

INSTITUTIONAL DRIVERS ON CORPORATE ECOLOGICAL INNOVATION: EVIDENCE FROM LISTED COMPANIES IN SHANGHAI AND SHENZHEN OF CHINA

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Abstract

The main objective of this study is to identify the impact of government-enterprise relationships on corporate eco-innovation. This study analyses the secondary data using a two-way stationary panel model and the study sample with all listed companies are from Shanghai and Shenzhen, China. This paper argues that the government-enterprise relationship consists of informal and formal systems. The proxy variable in this paper for the informal system is the percentage of directors on the board with governmental backgrounds and that for the formal system is the nature of the enterprise. The results show that the informal system facilitates corporate eco-innovation, i.e., as the proportion of government directors on the board increases, corporate eco-innovation also increases. Similarly, formal institution promotes corporate eco-innovation, i.e., as firms become more nationalized, corporate eco-innovation increases. The government policies' support and supervisory ability directly affect the eco-innovation behaviour of enterprises. By formulating innovation policies and establishing innovation systems, the government can stimulate the innovation vitality of enterprises and promote the emergence of eco-technologies and products, which is crucial to enterprise eco-innovation. This in-depth study of the impact of government-enterprise relationships on enterprise eco-innovation provides the government and enterprises with a scientific basis for decision-making and promotes the practical implementation and furtherance of eco-innovation.

Keywords: Eco-Innovation, Formal Institution, Informal Institution, Listed Companies.

INTRODUCTION

Ecological Innovation (EI) theory is an effective theory to solve the problem of a low-carbon economy using technological innovation (Abid et al., 2024). At present, some domestic scholars have begun to introduce and study the concept and theory of ecological innovation. However, the current understanding of the concept of ecological innovation is not systematic enough, the research methods are limited, and a comprehensive, systematic and recognized research system of ecological innovation has not been formed (Yin & Yu, 2022). Based on the in-depth study of a large number of foreign literature on ecological innovation theory and methods, this paper summarizes the foreign ecological innovation theory, methods and development status, and anticipates the future development direction of ecological innovation theory.

Comparing the enterprise innovation ecosystem with the natural ecosystem, the research believes that the enterprise ecosystem is a dynamic system that can adjust resources and realize certain functions through its factors. Through sorting out the concepts of enterprise innovation ecosystem from different perspectives, the research identifies that some core enterprises are the center of the whole ecosystem. These core enterprises provide various platforms and resources for the internal, enabling the enterprise system to operate in a healthy and orderly way.

The socialist attribute of China is rare in the world, so the research on the relative relationship between government and enterprise is of great significance and representativeness. Enterprise ecological technology innovation is a comprehensive and systematic engineering(Chen, 2023).To make the enterprise become the main driver of ecological technology innovation, it is not enough to focus solely on the enterprise to strengthen the construction of the internal environment, the strong support of the external environment of EI is also needed.From the perspective of the external and internal environment construction of enterprise ecological technology innovation, this paper analyzes the existing role of the Chinese government in constructing enterprise technological innovation environment and examines the relationship between government and enterprise in promoting enterprise ecological innovation.

At present, the legal institution of ecological protection and implementation mechanisms are imperfect(Liu et al., 2022). The informal institution is still playing an important role in people's economic and social life, but the lack of informal institution's supply of ecological civilization hinders its smooth construction of ecological civilization(Shuliang Zhao et al., 2023). In view of this, the study of the informal institution of China's ecological civilization construction is of great theoretical value and practical significance for promoting the development of China's ecological civilization construction and strengthening the arrangement and innovation of the informal institution of ecological civilization construction. Based on the analysis of the connotation, characteristics and functions of the informal institution, this paper proposes the arrangement for the construction of ecological civilization, discusses the dual influence of informal institution on it and explains the mechanism impact. This paper analyses the effects and laws of informal institution on ecological civilization construction, revealing the threshold related to human capital level and economic development levels. It also compares and analyzes the threshold effects of formal and informal institutions on ecological civilization construction and further discusses the impact of the cross-effect on the threshold. This paper aims to comprehensively and deeply reveal the effects and rules of the informal institution on ecological civilization construction.

In general, the research on the driving factors of eco-innovation strategy mainly focuses on the institutional, organizational, and behavioral decision-making perspectives(Rodríguez-Rebés et al., 2024). To sum up, the research has examined the impact of single perspectives such as institutional environment, organizational resources and capabilities, and corporate environmental awareness on green innovation strategy have also been developed to a certain extent.However, researches on how to promote new ventures to choose green innovation strategies based on the combination of multiple influencing factors still need to be further explored. A more systematic and comprehensive approach is needed to analyze the driving antecedents of green innovation strategy for new ventures.

China, as one of the few socialist countries in the world, is the focus country of this study. This paper examines whether the relationship between government and enterprise has an impact on the ecological innovation of enterprises. The influence path of the ecological innovation of Chinese enterprises under both formal and informal systems is identified in this study. Innovation is a highly attractive concept. First, China's ecological environment is deteriorating rapidly, and there has been no

prior study on the impact of government-enterprise relationships on ecological innovation, making this paper of groundbreaking significance. Second, the government-enterprise relationship is crucial in China. Thirdly, this paper establishes a path model to illustrate how this relationship affects the ecological innovation of Chinese enterprises.

The purpose of this study is to discuss and comprehensively understand the influence mechanism of the government-enterprise relationship on enterprise ecological innovation, and provide scientific reference and suggestions for the government and enterprises to promote sustainable development in the ecological field.

LITERATURE REVIEW

Theoretical approach

In order to solve the contradiction between environment and economy, General Secretary Xi has emphasized the strictest ecological environment protection system since the 19th National Congress of the Communist Party of China, and has strengthened the legal responsibilities of polluters (Zhu & Peng, 2022). In addition, due to the public goods attribute of ecological environment, few enterprises can realize their social responsibilities (Haisen Wang et al., 2022). While the formal legal system is still sound, some informal institutions cannot be ignored for restraining the damage to the environment. Paying close attention to China's cultural background, customs and habits can also effectively alleviate the destruction of ecological environment and play a complementary and promoting role in laws and regulations (Tang et al., 2024). Since the 1980s, the ecologicalization of technological innovation has been highly valued all over the world, and western developed countries have taken the lead in developing and promoting ecological technological innovation solidly (Zhu, 2022). For example, in 2011, the European Commission promulgated the Ecological Innovation Action Plan, aiming at accelerating the ecological innovation process among member countries and promoting various innovative technologies to enter the market, thus improving resource utilization efficiency and protecting the environment (Zou et al., 2024). [11] In this chapter, to enhance research and analysis, the literature review section is divided into statistical and relevant theories.

This study searches articles with terms such as "formal system", "informal system" and "ecological innovation" in their titles and abstracts. When conducting the survey, this study focuses on two inclusion criteria. First of all, this study only selects those articles specifically related to ecological innovation. Secondly, this study only selects those articles whose applications explicitly recognize at least one general theory. In order to confirm whether the articles involve ecological innovation or apply theoretical perspectives, this study examines the main bodies of the papers to ensure that they are properly classified and coded.

The panel data model is generally categorized into three types: the mixed-effects model, the fixed-effects model, and the random-effects model (Houghton & Kapatsinski, 2023). Panel data models are commonly used analytical methods in economics and statistics for studying data observed across multiple time periods and entities (Sun et al., 2023). In panel data models, the entities under observation can be individuals, companies, or regions, etc., while time can be either continuous or discrete. The three main types of panel data models are as follows:

Mixed Model: The mixed model combines the characteristics of both the fixed-effects model and the random-effects model (Kasper et al., 2021). It allows for the consideration of both fixed effects and random effects among entities, enabling the modeling of heterogeneity among individuals.

Fixed Effects Model: The fixed effects model assumes that the heterogeneity among entities is constant and unchanging, and the differences among entities can be represented by introducing dummy variables (Hamed et al., 2023). In this way, the model can control for inter-entity differences and focus solely on the variations within entities.

Random Effects Model: The random effects model assumes that the heterogeneity among entities is random, and the differences among entities can be expressed by introducing random terms (Song et al., 2022). Consequently, the inter-entity differences in the model are treated as random errors, allowing for the examination of variations within and between entities.

In the research, in addition to utilizing model indicators, the control variable factors are also fully considered. Control variables refer to factors outside the main regression influence that can significantly affect the explained variable (ecological innovation) (Li et al., 2022). In the econometric model, the bidirectional fixed panel regression model is improved by controlling variables to obtain more reliable research results. By combining relevant literature, this paper finally puts forward five control variables (N. Zhang et al., 2023).

With the rapid development of institutional economics, the term "institution" becomes increasingly widespread in social sciences (Dieleman et al., 2022). As early as 1990, North recognized the importance of institutions, pioneering the definition of "institutions" as "rules of the game for a society." (North, 1990) In recent years, the definition of "system" has evolved further, Xue et al. (2024) pointed out that a "system" is the process of regulating human behavior through the formulation of management rules and conventions, with shared beliefs and values, and contains a series of dynamic games and operational balances in forming social order. The formation of "system" reduces transaction costs, solves the problem of information asymmetry, and encourages certain behaviors of group members or outsiders, thus effectively promoting social and economic development (Bridoux & Stoelhorst, 2022). "Institutions" are usually divided into formal institutions and informal institutions, where formal institutions are derived from the slow transformation and the "evolution" of informal institutions (Dau et al., 2022).

A good formal institutional environment can effectively mitigate the information asymmetry between enterprises and reduce the opportunistic risks that cooperation and transactions may face, which has a significant impact on the survival and development of enterprises (Wang et al., 2024). More and more scholars have realized the importance of the formal system and clearly defined it from different perspectives. From the economics perspective, North (1990) believes that formal institutions are a series of policies and regulations consciously created by people. Zhang (2022) define formal institutions as rules that can be easily observed through written documents or established and enforced through formal status (such as power or ownership), including explicit incentives, contractual terms, and corporate boundaries defined by equity status. From the comparative perspective of different types of systems, Yifu

and Wang (2022) believes that the formal system is dominated by public managers such as governments at all levels, and changes can only be made by obtaining the permission of managers and implementing specific procedural processes. From the perspective of social development, Yin (2024) believe that the formal system comprises the law, regulation, and system related to the economic foundation and superstructure. From the institutional and entrepreneurial perspective, Su believes that formal institutions are designed by the government and other institutions, with the state as the center, and ensure their effective implementation through the authority of the government (Chen et al., 2024).

To sum up, by summarizing the definitions of formal institutions proposed by scholars from different perspectives, it can be found that although the definitions of formal institutions vary slightly due to different perspectives, they have common characteristics: codification, consciousness and state mandatory guarantee. Formal institutions have an important impact on the shaping of social, economic and legal framework and the regulation of business order (Lee et al., 2022).

An informal institution includes values, customs, cultural traditions and religious beliefs, which is a conventional and abiding code of conduct gradually formed through long-term social interaction process and recognized by the society (Xu et al., 2024). China's 5,000-year-old culture is profound and has a long history, which shows that Chinese people have been deeply influenced by traditional culture and values since ancient times, and has influenced and shaped the unique behavioral principles and habits of the Chinese people (Nie, 2022). Therefore, an informal institution plays an irreplaceable role in restraining people's behavior.

Many scholars have done a lot of research on external institutions to promote the coordinated development of environment and economy, seeking a deeper relationship and proposing solutions. In addition to the single guarantee provided by external system construction and macro factors, some informal institutions, such as subjective ideologies like social customs or religious customs, play an important role in the construction of ecological civilization (Zhao et al.). Even if they come from the same institutional background, their effects are not universally applicable. The customs and cultures accumulated by different countries, regions or societies over a long time jointly promote the development of social and ecological civilization. On the one hand, from the perspective of social customs, the compassion of "conscience can't pass" contained in Chinese traditional culture can regulate the environmental protection behavior of enterprises. In corporate governance, people always have an inch of morality in their hearts to measure their behavior. When they are accused by residents or the media because of damaging the local environment through corporate behavior, they will generally be condemned by their conscience and it is difficult to cross the illegal bottom line; On the other hand, from the perspective of religious culture, China is a country with land culture based on family blood relationship. For example, the relationship between people's desire for profit and morality is an ethical relationship of "a gentleman loves money and takes it properly". When enterprise managers are deeply influenced by this aspect, they will take it as a behavior constraint criterion independently, thus forming a "spiritual constraint", which urges them to measure their behavior and that of enterprises with higher value standards, so that they will take the initiative to comply laws and regulations even without constant external spur.

Generally speaking, Chinese people have the feeling of “falling leaves and returning to their roots”, which makes Chinese people have special attachment and recognition to their hometown, along with extraordinary emotional factors. In addition, since ancient times, China has had a strong sense of locality and hometown. When the environment is linked with one's hometown, it is easy to arouse the conscience of compassion deeply hidden in people's hearts. This kind of compassion complex makes people subconsciously take care of the land where they grew up. Endogenous sources of strength can also encourage corporate executives to make bottom-line concessions for the local environment above interests (Xue et al., 2022). External constraints and endogenous incentives, similar to the relationship between law and morality, complement and promote each other, which can enhance the improvement ecological innovation (Yi Zhang et al., 2023). External constraints from the system construction can standardize enterprise behavior from the top, while non-institutional factors can also promote enterprises to actively explore the balance between environmental protection and economic performance. Only when internal and external dual incentives exert their effects at the same time can everyone guarantee and realize an environmentally friendly economic society to the greatest extent, creating a beautiful vision of "Jinshan Yinshan is green water and green hills".

Hypotheses Development

In light of the theories previously presented, this section outlines the theoretical and empirical evidence from this study that supports the relationship between variables. This paper proposes three hypotheses to predict the impact of formal and informal institutions and their interaction on ecological innovation.

The formal system, as a collection of statutory rules, provides enterprises with clear guidance and frameworks, requiring the compliance with a series of environmental regulations, ecological protection laws, and other relevant legal provisions in their business operations (Singh, 2022). The existence of these legal rules prompts enterprises not only to include profit maximization in their operational objectives but also to focus on the sustainability of the ecological environment. For example, environmental protection regulations formulated at the national and local levels demand that enterprises reduce their negative impact on the environment in production and operations, directly driving innovation in product design, production processes, and waste disposal (Yu Zhang et al., 2023). The formal system shapes a proactive environmental culture within enterprises (J. Li et al., 2023). Due to legal constraints, enterprises are compelled to establish corresponding departments and processes internally to ensure the compliant management of the ecological environment. This includes establishing environmental management departments, deploying professional environmental engineers, and these institutions and personnel contribute to a better understanding and addressing environmental issues, thereby promoting ecological innovation (W. Zhang et al., 2023). The normative framework established by the formal system makes enterprises prioritize sustainability in their daily operational management, integrating environmental principles into corporate culture (Shahzad et al., 2023). The presence of the formal system encourages innovation in technology and management within enterprises. To comply with statutory rules, enterprises should continuously seek new technological means and management methods to reduce their impact on the ecological environment (Luo et al., 2023). For instance, companies may introduce more environmentally friendly

technologies and equipment in production, drive consideration of environmental factors in product design, and even optimize the supply chain to reduce resource wastage. All this is attributed to the constraints and guidance of the formal system. The formal system provides enterprises with a proactive avenue to fulfill social responsibilities(Li & Sasaki, 2023).In today's society, corporate social responsibility is no longer merely a moral requirement but a part of legal obligations. The formal system sets clear requirements for enterprises' social responsibility, including environmental responsibilities(W. Li et al., 2023). Fulfilling these responsibilities not only helps meet legal requirements but also enhances the social image of the enterprise, gaining more social recognition.Therefore, the promotion of ecological innovation by the formal system is mainly reflected in the clear provisions of laws and regulations, the construction of internal environmental cultures within enterprises, incentives for technological and management innovation, and the guidance of social responsibility. The formal system provides a clear behavioral framework for enterprises, guiding them to more actively address environmental challenges in their business activities, thus laying a solid foundation for ecological innovation.

METHODOLOGY

The rapid growth has brought increasingly serious environmental problems(Yang et al., 2023). In terms of air quality, data from China's National Environmental Protection Bureau shows that among 161 cities, only 16 at or above the prefecture level met air quality standards, accounting for 9.9 percent. Air quality exceeded the standard in 145 cities, or 90.1 percent. In terms of water quality, the results of 4,896 groundwater monitoring points showed that poor and extremely poor monitoring points accounted for 61.5%. In terms of soil, the total point position exceeding the standard rate in China is 16.1%. This indicates that the traditional extensive economy is no longer suitable for China's economic development, and there is a need to strengthen efforts in green production and technological research and development(Fang et al., 2022).This paper employs a mixed research method to explore the impact of government-enterprise relationships on ecological innovation. Firstly, by systematically reviewing and analyzing existing academic literature, government documents, corporate reports, and other materials, a comprehensive understanding of the influence of government-enterprise relationships on corporate ecological innovation is obtained. This involves grasping the interconnections between government policies, corporate behavior, and ecological innovation, clarifying influencing factors and mechanisms, and laying the theoretical foundation and research hypotheses for subsequent quantitative research. Secondly, this paper designs a quantitative research model, collects relevant data, and conducts empirical analysis primarily using a two-way fixed-effects panel model to validate the hypotheses and theoretical models proposed in this paper.In the framework of government to enterprise to ecological innovation, the influence of government on enterprises can be driven by external driving forces, such as government subsidies, environmental regulations and tax incentives, to promote enterprises to realize ecological innovation, which can also be driven by internal driving forces, such as improving enterprise performance and enhancing enterprise ecological innovation capability.In addition, the government realizes that formal institution through the property rights of enterprises can promote ecological innovation by the evolution of the nature of state-owned holding enterprises. And informal

institution can correlate between government and enterprise(Li, 2022). Improving the correlation between corporate executives and the government has a positive impact on enterprise ecological innovation(Hetong Wang et al., 2022). However, whether the above influence path is valid will be studied based on this.

Sample Selection

This paper takes listed companies in China, excluding ST and enterprises with severe data deficiency, as the object for empirical analysis, and the final sample size is expected to be 14,030. To ensure the availability of core data related to ecological innovation, this study selects a time span of nearly ten years and decides to conduct an empirical analysis based on the balance panel data from 2012 to 2021, all of which were derived from the CSMAR database.

This paper takes China's A-share listed companies as the object, namely RMB ordinary shares, which are issued by companies registered and listed in China with RMB as the par value, available for domestic institutions, organizations or individuals to subscribe and trade in RMB. The sample excludes ST listed companies, where "ST" refers to stocks listed in China that have posted losses for two consecutive years and have been warned about the risk of delisting. The data from these listed companies fluctuates greatly and lacks authenticity, which may interfere with the research conclusion, and the final sample number is 14,030.

The data in this paper are balance panel data from 2012 to 2021. This paper selects the data range from 2012 to 2021 to cover important development stages of China's economic policies. 2012 was a crucial year when the Chinese government implemented the "12th Five-Year Plan", which emphasized the development philosophy of "transforming the economic growth mode and promoting changes in economic development quality, efficiency, and driving forces." Subsequently, in 2015, China released the "13th Five-Year Plan", which clearly outlined development strategies such as 'green and low-carbon' and 'innovation-driven.' These policy directions have a positive impact on corporate ecological innovation, making this time period suitable for in-depth analysis of the influence of policies on the government-enterprise relationship and ecological innovation.[40] Additionally, a longtime span allows for a better exploration of the policies' long-term effects. Policy implementation and impact often require a certain lag period and cumulative effects. By utilizing panel data from 2012 to 2021, this study observes the long-term impact of the government-enterprise relationship on ecological innovation and gain a deeper understanding of the policy's lasting influence on corporate innovation behavior.

All the data in this paper are from CSMAR database. CSMAR is China's largest high-tech company specializing in the design and development of accurate financial information database.

Program of Sample Collection

All the data in this paper come from the CSMAR database. Firstly, the listed companies that meet the standards are screened through the CSMAR database. Then, the data uniformity of listed companies is defined, and the samples that lack uniformity are eliminated. Due to two consecutive years of operating losses of domestic listed companies, the authenticity of the financial statements of the stocks (Special treatment, referred to as ST) subject to delisting risk warning cannot be guaranteed,

and most financial indicators are abnormal, so they are also removed to obtain the final sample data.

Model Construction

The model constructed in this paper is shown in the figure. The data in this paper mainly come from the balanced panel data of CSMAR. Under the condition of certain uniformity of the data, the extreme value are removed through winsorization, and the data ranges from 1% to 99% of the original data after processing. At the same time, the data type is continuous quantitative data. Based on this, this paper adopts the two-way fixed panel regression model to analyze the influence of government-enterprise relationship on enterprise ecological innovation. In terms of endogeneity test, instrumental (explanatory) variables with one-stage lag will be used to replace the original explanatory variables for two-stage least squares (TSLS) regression analysis to solve the problem of enterprise endogeneity. In terms of robustness, the variable substitution method will be used to replace ecological innovation with R&D investment to observe the stability of panel regression model results after similar replacement of explanatory variables.

Explained Variables

Ecological innovation is a highly complex institution. There are significant differences in the concept of ecological innovation across different disciplines. For example, ecological innovation in biology refers to innovation in the biological environment (Xie, Liu, & Blanco, 2023). This paper takes enterprise eco-innovation as the core. Referring to the definition by the EU and CIP (2007), which defines eco-innovation as institutionatic innovation aimed at promoting sustainable development, such as reducing environmental impact or improving the efficiency and responsibility of resource use (including energy) throughout the entire product lifecycle, including the production, adoption or development of new products, processes, services or management and business methods, etc. [50] The main index of ecological innovation is "green patent" (Cai & Xu, 2022). Enterprises can reflect the degree of ecological innovation through the scale of green patent holdings.

To sum up, the research topic of this paper is the impact of government-enterprise relationship on enterprise ecological innovation, which is a complex issue involving many factors. Control variables are known factors that interfere with the results during the study in order to more accurately understand the influence of independent variables on dependent variables. In this study, five variables, including return on equity, free cash flow rate, shareholding ratio of the largest shareholder, proportion of independent directors and size of the board of directors, are selected as control variables, because these variables have been proved to significantly impact corporate performance and innovation ability in previous relevant studies. For example, return on equity reflects a firm's profitability, while free cash rate reflects a firm's financial stability and independent innovation ability. The shareholding ratio of the largest shareholder, the proportion of independent directors, and the size of the board of directors represent the ownership structure, corporate governance, and management scale of an enterprise, respectively, and are closely related to the enterprise's ecological innovation ability. Therefore, it is reasonable to select these five control variables, which can help eliminate other possible interfering factors and make the research results more accurate and reliable.

At the same time, selecting too many control variables will lead to multicollinearity problems, affecting the validity of research conclusions. In the research, it is necessary to avoid high correlation between control variables; otherwise, it becomes impossible to identify the degree of influence of different variables on dependent variables and it is also impossible to effectively analyze and explain different control variables. Therefore, the selection of key variables with an empirical basis and significant influence can better identify the influence of government-enterprise relationship on enterprise ecological innovation, avoid the multicollinearity problem, and grasp the research conclusions more accurately while maintaining proper quantity and correlation.

Finally, whether control variables are used more or less needs to be comprehensively considered according to specific research questions and the availability and quality of data. In order to better explain the influence of government-enterprise relationship on enterprise ecological innovation, this study selects five control variables, namely return on equity, free cash rate, shareholding ratio of the largest shareholder, proportion of independent directors and board size, and excludes other factors that may affect the research results. If other control variables are added, the complexity of the study may be increased, as well as the cost of the study and the difficulty of data collection. Therefore, this paper believes that the five control variables currently used are reasonable, and there is no need to add other control variables.

RESULTS ANALYSIS

Building upon the theoretical review and empirical research presented in Chapter 2, and in conjunction with the overview of the government-enterprise relationships and ecological innovation in Chapter 3, this chapter conducts a corresponding analysis of the mechanisms through which the government-enterprise relationships impact ecological innovation. And this chapter examines the influence of government-enterprise relationships on ecological innovation from both formal institutional and informal institutional perspectives.

This study conducts an empirical analysis focusing on Chinese listed companies, excluding ST (Special Treatment) firms and enterprises with substantial missing data. To ensure the availability of core data related to ecological innovation, we select a time span of nearly ten years. The State Council (2012) "Notice of the State Council on Issuing the Development Plan for Energy Conservation and Environmental Protection Industries in the Twelfth Five-Year Plan" signifies the beginning of China's corporate ecological innovation era. This policy points out that China's corporate-led ecological innovation system is incomplete, and it mandates that enterprises must achieve ecological innovation in both production and product aspects to reduce pollution. Therefore, this research utilizes the panel data from the CSMAR database for the period 2012 to 2021 for the empirical analysis.

Descriptive Statistical Analysis of the Overall Effect of Formal Institutions on Corporate Ecological Innovation

The researcher's results follow the objectives of (1) analysis of the overall effect of formal institutions on corporate ecological innovation, (2) analysis of the overall effect of informal institutions on corporate ecological innovation, (3) analysis of the overall effect of the impact of government-enterprise relationships on Ecological Innovation.

Descriptive statistical analysis is the process of organizing and summarizing collected data with the aim of providing an overview and description of its fundamental characteristics (Derindere Köseoğlu et al., 2022). Prior to conducting panel regression analysis, descriptive statistics aid in gaining familiarity with the basic features of the data. By computing metrics such as sample size, maximum value, minimum value, mean, and standard deviation, one can quickly grasp the data's range, central tendency, and dispersion. Furthermore, descriptive statistical analysis facilitates the detection of data anomalies and missing values. Data quality and completeness are crucial when performing panel regression analysis. Through descriptive statistical analysis, potential issues such as data outliers and missing values can be identified, thereby enabling subsequent data processing and imputation. In summary, conducting descriptive statistical analysis is an essential step in panel regression analysis. The descriptive statistical analysis for this study is presented in the following table.

Table 1: Descriptive Statistical Analysis

Variable Name	Sample Size	Maximum Value	Minimum Value	Mean	Standard Deviation
Ecological Innovation	14030	9726	0	2129.307	2802.14
Formal Institutions	14030	1	0	0.792	0.406
Informal Institutions	14030	7	0	2.384	2.383
Return on Equity (ROE)	14030	7	-0.006	2.346	2.656
Company Size	14030	1.064	-0.008	0.468	0.476
Top Shareholder's Ownership	14030	1	0.167	0.36	0.1
Proportion of Independent Directors	14030	0.5	0.333	0.373	0.049
Board Size	14030	25	7	14.315	6.182
Company Age	14030	20	6	11.262	4.194
Cash Leverage Ratio	14030	3.754	0.721	1.374	0.732

**Note: The variables 'Ecological Innovation' and 'Company Size' have been subjected to a natural logarithm transformation. 'Company Age' refers to the time elapsed from the company's listing to the observation period*

In the above table, the numerical values of 'Ecological Innovation' and 'Company Size' are relatively large, which may introduce disturbances into the panel regression model. To address this interference and meet the requirements of regression analysis, this study employs the natural logarithm transformation method. By applying the natural logarithm to the data of 'Ecological Innovation' and 'Company Size,' the data is transformed into a logarithmic form, making their distributions closer to normal distribution, reducing data skewness, and narrowing the range of data variation. Such transformation not only helps mitigate the impact of extreme values but also enhances the stability and interpretability of the regression model. Additionally, the natural logarithm transformation facilitates clearer interpretation and understanding of the relationship between 'Ecological Innovation' and 'Company Size'.

Based on the results of the descriptive statistical analysis presented in the above table, it can be observed that the data involved in the empirical analysis exhibits normal fluctuations, and the distribution and variability of the data are within reasonable bounds. This suggests that the statistical characteristics of the data are relatively stable, with no significant outliers or extreme fluctuations, indicating a certain robustness and credibility in the overall data distribution. In such circumstances, it becomes feasible to conduct further in-depth analysis of this data, exploring potential correlations, patterns, or trends within.

Descriptive Statistical Analysis of the Overall Effect of Informal Institutions on Corporate Ecological Innovation

Total Effect

Although this study demonstrates the significant role of formal institutions in influencing corporate ecological innovation, the ecological innovation behavior of enterprises is often influenced by various factors. Informal institutions, serving as the internal culture and mechanisms within enterprises, also play a crucial role in shaping corporate ecological innovation (Xie, Liu, & Chen, 2023). Exploring the relationship between informal institutions and ecological innovation allows for a more comprehensive understanding of the driving factors behind corporate ecological innovation behavior. The analysis results are presented in the following table :

Table 2: The Impact of Informal Institutions on Ecological Innovation in Enterprises

Variable	Dependent Variable: Eco-Innovation	
	(1)	(2)
Informal Institutions	415.532*** (8.201)	136.07*** (8.583)
Constant	1138.724*** (25.300)	-5.064 (168.62)
R2	0.079	0.314
F-test	2229.27***	1276.721***
Time Effects	Control	Control
Individual Effects	Control	Control
Industry Effects	Control	Control
Control Effects	No	Yes
N	14030	14030

**Note: The company is a listed company on the Shanghai and Shenzhen stock exchanges in China*

As indicated in the above table, in Model 1, the regression coefficient of informal institutions on ecological innovation is 415.532, and in Model 2, it is 136.07. This indicates a significant positive impact of informal institutions on corporate ecological innovation, and the effect is reliable. A robustness test is conducted to examine the impact of informal institutions on corporate ecological innovation, and the results are presented in the following table :

Table 3: Robustness Test of the Impact of Informal Institutions on Ecological Innovation in Enterprises

Variable	Dependent Variable:	
	Eco-Innovation	(R&D) Expenditure
	(1)	(2)
Informal Institutions	136.07*** (8.583)	0.022*** (0.001)
Constant	-5.064 (168.62)	0.244*** (0.002)
R2	0.314	0.096
F-test	1276.721***	1307.492***
Time Effects	Control	Control
Individual Effects	Control	Control
Industry Effects	Control	Control
Control Effects	Yes	Yes
N	14030	14030

**Note: The company is a listed company on the Shanghai and Shenzhen stock exchanges in China*

As shown in the above table, for ecological innovation (dependent variable 1), informal institutions have a significant impact with a regression coefficient of 136.07, and this relationship is robust (marked *** indicating the significance level). Regarding research and development (R&D) investment (dependent variable 2), informal institutions also have a significant impact with a regression coefficient of 0.022, and this relationship is robust (marked *** indicating the significance level). This implies that informal institutions have a significant positive impact on both corporate ecological innovation and R&D investment, and these relationships are robust, meaning they still hold after considering the influence of other factors.

Heterogeneity

This research also conducts a heterogeneity test on the informal system, and the results are shown in the table below.

Table 4: The Impact of Informal Institution on Corporate Ecological Innovation

Variable	Dependent Variable: Eco-Innovation		
	(1)	(2)	(3)
	Small Enterprise	Medium Enterprise	Large Enterprise
Informal Institutions	90.196*** (9.617)	117.308*** (10.215)	149.510*** (12.667)
Constant	6.193*** (1.316)	8.671*** (3.306)	5.071*** (1.089)
R2	0.287	0.371	0.302
F-test	1317.443***	1409.507***	1217.791***
Time Effects	Control	Control	Control
Individual Effects	Control	Control	Control
Industry Effects	Control	Control	Control
Control Effects	Yes	Yes	Yes
N	14030	14030	14030

**Note: The company is a listed company on the Shanghai and Shenzhen stock exchanges in China*

According to the table above, informal institutions have a significant impact on ecological innovation in small, medium, and large enterprises. However, the coefficient for small enterprises (90.196, $P < 0.01$) is weaker than that for medium enterprises (117.08, $P < 0.01$), and the coefficient for medium enterprises is weaker than that for large enterprises (149.510, $P < 0.01$). This implies that informal institutions promote ecological innovation in enterprises of different sizes. And with the increase in enterprise size, informal institutions exhibit an enhanced promoting effect on ecological innovation.

Descriptive Statistical Analysis of the Overall Effect of The Impact of Government-Enterprise Relationships on Ecological Innovation

Government-enterprise relationships mainly consist of formal and informal institutions. Therefore, as summarized above, the empirical analysis in this paper demonstrates that government-enterprise relationships play a promoting role in ecological innovation.

In terms of formal institutions, firstly, the nature of an enterprise primarily refers to the entity of the company or its affiliated departments, including administrative institutions, public-private partnerships, Sino-foreign joint ventures, foreign-funded enterprises, and collective enterprises but can be broadly categorized as state-owned enterprises and non-state-owned enterprises (Song et al., 2024). The impact of the enterprise's nature on the number of green patents is mainly attributed to the introduction of government resources and policy advantages, optimization of resource allocation, enhancement of competitive advantages and market position, government policy bias, optimization of management practices, and enhancement of innovative culture and organizational capabilities (Lian et al., 2022).

Secondly, a large number of patents in China are concentrated in the hands of a few enterprises, with most of them belonging to state-owned enterprises, while many small and medium-sized patents are held by certain private enterprises (Wei et al., 2024). However, many enterprises possess only a few hundred patents, indicating a lack of concentration in the industry. Particularly, state-owned enterprises are likely to receive more government investments and research and development funding for relevant technologies, whereas private enterprises may face challenges in accessing government resources and experiencing less prominent policy advantages. Compared to private enterprises, state-owned enterprises are more likely to benefit from policy advantages and resource allocation, leading to an elevated social status with increased government support, subsidies, funding, and the attraction of skilled personnel and technologies. For instance, the manufacturing industry is a resource-intensive sector with significant energy consumption, and during the '14th Five-Year Plan,' there is a pressing need to intensify research and development in green and environmental technologies (Dai et al., 2021). Through autonomous research and development of clean production technologies, state-owned enterprises can achieve a low-carbon transformation in manufacturing (Shuang Zhao et al., 2023). The government can also support state-owned enterprises in research and development investments in clean production and clean energy technologies (Qi et al., 2022). Subsequently, through the digestion and absorption of introduced or purchased low-carbon production technologies, enterprises are encouraged to develop more green and environmentally friendly patents (Li et al., 2021).

Thirdly, in comparison to private enterprises, state-owned enterprises hold an inviolable and irreplaceable position in China, where the basic economic system features the predominance of public ownership and the coexistence of various forms of ownership. State-owned enterprises are closely tied to the economic lifeline of the nation, assuming the responsibility of bolstering China's status as a major power and safeguarding economic security(Sheng, 2024). Furthermore, in the realm of green patent research and development, state-owned enterprises possess several advantages over their private counterparts. For instance, the government provides talent support and financial investment to state-owned enterprises, along with technical assistance for patent research and development. State-owned enterprises find it easier to attract talented personnel with technical expertise. Additionally, some special operating rights controlled by the government, such as licenses in the banking, securities, and telecommunications sectors, require administrative approval from the relevant national authorities. These special operating permits and industry qualifications not only serve as important powers held by the government but also become crucial resources for the development of state-owned enterprises. After obtaining these permits and qualifications, certain state-owned enterprises effectively transform them, through tangible or intangible markets, into special market prices, representing significant assets and unique advantages for the enterprises. For example, the tobacco industry, a typical state-owned enterprise functioning as a government-administered monopoly, possesses distinctive characteristics. However, concerning research on energy-saving and environmental protection-related green patents, the number of patents in the tobacco industry falls short of those in the manufacturing sector.

Fourth, the government, in deepening the reform of the corporate environmental supervision system, will reasonably design relevant regulatory policies(Zeng et al., 2022). Most enterprises still have relatively weak environmental awareness, especially with deficient wastewater treatment systems and limited investment in environmental and energy-saving technology research and development(Xu et al., 2022). However, state-owned enterprises show a greater emphasis on the environmental supervision system compared to private enterprises. For state-owned enterprises, the government will formulate more environmental protection laws, regulations, and industry standards to regulate them, prompting them to focus more on ecological innovation(Luo et al., 2023). This serves as a demonstrative effect, with incentives for environmental protection established through punitive measures against non-compliant behaviour. Some private enterprises contribute fewer innovations to ecological innovation, partly due to weak protection of intellectual property rights, an inadequate legal system, and limited investment in patent research and development(Cai & Xu, 2022). The government or state-owned enterprises can provide assistance, introduce funding, or offer policy support to address these issues. For instance, in the case of Huawei, a state-owned enterprise with the most patents in 5G development, the government can strengthen its environmental supervision system, encouraging it to play a demonstrative role in ecological innovation. Corporate executives refer to the top management group, including the board of directors, the board of supervisors, and senior management. This group, involved in top-level strategic decision-making, is influenced by their management knowledge, values, and backgrounds, including any government experience or connections. The characteristics of corporate executives,

influenced by the external business environment, impact strategic decision-making. Therefore, the background features of top executives are also an essential factor affecting corporate green patent innovation.

DISCUSSION AND CONCLUSION

Discussion of Research Findings

The results of the panel regression model indicate that all nine hypotheses proposed in this paper are statistically accepted. The research findings are presented in the following table:

Table 5: Hypothesis Testing Results Summary

Serial Number	Content	Results
H1	Formal institutions have a positive impact on corporate ecological innovation.	Accepted
H1A:	Formal institutions positively impact ecological innovation in large enterprises, and their influence is the strongest among all types of enterprises.	Accepted
H1B:	Formal institutions positively impact ecological innovation in medium-sized enterprises, but with a weaker influence compared to large enterprises	Accepted
H1C:	Formal institutions positively influence ecological innovation in small enterprises, but their impact is weaker compared to medium-sized enterprises.	Accepted
H2	Informal institutions have a positive impact on corporate ecological innovation.	Accepted
H2A	Informal institutions positively influence ecological innovation in large enterprises, and their impact is strongest among all types of enterprises.	Accepted
H2B	Informal institutions positively influence ecological innovation in medium-sized enterprises, but their impact is weaker compared to large enterprises.	Accepted
H2C	Informal institutions positively impact ecological innovation in small enterprises, but their influence is weaker compared to medium-sized enterprises.	Accepted
H3	Government-enterprise relationships have a positive impact on corporate ecological innovation.	Accepted

Research Conclusions

The main objective of this study is to clarify the impact of government-enterprise relationships on corporate ecological innovation. This paper posits that government-enterprise relationships consist of both informal and formal institutions. In this study, the proxy variable for informal institutions is the proportion of directors with a government background on the board of directors, while the proxy variable for formal institutions is the nature of the enterprise. The results reveal that informal institutions play a promoting role in corporate ecological innovation. Specifically, as the proportion of directors with a government background on the board increases, corporate ecological innovation also experiences a corresponding enhancement. Formal institutions also contribute to the promotion of corporate ecological innovation. As the enterprises become more state-owned, the level of corporate ecological innovation also increases correspondingly.

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