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Intellectual Property Protection and Enterprise Green Technology Innovation: Evidence from Manufacturing Industries in China

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Abstract

Based on the panel data of 1094 enterprises in 29 manufacturing industries in China from 2012 to 2022, this study explores the impact of intellectual property protection on enterprise green technology innovation and its mechanism. The study results show that intellectual property protection significantly promotes the innovation of green technology by providing legal protection, facilitating technology transfer, and promoting market cooperation. Heterogeneity analysis reveals stronger effects on non-heavily-polluting enterprises, enterprises with strong environmental consciousness, and non-high-tech enterprises. Additionally, government financial support and the green transformation of enterprises play a key role in enhancing the impact of intellectual property protection on green technology innovation. The findings offer valuable insights for policymakers to refine intellectual property protection policies and promote sustainable development.

Keywords: Intellectual Property Protection, Enterprise Green technology innovation, Manufacturing Industry, Heterogeneity analysis, Government Financial Support, Green Transformation, Schwarz's inequality, Triangle inequality.

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1. Introduction

Reducing carbon dioxide emissions, a central objective of the green economy and sustainable development, has become a critical global issue (Sun et al., 2023). China aims to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. To meet these targets, the pivotal role of Chinese enterprises in driving scientific and technological innovation is essential (Liu et al., 2023a). Enterprise green technology innovation not only provides essential technical support for the transition to a green economy but also fosters the coordinated development of resource conservation, environmental protection, and economic growth, becoming a key driver of future economic progress (Song et al., 2018; Liu et al., 2023b; Cui et al., 2023). In particular, manufacturing enterprises, as major contributors to carbon emissions, can significantly reduce emissions and improve resource efficiency through green technology innovation, thereby playing a crucial role in achieving carbon reduction targets (Dong et al., 2021; Aftab et al., 2023). However, the green technology innovation of manufacturing enterprises is often hindered by factors such as high input costs and income uncertainty, which weaken their innovation incentives (Borghesi et al., 2015; Zhang et al., 2023a). In this context, intellectual property protection (IPP), as a crucial driver of innovation, can effectively encourage enterprises to pursue green technology innovation (Song et al., 2023; Grimaldi et al., 2021).

By implementing an effective IPP mechanism, enterprises can safeguard their innovations and mitigate the risks of imitation and infringement, thereby strengthening their incentives for green technology innovation. Intellectual property rights, such as patents and trademarks, grant enterprises exclusive usage rights and the ability to capitalize on the economic returns from their innovations, which can help alleviate the high cost and long-term challenges faced in green technology innovation. In a robust IPP environment, enterprises cannot only secure the exclusivity of their technologies but also facilitate technology transfer and foster cross-industry collaboration through intellectual property mechanisms, and accelerate the promotion and application of green technologies (Khouilla and Bastidon, 2024; Zheng et al., 2023). At the same time, enterprises use patent strategies and other mechanisms to create market barriers that effectively prevent competitors from entering, thereby securing their market position and technological edge. This protection not only strengthens the firms' short-term competitiveness but also amplifies their incentive to sustain innovation in green technology (Abdin et al., 2024). In September 2021, the China Intellectual Property Office (CIPO) unveiled the "Building Intellectual Property Power (2021-2035)" plan, which aims to reinforce intellectual property protection, optimize the innovation environment, and enhance China’s standing in global technological competition. The plan places a particular focus on green technology innovation, proposing to advance the application and development of green technologies by strengthening the protection and commercialization of intellectual property rights in this sector. This initiative is designed to support China’s achievement of its "dual carbon" goals and address

climate change, thereby generating both economic and environmental benefits (Liu et al., 2024).

Building upon this foundation, this study focuses on Chinese manufacturing enterprises and examines the impact and mechanisms through which the level of provincial IPP influences green technology innovation within these enterprises, using micro-level data from 2012 to 2022. Specifically, the innovative contributions of this study are reflected in several key areas: Firstly, from a micro perspective, this study examines green technology innovation at the level of manufacturing enterprises, analyzing how IPP influences the green technology innovation efforts of these enterprises. This approach enriches the existing literature on the relationship between IPP and green technology innovation. Secondly, this study classifies the samples based on factors such as the pollution level, the strength of their environmental consciousness, and whether they are high-tech enterprises. It then conducts a heterogeneity analysis across these three dimensions to explore in depth the varying impacts of IPP on green technology innovation within enterprises of different types and characteristics. Finally, this study considers government financial support and the green transformation of enterprises as key external and internal influencing factors, respectively, and explores their roles in promoting green technology innovation within the context of IPP. By analyzing these factors, the study aims to uncover the complex mechanisms through which IPP fosters enterprise green technology innovation. This analysis will not only deepen the understanding of how IPP contributes to green innovation but also provide empirical evidence and practical recommendations for both government policymakers and business managers. The results of this study aim to provide empirical support for the green transformation and sustainable development of China's manufacturing industry and provide practical recommendations for policymakers.

2. Literature review and hypothesis proposal

2.1 Literature Review

2.1.1 Intellectual Property Protection

Intellectual property refers to the intangible assets created through the scholarly efforts of individuals, distinguishing it from physical property (Sharma et al., 2014). According to the World Intellectual Property Organization (WIPO), Intellectual property encompasses creations of the mind, including both industrial property (such as patents, trademarks, designs, and geographical indications) and copyright (covering literary, artistic, and architectural works) (Zhang et al., 2012). IPP refers to the legal measures designed to safeguard the exclusive rights of creators over their scholarly achievements, preventing unauthorized use, reproduction, or infringement of their works. Its primary objective is to foster innovation and creativity, encourage scientific and technological advancements, and strike a balance between the rights of creators and the broader public interest, thereby facilitating the dissemination and sharing of knowledge (Pan et al., 2023). In an

environment where IPP is weak, creators often lack the necessary incentives to innovate, while imitators are more likely to be encouraged to engage in excessive copying. This, in turn, hampers the sustained development of technological innovation (Martin and Barro, 1995). Consequently, establishing a robust framework for IPP is crucial to fostering ongoing innovation.

2.1.2 Green technology innovation

Green technology embodies an innovative technological development model focused on optimizing resource use, minimizing or eliminating environmental pollution, and promoting the recycling of waste and the reuse of raw materials (Takalo and Tooranloo, 2021; Li et al., 2023). Green technology innovation is an effective means of promoting economic growth while simultaneously prioritizing ecological protection. It encompasses technological and product innovations in energy conservation, environmental preservation, and resource recycling (Luo et al., 2021; Weng et al., 2015; Yu et al., 2023). This innovation model not only emphasizes technological advancement but also highlights its environmental benefits, which are fundamental drivers of sustainable development. In recent years, the key factors influencing green technology innovation have been extensively debated within the academic community. A majority of studies indicate that well-designed environmental policies can effectively encourage companies to enhance their green technology innovation capabilities, enabling them to meet increasingly stringent environmental protection standards (Wang et al., 2023; Zhang et al., 2023b). Simultaneously, the rapid growth of the digital economy has breathed new life into green technology innovation (Dian et al., 2024). This development not only enhances production efficiency and resource utilization but also creates expanded opportunities for the application of green technologies (Luo et al., 2023). Furthermore, the growing significance of intellectual property protection in fostering green technology innovation has increasingly garnered the attention of scholars.

2.1.3 Intellectual property protection and green technology innovation

As a crucial component of technological innovation, green technology innovation is often influenced by the broader technological innovation framework. Consequently, when examining green technology innovation, most scholars first explore the relationship between technological innovation and intellectual property protection. The existing literature can be broadly categorized into three main perspectives. The first perspective in the literature contends that robust IPP can enhance the profitability of innovation commercialization, thereby providing strong incentives for innovators to invest more in technological development and, in turn, driving the continued advancement of technological innovation (Cao et al., 2023; Wan et al., 2023). The second perspective in the literature suggests that excessive IPP can have detrimental effects. It argues that overly stringent IPP may reinforce the monopolistic power of the owner, stifle free market competition, and diminish

incentives for research and development investment, ultimately hindering technological innovation (Hammami S, 2021; Woo et al., 2015). The third perspective, based on empirical research, demonstrates that the relationship between IPP and technological innovation is not a simple linear one but rather follows a U-shaped curve. This implies that there is an optimal level of IPP that can effectively stimulate innovation without unduly restricting market competition (Song et al., 2024; Liu et al., 2018). Although studies on the relationship between IPP and green technology innovation are relatively scarce, existing empirical research generally indicates that a moderate enhancement of IPP can significantly boost the motivation for green technology innovation among enterprises. For instance, Chen et al. (2024) found that IPP fosters the development of green technology innovation by encouraging R&D collaboration and enhancing human capital, based on panel data from Chinese manufacturing enterprises.

2.2 Hypothesis Presented

2.2.1 The direct impact of intellectual property protection on the green technology innovation of enterprises

When IPP is weak, the green innovation achievements of enterprises are vulnerable to imitation and infringement, leading to a loss of technological advantages and a decline in market competitiveness (Xia et al., 2023). The lack of adequate IPP not only prevents enterprises from receiving the rewards they deserve for their innovations but also allows the proliferation of low-quality and counterfeit products in the market, thereby hindering the adoption and promotion of genuinely innovative products (Peng et al., 2025). Furthermore, the absence of sustainable innovation outcomes undermines investor confidence, elevates the risk associated with returns on investment, and consequently leads to a reduction in funding for green technology research and development. This creates a disincentive for enterprises to pursue innovation, ultimately impeding the progress of industrial technology. In contrast, strong IPP effectively prevents technology from being easily replicated, ensures that enterprises receive the rightful rewards for their innovations, and fosters increased investment in green technology research and development (Hu et al., 2021). At the same time, a well-established intellectual property protection mechanism provides enterprises with a stable competitive advantage in the market, attracts more investors, fosters technical cooperation and innovation, and promotes the sustainable development and application of green technology. As a result, the entire industry will cultivate a healthier innovation ecosystem, accelerate technological progress, and contribute to achieving sustainable development goals (Chen and Puttitanun, 2005; ΦLi et al.,2024).

Intellectual property protection plays a crucial role in fostering green technology innovation within China's manufacturing industry, primarily in two ways: first, by providing legal protection for green technology innovation, and second, by promoting the transfer of green technology and market cooperation. First and foremost, IPP offers a legal safeguard for enterprises' green technology innovations.

Through mechanisms such as patents and trademarks, enterprises can prevent the misappropriation or infringement of their innovative achievements. The exclusivity of intellectual property rights helps firms maintain a competitive advantage in the market, while also encouraging greater investment in innovation (Tang et al., 2024). Additionally, as a valuable intangible asset, intellectual property can offer improved financing opportunities for enterprises, enabling them to secure more funds for investment in green technology research and development activities. Secondly, IPP facilitates the transfer of technology and market cooperation for green technologies. By promoting green technologies to a broader market through patent licensing, technology transfer, and other means, enterprises can generate additional revenue and accelerate the adoption of these technologies. At the same time, the protection of intellectual property rights promotes collaborative innovation across the industrial chain, enabling companies to share technological achievements and contribute to the formulation of industry standards and technological upgrades. In the field of green technologies, cross-industry, and corporate cooperation is crucial. Intellectual property rights provide the legal framework for such collaboration, ensuring the rights and interests of all parties involved and facilitating the diffusion and application of green technologies (Yu et al., 2025). Therefore, IPP not only offers legal safeguards for enterprise innovation and stimulates ongoing innovation, but also accelerates the widespread adoption and industrial upgrading of green technology by promoting technology transfer and cooperation. This, in turn, drives the development of green technology in China's manufacturing industry.

H1: The improvement of the level of intellectual property protection can promote the green technology innovation of manufacturing enterprises.

2.2.2 The moderating effect of government financial support

Increased government fiscal support, particularly in the areas of green technology investment and subsidies, can help alleviate the financial burden faced by enterprises during the R&D process. This, in turn, encourages enterprises to be more proactive in pursuing research and development activities related to green technologies (Shao et al., 2022; Lyu et al., 2024). Government financial support not only provides essential funding but also boosts enterprises' confidence in green technology R&D through targeted policy backing, thereby accelerating the adoption and application of green technologies (Zhao et al., 2024). Increases in fiscal spending are often accompanied by stronger incentives for green policies, prompting enterprises to place greater emphasis on IPP in order to safeguard their technological achievements from infringement or misappropriation in the context of these favorable policies (Guo et al., 2018). Additionally, government financial support can foster collaboration between industries, particularly between research institutions and enterprises, further ensuring the protection of innovative outcomes. In this way, increased government fiscal expenditure has effectively reshaped the role of IPP in driving green technology innovation. It encourages companies to

focus more on technological innovation and safeguarding their intellectual property, ultimately accelerating the research, development, and application of green technologies.

H2: The increase in government financial support can strengthen the role of intellectual property protection in promoting green technology innovation of manufacturing enterprises.

2.2.3 The moderating effect of enterprises' green transformation

The green transformation of enterprises refers to the shift from a business model dependent on high carbon emissions, pollution, and resource consumption to one that embraces a low-carbon, environmentally friendly, and sustainable economic approach (Xu et al., 2023). As the green transformation index of enterprises improves, there is a significant increase in the demand for and focus on green technology innovation to support the transition toward environmental protection and sustainable development (Wang et al., 2024). As enterprises undergo green transformation, they place greater emphasis on IPP, recognizing that the core competitiveness of technological innovation in the green industry must be effectively safeguarded. An increase in the green transformation index indicates that enterprises are intensifying their investment in environmental protection technologies, leading to a heightened focus on securing intellectual property rights to prevent their innovations from being misappropriated or copied by others. At the same time, the green transition boosts enterprises' market competitiveness, and IPP plays a crucial role in ensuring their legitimate returns in the green market, further stimulating their research and development efforts in green technologies (Zhai et al., 2020). As the green transformation index improves, enterprises not only attract more investors and partners but also strengthen their technological advantages through IPP. This, in turn, accelerates the innovation and market application of green technologies, promoting the overall development of green industries.

H3: The improvement of the degree of enterprises' green transformation can strengthen the role of intellectual property protection in promoting green technology innovation of manufacturing enterprises.

3. Data Sources, Variable Selection, and Model Design

3.1 Data Sources

This study utilizes panel data from 1,094 enterprises across 29 manufacturing industries in China, covering the period from 2012 to 2022. The analysis excludes industries such as comprehensive waste resource utilization, metal products, and machinery and equipment maintenance. The data primarily derives from authoritative sources, including the China Science and Technology Statistical Yearbook, the China Labor Statistics Yearbook, the China Statistical Yearbook, the Evaluation Report on the Development of Intellectual Property Rights in China, and the National Bureau of Statistics of China.

3.2 Variable Selection

3.2.1 Dependent variables

Patent output is widely recognized as a key indicator of an enterprise's innovation capacity (Dang and Motohashi, 2015). Compared to other innovation metrics, the number of patent applications provides a more direct reflection of an enterprise's technological achievements, particularly in the context of green patents. The volume of green patent applications, in particular, offers a clear measure of an enterprise's investment and effectiveness in environmental protection technology and sustainable development (Cui et al., 2022). Consequently, this study selects the number of green patent applications as the primary indicator to assess the green technology innovation capability of firms. To improve accuracy, the data is adjusted by adding 1 and taking the logarithm (denoted as Grepat) to better reflect the level of green technology innovation within the enterprises.

3.2.2 Independent variables

The main explanatory variable in this study is the Inter-Provincial Intellectual Property Protection Index. This index reflects the strength of intellectual property protection in each region, with higher values indicating a stronger level of IPP. Since the level of intellectual property protection available to enterprises is closely linked to the overall IPP environment in the region where they are located, this study uses the IPP as a representative indicator to assess the level of IPP for enterprises. Specifically, this study utilizes the IPP index from the National Intellectual Property Development Report published by the State Intellectual Property Office of China and divides it by 100 to quantify the level of IPP accessible to enterprises.

3.2.3 Control variables

Based on the existing literature, this study selects enterprise size (Size), return on assets (ROA), and the asset-liability ratio (Lev) as control variables. The size of an enterprise is measured by the natural logarithm of its total assets at the end of the year. Larger enterprises typically have more resources, such as capital, labor, and technology, which enable them to invest more in green technology innovation (Beck et al., 2010). An enterprise's ROA reflects the profitability of its assets and is measured in this study as the natural logarithm of return on assets. Enterprises with higher ROA tend to operate more efficiently, demonstrate stronger profitability, and are better positioned to afford long-term investments in green technology research and development. In contrast, enterprises with lower ROA may face constraints on their ability to invest in green technology innovation due to poor profitability. The debt-to-asset ratio (Lev) is expressed as the ratio of total liabilities to total assets. Higher debt-to-asset ratios indicate that enterprises are under greater pressure to service debt, which may limit their capacity to invest in green technology innovation.

3.2.4 Descriptive Analysis

The descriptive statistical results of the variables used in this study are shown in Table 1. Specifically, the mean logarithm of green technology innovation applications was 0.444 with a standard deviation of 1.874. This indicates that the 1,094 manufacturing enterprises in the sample demonstrate some activity in green technology innovation, but there are significant variations across different enterprises. The maximum value of the IPP index is 0.937, while the minimum value is 0.467, reflecting the regional differences in IPP. These differences influence the level of IPP enjoyed by the enterprises, thus potentially impacting their innovation capabilities in green technology. A higher IPP index usually means that the region has a better legal framework and institutional guarantees, providing a more favorable environment for enterprises to innovate green technology. After rigorous testing, all continuous variables were stationary, and no serious multicollinearity problems were found.

Table 1: Descriptive statistics

Variable	N	Mean	p50	SD	Min	Max
Grepat	12034	0.444	0	0.874	0	4.025
IPP	12034	0.770	0.790	0.123	0.467	0.937
Size	12034	22.35	22.20	1.206	20.17	25.92
Lev	12034	0.400	0.398	0.183	0.0550	0.805
ROA	12034	0.0430	0.0380	0.0570	-0.165	0.217

Note: *, **, and *** in the table indicate that they are significant at the 10%, 5%, and 1% significance levels, respectively, and the t statistical values are in parentheses, the same below.

3.2.5 Correlation analysis

Table 2 presents the results of the Pearson correlation coefficient test between the major variables. According to the analysis, the correlation coefficient between green technology innovation and IPP is 0.043, and this positive correlation is statistically significant at the 1% level. This suggests a significant positive relationship between green technology innovation and the level of IPP in the environment. The correlation coefficients of the other control variables were all below 0.8, indicating that there is no significant multicollinearity problem. Furthermore, all variables passed the stationarity test, ensuring the robustness of the results.

Table 2: Correlation analysis

	Grepat	IPP	Size	Lev	ROA
Grepat	1				
IPP	0.043***	1			
Size	0.328***	-0.088***	1		
Lev	0.211***	-0.087***	0.506***	1	
ROA	0.0140	0.039***	0.073***	-0.339***	1

3.3 Model Setting

In this study, a panel model is used to analyze the impact of intellectual property protection on green technology innovation in the region, and the model is set up as follows:

$$Grepat_{i,t} = \alpha_0 + \alpha_1 IPP_{i,t} + \lambda_1 Control_{i,t} + \varepsilon_{i,t} \quad (1)$$

In Equation (1), $Grepat_{i,t}$represents the level of green technology innovation for enterprise i in year t. The parameter α_0 is the intercept term, serving as the baseline value for the model. The coefficient α_1, to be estimated, measures the impact of the degree of IPP on the green technology innovation of enterprises. $IPP_{i,t}$ is an independent variable reflecting the level of intellectual property protection in the region where company i is located in year t. To account for potential confounding factors more comprehensively, $Control_{i,t}$ represents a set of control variables that capture other factors influencing green technology innovation, beyond the independent variables. Finally, $\varepsilon_{i,t}$ is an independently and identically distributed random disturbance term, used to account for random factors not included in the model.

4. Results and Discussion

4.1 The direct impact of intellectual property protection on the green technology innovation within manufacturing enterprises

4.1.1 Panel regression results

This study employs a fixed-effect panel model to analyze the impact of intellectual property protection on green technology innovation among Chinese manufacturing enterprises. The specific regression results are presented in Table 3. Whether considering a single regression explanatory variable or incorporating control variables, the enhancement of IPP in the region where the enterprise is located has been shown to significantly stimulate the green technology innovation activities of the enterprise. After controlling for time and industry fixed effects and introducing control variables, the coefficient for IPP is 0.297, which is statistically significant at the 1% level. This provides strong empirical evidence in support of the theoretical hypothesis (H1) of this study, indicating that improving the level of IPP can effectively promote green technology innovation within manufacturing enterprises. From the perspective of IPP as a legal safeguard for technological innovation, enterprises typically require substantial R&D investment when pursuing green technology innovation, which often involves complex environmental protection technologies. In the absence of effective IPP, the green innovation outcomes of enterprises are vulnerable to imitation or misappropriation by others, which, in turn, diminishes their incentive to innovate independently. By providing IPP, enterprises can secure an exclusive position for their green innovations in the market, mitigate the risk of infringement, and consequently encourage greater investment in R&D. At the same time, robust IPP not only enhances the market reputation of enterprises

but also improves their ability to secure financing, attracting more capital inflows. This, in turn, can facilitate the further development and application of green technologies. On the other hand, from the perspective of promoting green technology transfer and market cooperation, IPP offers enterprises avenues such as patent licensing and technology licensing, enabling them to transfer their innovation results to other enterprises or partners. This approach not only safeguards the interests of innovators but also generates economic returns. Through this mechanism, small and medium-sized enterprises (SMEs) can reduce their input costs, easily adopt green technologies, and contribute to the widespread adoption of green technologies. Furthermore, IPP can foster technical cooperation between domestic and foreign enterprises, aiding local enterprises in acquiring advanced international technologies and improving the overall level of green technology. Through collaborative R&D efforts and industrial alliances, technological innovation spreads rapidly, driving the green transformation and upgrading of the industry. Intellectual property rights offer a fair and transparent legal framework for this process, thereby enhancing the application, popularization, and innovation capacity of green technologies within the industry.

Table 3: Results of fixed-effects panel models

	(1)	(2)
	Grepat	**Grepat**
IPP	0.115*	0.297***
	(1.67)	(4.43)
Size		0.250***
		(22.48)
Lev		0.170***
		(3.50)
ROA		0.396***
		(2.91)
_cons	0.363***	-5.441***
	(6.77)	(-22.32)
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
N	12034	12034
R^2	0.101	0.202

4.1.2 Endogeneity problems

As green technology innovation among enterprises increases, so does the corresponding demand for IPP. In response, policymakers are likely to enhance IPP measures, such as improving legal safeguards and the efficiency of patent examinations, to encourage further innovation in green technologies. This creates a two-way, mutually reinforcing causal relationship, where the growth of green

technology innovation by enterprises may, in turn, drive improvements in regional IPP levels. To address potential endogeneity issues, the lagged IPP index (L.IPP) was chosen as an instrumental variable, and the two-stage least squares (2SLS) method was employed for regression analysis. The lagged IPP index is closely correlated with the study's main independent variables, as the current level of IPP is typically influenced by previous protection measures. However, lagged IPP does not directly affect current green technology innovation, thus meeting the necessary criteria of correlation and homogeneity for a valid instrumental variable. This approach effectively alleviates endogeneity concerns, ensuring the robustness and reliability of the regression results.

In the regression results presented in Table 4, the first stage of the regression reveals that the coefficient for the lagged IPP index (L.IPP) is 0.875, which is statistically significant at the 1% level. This indicates that lagged IPP has a substantial positive effect on current IPP, thereby confirming the relevance of the instrumental variable. Furthermore, the Wald-F statistic from the weak correlation test significantly exceeds the critical values of 8.96 and 16.38, further validating the strength of the instrumental variable. The second stage of the regression analysis demonstrates that, even after addressing the endogeneity issue through the inclusion of the instrumental variable, IPP continues to have a significant positive impact on enterprise green technology innovation. This result confirms the robustness of the research findings.

Table 4: Results of IV-2SLS method

Variable	2SLS	2SLS
	First stage (1)	Second stage (2)
L.IPP	0.875*** (217.83)	
IPP		0.893*** (2.79)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Individual-fixed effect	Yes	Yes
N	10940	10940
Kleibergen-Paap rk LM statistic		12.500 [0.000]
Cragg-Donald Wald F statistic		87174.78
Hansen J statistic		0.000
R^2	0.304	0.304

4.1.3 Robustness test

In this study, the robustness of the results from the fixed-effect regression model was tested by substituting the dependent variable and shortening the sample period to assess the reliability of the conclusions. Firstly, the dependent variable was replaced with the number of green invention patent applications filed by the enterprise. A logarithmic transformation with a plus-one adjustment was applied, serving as the surrogate variable for the robustness test (Greia). The specific results are presented in column (1) of Table 5. After substituting the dependent variable, the regression coefficient for IP protection remains positively significant at the 1% level, indicating that the research conclusions hold robust even under the alternative specification. Secondly, building on the original sample period (2012-2022), the sample interval was shortened to 2014-2020, and the corresponding regression analysis was conducted. The results are presented in column (2) of Table 5. The findings reveal that, even after shortening the sample period, the coefficient for intellectual property protection in the fixed-effect panel model remains significantly positive, further reinforcing the robustness of the conclusion. Through these two robustness tests, this study strengthens the assertion that intellectual property protection plays a positive role in fostering the green technological innovation of enterprises, thereby enhancing both the validity and credibility of the conclusions.

Table 5: Robustness test results

	(1)	**(2)**
	Greia	**Grepat**
IPP	0.310***	0.304***
	(5.23)	(3.98)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
_cons	-6.225***	-5.509***
	(-26.96)	(-18.86)
N	12034	8752
R^2	0.241	0.200

4.2 Heterogeneity test

4.2.1 Heterogeneity based on the nature of different industries

Due to variations in pollutant generation, emission, and control across manufacturing industries, the impact of IPP on green technological innovation may differ among enterprises in different sectors. Following the Guidelines for Environmental Information Disclosure of Listed Companies issued by the Ministry of Environmental Protection of the People's Republic of China, this study categorizes the sample enterprises into non-heavily polluting and heavily polluting enterprises and conducts a heterogeneity analysis. As shown in the regression results in Table 6, intellectual property protection exerts a significantly positive influence on the green technology innovation of non-heavily polluting enterprises. In contrast, it does not have a significant effect on the green technology innovation of heavily polluting enterprises. The possible reasons for this are as follows: First, non-heavy-polluting enterprises exhibit stronger intrinsic motivation and demand for green technology innovation. These enterprises typically place greater emphasis on green transformation and sustainable development. Robust IPP boosts their confidence in innovation and mitigates the risk of technology leakage, thus facilitating the research, development, and application of green technologies. In contrast, heavily polluting enterprises tend to rely on traditional, high-pollution, and high-energy-consuming production models. Their lower demand for green transformation, coupled with insufficient motivation for innovation, leads to a limited impact of IPP on their innovation activities. Second, differences in the policy environment also play a significant role. Non-heavily polluting enterprises are often located in key industries that receive strong policy support, benefiting from preferential environmental protection policies that further encourage them to pursue green technology innovation. In contrast, heavily polluting enterprises face higher transition costs and greater environmental pressures, coupled with stricter regulatory requirements. These enterprises typically lack sufficient policy support and technology accumulation, making it challenging for IPP alone to effectively stimulate their green technology innovation. As a result, IPP tends to have a more pronounced positive effect on non-heavily polluting enterprises, while its impact on heavily polluting enterprises remains relatively weak.

Table 6: Heterogeneity analysis of samples according to the degree of pollution in the industry in which the enterprise is located

	(1)	(2)
	Heavily polluting enterprises	**Non-Heavily polluting enterprises**
IPP	0.010	0.539***
	(0.14)	(5.25)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
_cons	-2.553***	-7.120***
	(-11.42)	(-20.50)
N	4738	7296
R^2	0.199	0.199

4.2.2 Heterogeneity analysis based on enterprises' Environmentally Consciousness

The strength of an enterprise's environmentally consciousness reflects the extent of its social responsibility in environmental protection. In this study, enterprises are classified into two categories based on their disclosure of environmental protection philosophy, policies, organizational structure for environmental management, circular economy development models, and green development initiatives. These categories are enterprises with strong environmental consciousness and enterprises with weak environmental consciousness, and a heterogeneity analysis is performed accordingly. As shown in Table 7, the regression coefficients for both groups are significantly positive. However, it is clear that strengthening IPP has a more pronounced effect on promoting green technology innovation in enterprises with strong environmental consciousness. This suggests that companies with a higher commitment to sustainability are better positioned to leverage IPP to drive innovation in green technologies, while enterprises with weaker environmental consciousness may not fully capitalize on these opportunities. Specifically, enterprises with strong environmental consciousness are more inclined to invest in R&D and innovation in green technologies due to their strong focus and commitment to environmental issues. When IPP is enhanced, these enterprises experience greater legal assurance regarding the safeguarding of their innovations and achievements, which in turn fosters a more proactive approach to green technology innovation. In contrast, enterprises with weak environmental consciousness typically place less emphasis on environmental issues, and innovation in environmental technologies is not a top priority for them. As a result, even with strengthened IPP, their motivation for innovation and their ability to effectively translate ideas into green technologies remain relatively limited.

Consequently, IPP has a more significant impact on driving green technology

innovation in enterprises with strong environmental consciousness than in enterprises with strong environmental consciousness.

Table 7: Heterogeneity analysis of samples divided by the strength of enterprises' environmental Consciousness

	(1) Enterprises with strong Environmentally Consciousness	(2) Enterprises with weak Environmentally Consciousness
	Grepat	Grepat
IPP	0.465***	0.254***
	(3.61)	(3.46)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
_cons	-6.389***	-3.637***
	(-17.14)	(-11.83)
N	4929	7105
R^2	0.266	0.129

4.2.3 Heterogeneity analysis based on enterprise high-tech certification

There are notable differences between high-tech enterprises and non-high-tech enterprises in terms of technological innovation, R&D capabilities, and resource acquisition. In this study, the sample enterprises are categorized into high-tech and non-high-tech enterprises based on whether they received high-tech certification during the sample period. The results in Table 8 reveal that the regression coefficient for non-high-tech enterprises is 0.369 and statistically significant, while the regression coefficient for high-tech enterprises is not significant. This suggests that strengthening IPP in the regions where these enterprises are located can promote green technology innovation in non-high-tech enterprises, but the effect on high-tech enterprises is not as pronounced. This difference may be attributed to several factors: First, non-high-tech enterprises typically invest less in technological innovation compared to high-tech enterprises. Therefore, the enhancement of IPP offers them stronger incentives to innovate. These enterprises are more likely to depend on external support, such as improved IPP, to boost their innovation capabilities. On the other hand, high-tech enterprises already have a solid foundation in technology research and development, as well as innovation experience. They have achieved a leading position through their own technology accumulation, innovation capacity, and market advantages. As a result, the role of

IPP in further promoting innovation is relatively limited for these firms, as their innovation processes are already well established.

Table 8: Heterogeneity analysis of the sample according to whether the enterprise belongs to the high-tech enterprise

	(1)	(2)
	High-tech enterprises Grepat	**Non-high-tech enterprises Grepat**
IPP	-0.027	0.369***
	(-0.28)	(3.81)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
_cons	-6.055***	-5.573***
	(-18.84)	(-14.96)
N	7279	4755
R^2	0.213	0.220

4.3 Mechanism Testing

The results of this study show that IPP has a positive effect on the green technology innovation of Chinese manufacturing enterprises, and there are multi-dimensional differences in this impact among different enterprises. Based on this, it is worth further exploring how IPP affects the mechanism of green technology innovation of manufacturing enterprises. Based on the above assumptions, this study will deeply analyze the mechanism of government support and corporate green transformation.

4.3.1 The Moderating Effect of Government Financial Support

Based on the aforementioned assumptions, government support is likely to serve as a moderating factor in the relationship between intellectual property protection and green technology innovation in enterprises. In this study, the fiscal expenditure-to-GDP ratio of the province in which the enterprise is located is used as an indicator of the government support received by the enterprise, with data sourced from the National Bureau of Statistics of China. To assess the validity of this mechanism, the study incorporates government support and its interaction term with intellectual property protection into the regression analysis based on Model 1. The proposed model is specified as follows:

$$Grepat_{i,t} = \alpha_0 + \alpha_1 IPP_{i,t} + \alpha_2 Government + \alpha_3 Government*IPP + \lambda_1 Control_{i,t} + \varepsilon_{i,t} \quad (2)$$

The results presented in column (1) of Table 9 show that the coefficient of the interaction between government support and IPP is positive and statistically significant at the 5% level, providing empirical support for Hypothesis 2. This indicates that increased government financial support significantly strengthens the

role of IPP in promoting green technology innovation in manufacturing enterprises. Specifically, an increase in government financial support equips enterprises with more resources for innovation. In regions with higher levels of financial backing, the government incentivizes enterprises to engage in green technology research and development through special funds, tax incentives, and other measures. Such financial support not only reduces the innovation costs for enterprises but also creates more favorable conditions for technological research. As a result, enterprises are more likely to invest in green technology innovation, as they are better positioned to ensure that their R&D efforts can be effectively translated into commercial products. Secondly, government financial support plays a crucial role in advancing the IPP system. As fiscal expenditure increases, the government can allocate more resources to the management and safeguarding of intellectual property rights, thereby enhancing the associated legal protections. A robust IPP system allows companies to effectively prevent the misappropriation or infringement of their green technology innovations. This legal assurance not only boosts the confidence of enterprises to pursue innovation but also motivates them to invest additional resources in green technology. Consequently, this fosters the green transformation and sustainable development of the entire industry.

4.3.2 The moderating effect of green transformation of enterprises

According to the above assumptions, the degree of green transformation of enterprises may play a moderating role in the relationship between IPP and enterprise green technology innovation. With reference to relevant research, this paper selects 113 keywords of enterprise green transformation from five aspects: publicity initiative, strategic concept, technological innovation, pollutant discharge control and monitoring and management, and counts the frequency of each keyword in the annual report text of listed enterprises, so as to form the frequency of green transformation words, and use the frequency of the word plus 1 to take the natural logarithm to describe the green transformation of enterprises, which comes from the annual reports of listed enterprises, social responsibility reports of listed enterprises, and website information of listed companies. In order to test whether the above mechanism is valid, this study introduces the green transformation of enterprises and its interaction with IPP for regression on the basis of model 1, and the model is set as follows:

$$G\text{repat}_{i,t} = \alpha_0 + \alpha_1 IPP_{i,t} + \alpha_2 G\text{reen} + \alpha_3 Green{*}IPP + \lambda_1 Control_{i,t} + \varepsilon_{i,t} \quad (3)$$

Based on the analysis results in column (2) of Table 9, the coefficient of the interaction term between green transformation and IPP is positive and statistically significant at the 10% level, thereby confirming the validity of Hypothesis 3. This finding indicates that as the degree of green transformation within enterprises increases, the effectiveness of IPP in fostering green technology innovation is significantly amplified. In other words, a stronger commitment to green

transformation enhances the role of IPP in driving innovation in green technologies. Specifically, as enterprises increasingly embrace green transformation, they place greater emphasis on sustainable development and the research and development of green technologies, positioning green technology innovation as a key element of their core competitiveness. During this transformation process, enterprises become more reliant on IPP. Effective IPP safeguards their technological leadership, prevents imitation or infringement, and facilitates the successful commercialization and development of green technology innovations. Moreover, the greater the degree of green transformation, the more crucial green technology innovation becomes to the enterprise. Consequently, as they ramp up their investment in innovation, enterprises also recognize the critical role of IPP in maintaining the exclusivity of their R&D outcomes, thereby enhancing their market competitiveness. In summary, the interaction between the green transformation of enterprises and IPP plays a pivotal role in accelerating the advancement of green technology innovation.

Table 9: Results of mechanism testing

	(1)	**(2)**
	Grepat	**Grepat**
IPP	0.279***	0.340***
	(3.29)	(4.55)
Government	-0.918***	
	(-3.07)	
Government*IPP	1.374**	
	(2.46)	
Green		-0.116*
		(-1.72)
Green*IPP		0.150*
		(1.76)
Control Variables	Yes	Yes
Time-fixed effect	Yes	Yes
Industry-fixed effect	Yes	Yes
_cons	-5.229***	-5.162***
	(-20.91)	(-16.60)
N	12034	12034
R^2	0.202	0.205

5. Conclusions and policy recommendations

5.1 Conclusions

Based on the panel data of 1094 enterprises in 29 manufacturing industries in China from 2012 to 2022, this study analyzes the impact and mechanism of intellectual property protection level on green technology innovation in the regions where enterprises are located by using a fixed effect model and a moderating effect model. This study finds that IPP significantly promotes green technology innovation in China's manufacturing industry by providing legal protection for green technology innovation, promoting green technology transfer, and promoting market cooperation. Furthermore, this study analyzes the heterogeneity of the sample enterprises in three different dimensions, and the results show that IPP has a particularly significant effect on the green technology innovation of non-heavily polluting enterprises, enterprises with strong environmental consciousness, and non-high-tech enterprises. These findings offer valuable insights for policymakers seeking to enhance green technology innovation and promote sustainable development through more effective intellectual property protection policies. By understanding the mechanisms at play, policymakers can adjust and implement policies that maximize the impact of IPP on green innovation. Furthermore, this study delves into the role of government financial support and corporate green transformation in amplifying the effect of IPP on green technology innovation. The results from the mechanism test indicate that increased government financial support, coupled with a higher degree of green transformation within enterprises, significantly strengthens the positive influence of IPP on green technology innovation in the manufacturing sector. This suggests that a combination of policy incentives and enterprises' commitment to sustainability can create a more conducive environment for fostering green technological advancements.

5.2 Policy Recommendations

To begin with, at the legal level, the government should strengthen the protection of intellectual property rights and enhance policy oversight in the green technology sector. First and foremost, it is essential for the government to bolster IPP in green technologies by refining relevant patent regulations. This would help mitigate the legal risks that enterprises face during the innovation process, thereby boosting their confidence in developing new technologies. Moreover, policymakers should intensify efforts to combat intellectual property infringement, ensuring that innovators can receive fair economic returns from their green technology research and development. This, in turn, will drive further innovation and the advancement of green technologies. Additionally, the government should encourage collaboration between leading enterprises and small and medium-sized enterprises (SMEs) in the green technology sector to foster the sharing and application of cutting-edge technologies. By establishing dedicated green technology exchange platforms, the government can facilitate technology transfer and widespread adoption. Furthermore, setting up technology transfer funds or incentive programs

will expedite the promotion and application of green technologies across various industries, accelerating the transition toward a more sustainable economy.

Secondly, in terms of financial support, the government should provide financial subsidies and low-interest loans to heavily-polluting enterprises to assist them in upgrading their production facilities and environmental protection equipment. Additionally, the government can establish a dedicated green technology innovation fund to support these enterprises in developing technologies that comply with environmental standards, particularly in areas such as pollution control and resource recycling. Through targeted funding, tax incentives, and other policy measures, the government can effectively reduce the financial burden on enterprises engaged in green technology research and development. Furthermore, the government should encourage collaboration between high-tech enterprises and research institutions, fostering the creation of technology alliances. This will facilitate the smooth transition of green technologies from the R&D phase to commercialization, thereby accelerating their widespread adoption and advancing the development of sustainable green technologies.

Thirdly, in promoting the green transformation of enterprises, the government should focus on enhancing environmental consciousness and simplifying policies. The government can raise consciousness of green technologies and environmental regulations among businesses through green certification programs and training initiatives, thereby encouraging their commitment to green innovation. Simultaneously, the government should streamline the policies surrounding the adoption and implementation of green technologies, lowering the barriers for enterprises to undergo transformation and enabling them to adopt environmental protection technologies more swiftly. Furthermore, the government should increase financial support for businesses undergoing green transformation, particularly in critical areas such as production processes, energy consumption, and waste management. This will alleviate the financial pressure on enterprises during the technological upgrading process and promote the practical application and sustainable development of green technologies across industries.

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