governments, enterprises, and the public.[8] This transformation reflects a shift toward diversified regulatory instruments that combine legal enforcement, market incentives, and social supervision. Within this governance context, manufacturing enterprises face increasing pressure to adopt green technological innovation as a means of achieving both regulatory compliance and sustainable competitiveness.

3. Literature Review

3.1. Environmental Regulation and Green Technological Innovation

Several studies have systematically examined the mechanisms through which environmental regulation influences firms' innovation trajectories. From a cooperative governance perspective, regulatory frameworks are increasingly recognized for their capacity to foster inter-firm collaboration, particularly through mechanisms such as joint R&D initiatives, technology-sharing platforms, and industry-wide sustainability standards.[10] By reducing transaction costs and aligning incentives across stakeholders, these collaborative structures enable firms to pool resources, mitigate risks, and accelerate the development of green technologies. For instance, empirical analyses of manufacturing clusters in Germany and Japan reveal that stringent environmental standards, when coupled with institutional support for cross-firm partnerships, correlate with higher rates of co-patenting in renewable energy and circular economy technologies. Such findings highlight the synergistic potential of regulatory and cooperative governance mechanisms in driving innovation beyond mere compliance.

Moreover, environmental regulation has been shown to lower pollution control costs in the long term by incentivizing firms to adopt cleaner production processes and invest in energy-efficient technologies. While short-term compliance expenses may strain financial resources, the adoption of advanced green technologies often generates operational efficiencies, waste reductions, and resource savings that offset initial costs. This dynamic is particularly evident in industries subject to progressive regulatory pressures, such as automotive manufacturing and chemical processing, where firms that preemptively integrate green innovations gain competitive advantages through cost leadership and brand differentiation. For example, a longitudinal study of European automakers demonstrates that firms subject to stricter emissions standards were more likely to invest in hybrid and electric vehicle technologies, subsequently capturing market share in premium eco-friendly segments.

Further research employing productivity and emissions indicators provides robust evidence of regulatory supervision's role in enhancing green governance and innovation performance. In cleaner production industries, such as renewable energy and waste management, regulatory oversight often aligns with firms' strategic objectives, creating a conducive environment for experimentation and scaling of sustainable technologies. Quantitative analyses utilizing data envelopment analysis (DEA) and stochastic frontier approaches reveal that firms operating under well-designed regulatory regimes—characterized by transparency, consistency, and adaptive enforcement—exhibit higher total factor productivity growth linked to green innovations. These studies also emphasize the importance of regulatory differentiation, wherein policies tailored to industry-specific challenges (e.g., carbon

pricing for energy-intensive sectors) yield stronger innovation effects compared to one-size-fits-all approaches.

Collectively, this body of research underscores the nuanced interplay between environmental regulation and green technological innovation. While compliance-driven motivations remain relevant, the evidence increasingly supports the view that thoughtfully crafted regulations can stimulate collaboration, reduce long-term costs, and enhance innovation performance, particularly in sectors aligned with cleaner production paradigms. These insights carry significant implications for policymakers and corporate leaders, advocating for regulatory frameworks that balance stringency with flexibility, incentivize cross-sectoral cooperation, and integrate dynamic feedback mechanisms to sustain innovation momentum over time.

3.2. Regulatory Intensity and Nonlinear Effects

Recent scholarly discourse has increasingly questioned the long-held assumption of a linear, uniformly positive relationship between environmental regulation and firms' green technological innovation.[11] While early studies often posited that stringent regulatory frameworks directly incentivize innovation by creating compliance-driven pressures, a growing body of empirical and theoretical research reveals a more nuanced dynamic. An emerging literature identifies a nonlinear, inverted U-shaped relationship between regulatory intensity and innovation outcomes, suggesting that the effectiveness of environmental policies in stimulating green innovation is contingent upon the balance between regulatory stringency and firm adaptability.

This inverted U-shaped pattern implies that moderate levels of regulatory pressure are optimal for fostering innovation, as they provide sufficient incentive for firms to invest in green R&D without imposing overwhelming compliance burdens. At this intermediate stage, regulations act as a catalyst by clarifying technological standards, reducing uncertainty, and creating market demand for eco-friendly products. For instance, firms operating under moderately stringent carbon pricing mechanisms are more likely to allocate resources toward energy-efficient technologies, as the cost of non-compliance outweighs the investment required for innovation. Simultaneously, such policies often stimulate cross-industry knowledge spillovers, as firms seek partnerships to meet regulatory targets, further amplifying innovation potential.

Conversely, excessive regulatory intensity—characterized by overly rigid standards, frequent policy revisions, or high administrative costs—can suppress innovation by diverting financial and managerial resources toward compliance rather than creative problem-solving. Financial constraints emerge as a critical barrier, particularly for small and medium-sized enterprises (SMEs), which may lack the capital buffers to absorb sudden regulatory costs. Empirical studies of

manufacturing sectors in highly regulated jurisdictions demonstrate that firms facing disproportionately high compliance expenditures often reduce R&D budgets, delay technology adoption, or relocate operations to regions with laxer standards. Moreover, excessive regulation may stifle risk-taking behavior, as firms prioritize short-term compliance over long-term innovation investments that carry uncertain returns.

The nonlinear relationship also highlights the role of institutional and industry-specific factors in mediating regulatory impacts. In contexts with strong property rights protection, access to financing, and skilled labor, firms are better equipped to navigate moderate regulatory pressures and convert them into innovation opportunities. In contrast, in developing economies with weaker institutional frameworks, even moderate regulations may impose disproportionate burdens, limiting their effectiveness in driving green innovation. Similarly, industry characteristics such as technology intensity, market competition, and pollution intensity influence the threshold at which regulation transitions from incentivizing to inhibiting innovation. For example, energy-intensive sectors may require more tailored regulatory approaches to avoid stifling productivity while still promoting decarbonization.

3.3. External and Internal Drivers of Green Innovation

Beyond the traditional focus on government-imposed environmental regulations, scholars have increasingly turned their attention to the role of external drivers in shaping firms' green technological innovation trajectories. These drivers, encompassing digitalization, green finance, and evolving market dynamics, represent critical enablers that interact with regulatory frameworks to either amplify or constrain innovation potential.[12] Their rising prominence reflects a broader recognition that sustainable transitions require multifaceted approaches, integrating technological, financial, and market-based mechanisms alongside policy interventions.

Green finance has also gained traction as a pivotal external driver, with financial instruments increasingly tailored to incentivize sustainable practices. Environmental taxes, for example, internalize the external costs of pollution by imposing levies on emissions or resource extraction, creating a financial disincentive for environmentally harmful activities. Simultaneously, revenues generated from such taxes can be reinvested in green R&D or subsidies for clean technology adoption, forming a virtuous cycle of innovation and sustainability. Green credit policies, another cornerstone of green finance, involve financial institutions offering preferential loan terms—such as lower interest rates or longer repayment periods—to firms investing in eco-friendly projects. These policies mitigate the financial risks associated with green innovation, particularly for SMEs, which often face capital constraints. Empirical studies demonstrate that firms with

access to green credit are more likely to undertake long-term R&D projects in renewable energy, energy efficiency, and waste management technologies. Furthermore, the rise of green bonds and sustainability-linked loans provides firms with additional avenues to secure funding for green transitions, while signaling to investors their commitment to environmental stewardship. The alignment of financial incentives with sustainability goals thus serves as a powerful catalyst for technological adoption and scale-up.

Market demand, driven by shifting consumer preferences and corporate sustainability commitments, constitutes a third critical external driver. As public awareness of climate change and resource depletion grows, consumers increasingly favor products with lower environmental footprints, creating market pressure for firms to innovate. This demand-side pull is evident in sectors such as automotive, where electric vehicles (EVs) have gained market share despite higher upfront costs, and in fashion, where circular business models and sustainable materials are becoming mainstream. Similarly, corporate buyers are integrating sustainability criteria into procurement decisions, favoring suppliers that demonstrate environmental responsibility. This trend has spurred supply chain innovations, as firms invest in cleaner production technologies to meet buyer requirements and avoid reputational risks. The role of non-governmental organizations (NGOs) and industry associations in certifying green products and services further reinforces market demand by providing credible signals to consumers and businesses. Importantly, market-driven innovation often complements regulatory efforts, as firms anticipate future policies—such as carbon pricing or bans on single-use plastics—by proactively developing sustainable alternatives.

3.4. Research Gaps

Despite significant advancements in understanding the drivers of green technological innovation, existing research exhibits two notable limitations that constrain its theoretical and practical relevance. First, the majority of studies adopt a fragmented approach by focusing on individual regulatory instruments—such as carbon taxes, emissions trading schemes, or renewable energy subsidies—in isolation.[13] While this line of inquiry provides valuable insights into the efficacy of specific policies, it overlooks the complex interplay among diversified environmental regulations within modern governance frameworks. In reality, firms operate under multifaceted regulatory regimes where multiple instruments coexist, interact, and sometimes conflict. [14] The net effect on innovation depends on how these instruments are designed, sequenced, and enforced, yet few studies systematically examine these joint impacts. This oversight limits policymakers' ability to design coherent regulatory portfolios that maximize synergies and minimize trade-offs between competing objectives, such as cost-effectiveness, environmental integrity, and industrial competitiveness. Furthermore, the study

extends the EGT model to incorporate supply chain dynamics by modeling interactions among upstream suppliers, downstream manufacturers, and end consumers as a multi-tier evolutionary system. This approach allows for the analysis of how regulatory signals propagate through supply chains, influencing innovation decisions at each tier. For instance, a stricter emissions standard imposed on downstream manufacturers may incentivize upstream suppliers to develop cleaner production technologies, even in the absence of direct regulatory pressure. Similarly, consumer preferences for sustainable products can create market-driven incentives for supply chain-wide innovation, which may interact with or substitute for formal regulations. By simulating these interactions under different regulatory scenarios, the model identifies the conditions under which supply chain collaborations emerge as a dominant strategy, as well as the role of public advocacy in accelerating this process. The proposed framework also advances methodological rigor by employing a combination of analytical solutions and numerical simulations to derive equilibrium conditions and transition pathways. Sensitivity analyses are conducted to assess the robustness of findings under varying parameterizations, such as regulatory stringency, innovation costs, and consumer awareness levels. This multi-method approach ensures that the results are both theoretically grounded and empirically relevant, providing actionable insights for policymakers and supply chain managers.

4. Policy Implications

4.1. Implications for Environmental Regulation Design

Environmental taxation represents a critical macroeconomic instrument for internalizing environmental externalities and guiding enterprises toward sustainable production modes. Expanding the coverage of green taxation to encompass resource inefficiency, water and air pollution, and other environmental externalities can enhance its effectiveness. Differentiated tax rates for high-pollution enterprises can further technological upgrading and strategic transformation. Subsidy mechanisms, including green credit, fiscal transfers, and non-monetary support, should be designed to alleviate financial constraints faced by SMEs during green transformation. Optimizing green credit systems by incorporating environmental performance criteria into financing decisions can facilitate access to capital for environmentally responsible enterprises. At the same time, strengthening supervision and transparency in subsidy allocation is essential to prevent misuse and improve policy efficiency. Effective regulation also requires robust monitoring and enforcement mechanisms. A multi-level regulatory network integrating central coordination and local implementation can enhance policy consistency while allowing for regional flexibility. Digital technologies such as big data, artificial intelligence, and blockchain can further improve monitoring accuracy, reduce information asymmetry, and enhance regulatory credibility.

4.2. Managerial Implications

From a managerial perspective, SMEs should prioritize internal green culture development and sustained investment in green technological innovation. Embedding environmental values into organizational routines and fostering employee engagement can facilitate long-term behavioral change. Strategic collaboration with supply chain partners can further enhance resource sharing, joint R&D, and collective emission reduction. Leading firms play a critical role in driving supply chain-wide green upgrading. Through technological support, financial empowerment, and knowledge sharing, core enterprises can reduce SMEs' transformation barriers and promote coordinated green governance. By disseminating best practices and facilitating collaborative innovation, leading firms can strengthen the resilience and sustainability of the entire supply chain.

5. Summary

This study significantly advances the academic discourse on green innovation by developing a unified governance framework that systematically integrates diversified environmental regulatory instruments, including command-and-control regulations, market-based mechanisms, and voluntary initiatives. Unlike prior research focusing on isolated regulatory tools or single-agent interactions, this study adopts a multi-level governance perspective to analyze strategic interdependencies among governments, enterprises, and the public. Through game-theoretic modeling and empirical analysis of panel data from 32 OECD countries spanning 2000–2020, it reveals how aligned regulatory incentives foster collaborative innovation ecosystems, addressing collective action dilemmas in environmental governance.

The theoretical framework posits that governments act as both rule-setters and facilitators, balancing regulatory stringency with flexibility to incentivize firms' R&D investments in green technologies. Enterprises dynamically respond to regulatory signals by reallocating resources toward sustainable production, particularly when public demand for eco-friendly products and civic engagement in policy advocacy reinforce market incentives. The study identifies threshold effects in regulatory intensity: moderate, predictable policies outperform rigid or volatile ones in stimulating long-term innovation, as firms require stability to justify high-risk investments. It further highlights the complementary role of non-regulatory instruments, such as public-private partnerships, in reducing information asymmetries and accelerating technology diffusion.

Empirical results confirm that jurisdictions adopting integrated regulatory portfolios—combining carbon pricing with R&D subsidies and industry-specific standards—experience a 12–15% higher rate of green patent filings in manufacturing compared to those using isolated measures. Cross-country heterogeneity analysis reveals that institutional context shapes policy effectiveness: in countries with strong property rights and skilled labor, market-based instruments

drive stronger innovation, while in developing economies, command-and-control regulations paired with technical assistance yield greater compliance and technological uptake.

These findings offer critical implications for policymakers and corporate leaders. Governments are advised to design adaptive regulatory frameworks incorporating feedback loops from enterprise innovation outcomes and public sentiment, ensuring alignment with technological trajectories. Enterprises receive guidance on strategic sustainability transitions, emphasizing proactive engagement with regulators and co-creation of industry standards to mitigate regulatory risks. By bridging theoretical gaps in governance literature and providing actionable insights, this research supports the dual objectives of ecological preservation and industrial competitiveness, fostering coordinated, inclusive, and resilient green development globally.

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