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# Environmental regulation and corporate green innovation performance: A study on the relationship between technological innovation and green innovation performance

Lan Wang[1,2], Tuan Zainun Tuan Mat[1*], Azizah Abdullah[1]
[1]Faculty of Accountancy, Universiti Teknologi MARA, Puncak Alam, Selangor 42300, Malaysia; wanglan2009@hotmail.com (L.W.) tuanz693@uitm.edu.my (T.Z.T.M.) aziza588@uitm.edu.my (A.A.)
[2]Faculty of Accountancy, Tianjin University of Finance and Economics Pearl River College, Tianjin 301811, China.

**Abstract:** Green innovation is the key to achieving a win-win situation between economic development and environmental protection, involving areas such as energy conservation, resource recycling, and pollution control. It helps reduce environmental costs for enterprises, enhance competitiveness, and promote industrial upgrading. Studying the impact of environmental regulations on green innovation in enterprises is of great significance for reality. This article delves into the relationship between technological innovation and corporate green innovation performance under the background of environmental regulation. By reviewing relevant literature on Scopus, Web of Science, ScienceDirect, SpringerLink, Wiley, and SAGE, it elucidates the internal mechanism by which technological innovation promotes the improvement of green innovation performance, analyzes the moderating effect of environmental regulation on the relationship between the two, and looks forward to future research directions, aiming to provide theoretical references for enterprises to achieve green innovation development under environmental regulation. In the face of constantly changing market and competitive environments, technological innovation helps enterprises enhance their dynamic capabilities, enabling them to quickly adapt to environmental changes, seize opportunities for green innovation, and thereby improve green innovation performance.

***Keywords:*** *Environmental regulation, Green Innovation, Performance, Technological innovation.*

## 1. Introduction

In recent years, green innovation has become a hot research topic in the academic community, and related literature has gradually become abundant. In the concept of green innovation, it is defined as three categories: the first category considers green innovation as an innovative behavior that reduces environmental and ecological hazards; The second type describes green innovation as measures to improve the performance of environmental and ecological protection activities by introducing innovative mechanisms; The third category defines green innovation as an innovation that conforms to the trend of environmental improvement. Wang and Zhao [1] believe that green innovation is an innovative activity that significantly reduces the negative impact on the environment and brings valuable products and processes to customers and enterprises. It is a dynamic process, and green innovation has a herd effect, which can accelerate the green development of enterprises and enhance their industry competitiveness and green innovation capabilities. Many scholars equate green innovation with environmental innovation, ecological innovation, green technology innovation, sustainable development innovation, etc. They are essentially emphasizing the importance of the environment, but with different focuses. Environmental innovation focuses on environmental protection and pollution control, ecological innovation involves ecosystem protection, green technology innovation


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* Correspondence: tuanz693@uitm.edu.my

emphasizes the technical aspect, and sustainable development innovation covers economic and social dimensions [2-4].

Enterprises engaging in green innovation can enhance their green innovation performance and improve their competitive advantage. Scholars have gradually shifted from studying green innovation to linking it with green innovation performance, and their definitions of green innovation performance are also different. From the perspective of the green innovation process, Cheng [5] stated that green innovation performance is the presentation of the joint effects of green innovation within the internal organization and external environment of the enterprise. Green innovation performance is the result of green innovation, which can be used to measure the effectiveness of green innovation in the economic, environmental, and social aspects of enterprises. In addition, the performance of green innovation is closely linked to the sustainable development strategy of enterprises. High green innovation performance means that enterprises not only achieve economic goals, but also better fulfill their social responsibilities, contribute to the protection and improvement of the ecological environment, and promote the steady progress of enterprises on the coordinated development path of economy, society, and environment, forming a virtuous cycle [6].

In the early stages of implementation, environmental regulations often bring a series of challenges to enterprises, mainly manifested in additional compliance costs, including capital costs that enterprises must invest to meet environmental regulations, operating costs, and indirect costs caused by possible production interruptions or slowdowns. These costs may have a negative impact on the economic performance of enterprises in the short term, especially for those lacking sufficient funds and technical support to make rapid adjustments [7-9]. However, with the continuous and strengthening of environmental regulations, companies are gradually realizing that simply passively responding to regulations is not a long-term solution. In this context, technological innovation has become a key way for enterprises to respond to environmental regulations and achieve sustainable development [10-12]. Through technological innovation, enterprises can find more cost-effective emission reduction solutions and reduce the economic burden brought by environmental upgrades. In addition, technological progress has improved the efficiency of resource utilization, reduced waste in the production process, and enhanced overall production efficiency. Therefore, by researching and applying green technologies, enterprises can not only effectively reduce the cost of complying with environmental standards, but also improve their market competitiveness and environmental performance.

## 2. Environmental Regulation

Environmental regulation forms an institutional context. According to institutional theory, changes in institutions prompt enterprises to adjust their management processes, organizational structures, and technological innovations. Environmental regulation, fundamentally speaking, refers to the restrictions and management imposed by the government on the activities of enterprises and individuals in the production and consumption processes in order to protect the environment. This includes setting emission standards, limiting energy consumption, promoting green technologies, and other aspects.

From an economic perspective, environmental regulation is seen as an intervention in market mechanisms aimed at correcting market failures caused by environmental externalities and promoting economic development towards a more sustainable direction. China has shown a unique path in implementing environmental regulations.

On the one hand, the government strengthens environmental supervision and promotes the optimization and upgrading of industrial structure by formulating strict emission standards and energy efficiency standards. For example, for traditional industries with high pollution and energy consumption, such as steel, cement, chemical industry, etc., the government has implemented stricter environmental emission standards, promoting the green transformation of these industries.

On the other hand, the government strongly supports the research and application of green technologies, such as new energy vehicles, solar energy, wind energy, etc., and encourages enterprises to invest in the research and marketization of green technologies through financial subsidies, tax

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reductions, and other measures. The impact of environmental regulations on China's green economic growth is multifaceted. Porter and vanDerLinde [13] pointed out that appropriate environmental regulation can stimulate innovation, prompting enterprises to pursue environmental protection while improving production efffciency, reducing long-term operational costs, and enhancing market competitiveness. Speciffcally, government regulation signiffcantly drives substantial innovation and limits symbolic green behaviors aimed at attracting investment [14, 15]. The pursuit of "dual carbon" goals implies that enterprises will consistently implement pollution reduction strategies. Zhou, et al. [16] point out that enterprises capable of transforming pressure from environmental regulations into motivation will engage in more green innovation. Additionally, in the long run, companies tend to replace traditional pollution control methods with green innovation and gain a competitive edge in the market through green R&D, leading to profft growth.

## 3. The Influencing Factors of Green Innovation Performance

Domestic and foreign scholars have conducted extensive research on the influencing factors of green innovation performance from different perspectives both inside and outside the enterprise. The external influencing factors of enterprises are mainly divided into government level and stakeholder level. From a government perspective, factors such as environmental regulations, government subsidies, talent policy support, and innovation policy incentives mainly affect the green innovation performance of enterprises. Zhao [17] used China Aluminum as a case study and found that with the development of green innovation in enterprises, environmental regulations have a significant promoting effect on green innovation performance. In addition, government subsidies and talent policy support can promote the green innovation performance of enterprises [18, 19]. However, the impact on green innovation performance is not always a promoting effect. Wang [20] found that innovation policy incentives can significantly improve the green innovation performance of circulation enterprises. This promoting effect gradually weakens with the increase of innovation policy incentives and exhibits non-linear characteristics. Wang and Li [21] found that the positive impact of the digital economy on green innovation performance exhibits a non-linear feature of marginal increase with the improvement of technology absorption capacity. From the perspective of stakeholders, Kumar, et al. [22] found through modeling that stakeholder pressure promotes green innovation activities and improves corporate performance by influencing a company's green dynamic capabilities. Han and Gan [23] found that investors' attention can reduce information asymmetry and alleviate financing constraints, thereby enhancing the R&D drive of enterprises and improving their green innovation performance, and there is industry heterogeneity. Starting from internal factors of enterprises, scholars have found that organizational capacity, executive environmental awareness, R&D investment, and environmental investment all have a promoting effect on the green innovation performance of enterprises. From a personnel perspective, Kesidou and Demirel [24] found that organizational capabilities related to environmental management systems have a positive impact on green innovation. Pan and Tian [25] studied the impact of internal organizational green environmental awareness on corporate green innovation performance and found that organizational environmental awareness has a promoting effect on corporate green innovation, but the promoting effect is weakened when facing external environmental shocks and internal governance issues. Shi [26] conducted a study on the relationship between environmental regulations and corporate green innovation performance based on relevant data of manufacturing listed companies from 2014 to 2023 The research results indicate that, on the one hand, there is a U-shaped relationship between command based and market-oriented environmental regulations and corporate green innovation performance. The impact of command based environmental regulations is manifested as "first suppression and then promotion", while the impact of market-oriented environmental regulations is manifested as "first promotion and then suppression"; On the other hand, both command and market environmental regulations can have an impact on the green innovation performance of enterprises through technological innovation It is suggested to balance command based and market-oriented environmental regulations while further enhancing technological innovation

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support, and more effectively promoting green innovation for enterprises in the face of environmental regulations. This will not only enhance their competitiveness, but also contribute to environmental protection and sustainable development, achieving a win-win situation for both the economy and the environment [27] explored the mediating effect of green innovation on the relationship between environmental regulation and corporate performance, as well as the moderating effect of government technology funding on the relationship between environmental regulation and green innovation. Using panel data from 30 provinces in China from 2009 to 2017 as samples, the mediating and moderating effect models were used for analysis Research has shown that command based and market-oriented environmental regulations not only have a direct incentive effect on corporate performance, but also indirectly improve corporate performance through green product innovation and green process innovation; Government technology funding can enhance the incentive effect of command based and market-oriented environmental regulations on green product innovation, but it has a negative moderating effect on the relationship between command based environmental regulations and green process innovation, and a less significant positive moderating effect on the relationship between market-oriented environmental regulations and green process innovation On this basis, strategic suggestions were proposed to moderately strengthen command based environmental regulations, gradually increase the scope and intensity of environmental tax collection, implement differentiated environmental tax rates, fully leverage the synergistic effect of environmental regulations and government technology funding policies, and shift government technology funding towards green process innovation

In terms of executive characteristics, Liang, et al. [28] used manufacturing companies as samples and found that high levels of environmental awareness among executives can motivate companies to fully utilize their dynamic capabilities, thereby promoting the improvement of green innovation performance. In terms of corporate investment, Yu [29] found that Baosteel's R&D investment and environmental protection investment have varying degrees of positive effects on the three indicators of green innovation performance (green innovation economic performance, social performance, and environmental performance). In addition, Jiang and Yao [30] found that organizational capital can help enhance a company's green innovation capability, thereby improving its sustainable development performance. Moreover, investors' attention to the company will enhance the promoting effect of organizational capital on green innovation, while environmental regulations will weaken this promoting effect.

## 4. Evaluation Index System for Green Innovation Performance

According to the relevant literature on the evaluation index system of green innovation performance, it can be seen that due to the lack of a clear conceptual definition of green innovation performance, the selection of indicators has also shown diversity. Scholars have selected indicators based on the triple bottom line theory to evaluate green innovation performance in three aspects: economic performance, environmental performance, and social performance (EES) [31-35]. In previous studies, economic performance indicators often selected production equipment renovation rate, sales growth rate, market share growth rate, etc; Environmental performance indicators include the reduction rate of three wastes emissions, energy consumption per unit of output value, and material utilization rate; Social performance indicators include overall labor productivity, number of green suppliers, and number of green patent applications. Scholars have evaluated the green innovation effectiveness of manufacturing enterprises based on the theory of product lifecycle, using green research and development performance, green manufacturing performance, green marketing performance, and green service performance. Green R&D performance indicators often include R&D funding intensity, proportion of green new products, and proportion of R&D personnel; Green manufacturing performance indicators include energy consumption reduction rate, pollutant emissions, pollutant treatment, and material recycling rate for individual products; Green marketing performance selection includes green sales capability, green marketing efficiency, etc; Green service performance includes product recycling and remanufacturing rate, revenue from green service products, number of green service talents, and

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revenue from green technology services. Some scholars have established an evaluation index system from the perspective of input and output, and applied it to case studies to measure the green innovation performance of enterprises, which can more intuitively feel the changes and effects brought by green innovation of enterprises. In terms of investment, funding, government subsidies, and the number of scientific researchers are commonly used indicators; In terms of output, the number of green patent applications, the number of green patent authorizations, and the annual sales value of environmentally friendly products are all indicators that can be used [36].

*4.1. Theory of Technological Innovation*

The origin of the theory of technological innovation can be traced back to the early 20th century. Schumpeter [37] an Austrian American economist, first systematically proposed the theory of innovation in his work "Economic Development Theory" in 1912. The proposal of this theory was like a brilliant new star, causing a huge sensation in the economic community and laying a solid foundation for the development of subsequent technological innovation theories. Schumpeter believed that "innovation" is "establishing a new production function", which means combining production factors and conditions in an unprecedented way and introducing them into the production system. This new combination covers five important aspects: first, product innovation, that is, creating new products that consumers are not yet aware of; The second is technological innovation, adopting production methods that are not actually known in the industry sector; The third is market innovation, opening up markets that the country and specific industrial sectors have not yet entered; Fourth, material innovation, obtaining new sources of supply for raw materials or semi-finished products; The fifth is to innovate organizational management and implement a new form of enterprise organization. In Schumpeter's view, innovation is not just a simple technological invention, but a dynamic process of introducing invention into production practice, thereby having a transformative impact on the existing production system, and is the core force driving economic development. He emphasized that innovation is the endogenous driving force of economic development, and entrepreneurs play a key role in the innovation process. They are brave enough to break tradition and try new combinations of production factors, thereby promoting economic development and change [38-40].

The Impact Mechanism of Technological Innovation on Green Innovation Performance

*4.2. Technological Innovation Investment and Green Innovation Performance*

The key role of R&D investment R&D investment is the foundation for enterprises to carry out technological innovation activities and plays a crucial role in improving green innovation performance. Adequate R&D funding can provide necessary material support for the green technology research and development of enterprises, enabling them to purchase advanced R&D equipment and introduce cutting-edge technological information, thereby laying a solid material foundation for green technology innovation. A large amount of R&D investment can also support enterprises to carry out large-scale R&D projects, conduct in-depth technological exploration and innovative practices.

Huawei, as a globally renowned technology company, can be regarded as a model in terms of research and development investment. Over the past decade, Huawei has invested an average of more than 15% of its annual revenue in research and development. The sustained high-intensity R&D investment has enabled Huawei to achieve numerous breakthroughs in fields such as communication technology and 5G technology. In terms of green technology innovation, Huawei actively responds to the global trend of carbon neutrality and invests a large amount of funds in green technology research and development. In order to adapt to the global trend of carbon neutrality, Huawei released the Green Development Solution at the World Mobile Congress, which is a set of indicators for building networks around green development, taking into account both high energy efficiency and ultra-low energy consumption scenarios, including a three-layer systematic solution for site, network, and operation construction. This achievement is inseparable from Huawei's huge investment in research and development funds. Through continuous R&D investment, Huawei has not only enhanced its

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technological strength, but also provided customers with more environmentally friendly and efficient communication solutions, effectively improving green innovation performance and enhancing market competitiveness.

R&D investment can also attract and retain excellent R&D talents. In the era of knowledge economy, talent is the core resource for enterprise innovation, and a good R&D investment environment can provide better development space and salary guarantee for talents, thereby attracting more outstanding talents to join the R&D team of enterprises. These high-quality R&D talents can bring new technological concepts, innovative thinking, and professional skills to enterprises, promoting the continuous development of green technology innovation in enterprises. R&D investment can also be used to carry out talent training and academic exchange activities, enhance the professional competence and innovation ability of R&D personnel, and further promote the development of green technology innovation.

### *4.3. The Core Values of R&D personnel*

R&D personnel are at the core of green technology innovation and play a decisive role in improving the performance of green innovation. R&D personnel are the direct drivers of green technology innovation in enterprises. With their professional knowledge, keen insight, and excellent innovation capabilities, they are able to capture cutting-edge information and market demand in the field of green technology, and propose innovative R&D ideas and solutions. R&D personnel can also use advanced technological means and methods in the R&D process to solve various technical problems encountered in the process of green technology innovation, and promote the continuous breakthrough and innovation of green technology.

As a globally leading new energy innovation technology company, CATL's R&D team has played a key role in the company's green technology innovation. The R&D team of CATL has gathered numerous professionals from different fields, including materials science, electrochemistry, engineering technology, etc. They possess solid professional knowledge and rich practical experience. In terms of battery technology research and development, the R&D team continuously explores new materials and processes, committed to improving battery energy density, reducing costs, and extending lifespan to meet the market's demand for green energy. After years of effort, CATL has achieved significant results in power battery and energy storage battery technology. Its power battery usage has ranked first in the world for seven consecutive years, and its shipment volume in the energy storage field has also ranked first in the world for three consecutive years. These achievements cannot be achieved without the hard work and outstanding contributions of the R&D team.

R&D personnel can also promote knowledge sharing and technical exchange within the enterprise. In the process of green technology innovation, communication and collaboration among R&D personnel with different professional backgrounds are crucial. They can share their professional knowledge and experience through team collaboration, project discussions, and other means to achieve complementary knowledge and technological integration, thereby improving the efficiency and quality of green technology innovation. R&D personnel can also collaborate and exchange ideas with external research institutions, universities, etc., to obtain the latest scientific research achievements and technical information, injecting new vitality into the green technology innovation of enterprises.

### *4.4. Technological Innovation Output and Green Innovation Performance*

The embodiment of patents and intellectual property rights Patents and intellectual property are important manifestations of technological innovation output and play a crucial role in the green innovation performance of enterprises. Taking Apple as an example, its remarkable achievements in green technology patents fully demonstrate the positive impact of patents and intellectual property on green innovation performance.

Apple has always been committed to green technology innovation, actively conducting research and development in multiple green technology fields such as energy efficiency, material sustainability, and

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waste reduction, and has achieved fruitful patent results. In terms of energy efficiency, Apple's intelligent energy-saving technology enables devices to automatically adjust power consumption based on usage, effectively reducing energy consumption. In the field of material sustainability, Apple is committed to developing recyclable and environmentally friendly materials to reduce its impact on the environment. Through continuous research and development investment, Apple has obtained a series of related patents, which are not only a powerful proof of Apple's technological innovation capabilities, but also an important support for improving its green innovation performance.

Apple's green technology patents have improved its green innovation performance in multiple ways. From the perspective of environmental performance, the application of these patented technologies effectively reduces energy consumption and environmental pollution in the production, use, and recycling processes of Apple products. In the production process, environmentally friendly materials and energy-saving technologies are used to reduce carbon emissions and pollutant emissions during the production process; During the product usage phase, intelligent energy-saving technology reduces equipment energy consumption, decreases energy demand, and greenhouse gas emissions; In the product recycling process, the application of recyclable materials has improved the resource recycling utilization rate and reduced the generation of waste.

### *4.5. The Contribution of New Products and New Processes*

New products and processes are important forms of technological innovation output, and have an undeniable contribution to improving the green innovation performance of enterprises. Taking Haier's innovative practice in the field of green home appliances as an example, it can be clearly seen that new products and processes play a significant role in improving the green innovation performance of enterprises.

Haier has always regarded green innovation as an important strategic direction for enterprise development, continuously increasing research and development investment in the field of green home appliances, and launching a series of innovative new products and processes for green home appliances. In terms of new products, Haier's intelligent energy-saving refrigerator adopts advanced frequency conversion technology and intelligent temperature control system, which can automatically adjust the cooling power and temperature according to the quantity and frequency of use of items in the refrigerator, achieve precise temperature control, and effectively reduce energy consumption. The energy consumption of this refrigerator is reduced by more than 30% compared to traditional refrigerators, meeting the national first level energy efficiency standard. Haier has also launched air conditioning products with self-cleaning function, which use special antibacterial materials and self-cleaning technology to automatically clean the evaporator and filter inside the air conditioner, effectively removing bacteria and dust, keeping the air fresh, reducing the frequency of users cleaning the air conditioner, improving convenience of use, and also reducing energy waste and environmental pollution caused by untimely cleaning.

## 5. Conclusions

The performance of green innovation is influenced by multiple external and internal factors of enterprises. Research on external factors mainly focuses on the government level and stakeholder level. The former mainly involves environmental regulations, innovation policy incentives, government subsidies, talent policy support, etc., while the latter mainly involves stakeholder pressure, investor attention pressure, etc. The research on internal factors mainly focuses on personnel, executive characteristics, and corporate R&D and environmental investment.

The performance evaluation index system for green innovation is diversified. There are currently three main types: firstly, from the perspective of Economic Environmental Social (EES), they are divided into three categories: economic performance, environmental performance, and social performance; Secondly, from the perspective of input and output, it can reflect the efficiency of green innovation in enterprises; Thirdly, from the perspective of innovation process, based on the theory of

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product lifecycle, the entire chain from research and development to production and sales is comprehensively measured, which can be divided into four categories: green R&D performance, green manufacturing performance, green marketing performance, and green service performance. It is necessary to comprehensively consider factors such as industry characteristics, enterprise nature, research objectives, etc., and select a suitable green innovation performance evaluation index system.

From a theoretical perspective, technological innovation has a significant positive impact on the green innovation performance of enterprises, which is strongly supported by resource-based theory, organizational learning theory, and dynamic capability theory. Technological innovation can bring unique resource advantages to enterprises, providing a solid material foundation for improving green innovation performance by acquiring scarce resources such as new technological knowledge and patented technologies; In the process of technological innovation, enterprises continuously learn new knowledge and experience, enhance their innovation and organizational capabilities, and better carry out green innovation activities to improve green innovation performance; In the face of constantly changing market and competitive environments, technological innovation helps enterprises enhance their dynamic capabilities, enabling them to quickly adapt to environmental changes, seize opportunities for green innovation, and thereby improve green innovation performance.

## Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

## Copyright:



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