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How Does Green Innovation Affect Corporate Profitability? An Empirical Study Based on the Mediating Effect of Green Patents of Agricultural Listed Companies

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Abstract

In the context of global sustainable development strategies and China's "dual carbon" goals, green innovation has become a critical driving force for the transformation and development of agricultural enterprises. This study takes Chinese A-share agricultural listed companies from 2016 to 2024 as the research sample and systematically examines the impact mechanism of green innovation on corporate profitability. It particularly introduces green patents as a mediating variable to reveal the transmission path between green innovation and profitability. The study employs the entropy weight method to construct a comprehensive corporate profitability score. Green innovation is measured from two dimensions: R&D intensity and financing constraints. Empirical tests are conducted using multiple regression models. The results show that R&D intensity has a significant negative impact on corporate profitability, while financing constraints exert a significant positive impact. Green patents play a positive mediating role between R&D intensity and profitability, but a negative mediating role between financing constraints and profitability. Heterogeneity analysis indicates that the above relationships are more pronounced in the northern regions and in the post-epidemic period. The findings provide empirical support and policy implications for agricultural listed companies to optimize green innovation resource allocation and enhance profitability, and offer experience and path references from the Chinese capital market for global agricultural green transformation and sustainable development.

Keywords

green innovation, corporate profitability, green patents, financing constraints, agricultural enterprises

1. Introduction

The United Nations 2030 Agenda for Sustainable Development lists green development as a core global issue. The World Economic Forum continues to promote corporate climate action, and the International Organization for Standardization (ISO) also guides corporate transformation through environmental management standards. Under this international consensus, China has proposed the "dual carbon" goals,

incorporating carbon peaking and carbon neutrality into the overall layout of ecological civilization construction. Facing increasingly stringent environmental regulations and rising social awareness of environmental protection, green innovation has become an important strategic means for enterprises to achieve sustainable development. Green innovation refers to the introduction of new practices in product design, production processes, or management methods that reduce negative environmental impacts and improve resource efficiency [1]. Enterprises are using this as a core strategy to build sustainable competitive advantages [2].

For agricultural listed companies, green innovation not only involves technological innovations in production such as water-saving irrigation, precision fertilization, and green prevention and control of pests and diseases, but also encompasses the transformation of business models such as circular agriculture, ecological planting, and low-carbon breeding. These innovations hold special significance for the control of agricultural non-point source pollution and the intensive utilization of resources. The above characteristics of agricultural green innovation make the relationship between environmental benefits and financial performance particularly worthy of attention. On the one hand, based on the natural resource-based view and the Porter Hypothesis, green innovation can ultimately be transformed into financial gains by reducing energy consumption and compliance costs and by opening up green product markets [3]. Recent large-sample studies have also confirmed a significant and robust positive relationship between green innovation and corporate profitability [4]. On the other hand, some studies point out that green innovation often requires substantial upfront investment and has a long payback period, and its effects are highly dependent on internal and external contextual factors of the enterprise [5]. Therefore, an in-depth exploration of the relationship between green innovation and corporate profitability holds important theoretical value and practical significance for agricultural listed companies in optimizing green strategies and achieving a win-win outcome of economic and environmental benefits.

Green patents, as the most direct intellectual property output of corporate green innovation activities, play a key mediating role between green innovation and corporate profitability [7,8]. On the one hand, obtaining green patents requires enterprises to invest substantial R&D resources, and the application and authorization process itself reflects the substantive efforts of corporate green innovation [7]. On the other hand, the technological value embedded in green patents can be transformed into corporate financial gains through channels such as efficiency improvement and cost reduction [6,9]. However, existing studies still lack systematic examination of the mediating transmission mechanism of green patents. How factors such as the pollution intensity of the industry in which the enterprise operates, its own financial flexibility, and its sustainable development performance affect the mediating effect of green patents remains to be further revealed [8,9]. In addition, the impact of green patents on corporate profitability may exhibit non-linear characteristics; that is, R&D investment in the short term may squeeze corporate profits, while long-term accumulation is expected to achieve positive returns [8,10]. Therefore, this study takes green patents as a mediating variable and systematically examines its transmission mechanism in the process of green innovation affecting corporate profitability, in order to provide a more detailed theoretical explanation and empirical evidence for understanding the complex relationship between the two.

In summary, this paper takes Chinese A-share agricultural listed companies as the research object. Based on panel data from 2016 to 2024, it constructs multiple regression models to systematically examine the impact of green innovation on corporate profitability and introduces green patents as a mediating variable to reveal its internal transmission mechanism. In terms of measuring green innovation, this paper analyzes it from two dimensions: R&D intensity and financing constraints. The former reflects the level of corporate resource investment in green technologies, while the latter characterizes the degree of funding constraints faced by enterprises in carrying out green innovation. Furthermore, from the perspectives of regional heterogeneity and temporal heterogeneity, this paper examines the impact of institutional differences between northern and southern regions and the shock of the COVID-19 pandemic on the main effects, with a view to revealing the differentiated performance of corporate green innovation under changes in the external environment. It aims to provide theoretical basis and practical reference for enterprises to optimize resource allocation and achieve sustainable development in the process of green transformation. It also holds important practical significance for promoting the control of agricultural non-point source pollution, improving the level of intensive resource utilization, and achieving the long-term strategic goal of high-quality agricultural development.

2. Theoretical Basis and Hypotheses

2.1 Green Innovation and Corporate Profitability

R&D intensity, as a core proxy variable for corporate innovation input, is widely used to characterize the level of resource investment in enterprises' green innovation [14]. This indicator is typically measured as the ratio of R&D expenditure to sales revenue and can effectively reflect the degree of emphasis enterprises place on green technology R&D and their resource allocation orientation [15]. Green R&D activities inherently feature large-scale investment, long payback periods, and high technological uncertainty. In the short term, high R&D expenditures may crowd out funds for daily operations. In addition, the time lag between technological breakthroughs and commercial application means that R&D intensity is difficult to translate into profitability contributions in the current period and may even exert a negative squeezing effect on profitability [5,10]. For agricultural listed companies, agricultural R&D activities are highly dependent on uncontrollable factors such as natural conditions and biological cycles. The process from laboratory to field application, and from experimental demonstration to large-scale adoption, often requires crossing longer validation cycles and higher adoption thresholds [44]. This implies that R&D investment in agricultural enterprises is even more difficult to achieve results conversion in the short term. Therefore, this paper chooses to measure corporate green innovation from the dimension of R&D intensity, so as to depict the level of resource investment and innovation efforts of agricultural listed companies in the green transformation process.

Accordingly, the following hypothesis is proposed:

H1a: R&D intensity has a negative impact on corporate profitability.

Financing constraints, as an important dimension for measuring corporate green innovation, have received extensive attention in the existing literature. Hottenrott and Peters argue that financing constraints reflect an enterprise's ability to raise external funds for innovation activities and constitute a key dimension for measuring the efficiency of innovation resource acquisition and allocation [19]. Some studies suggest that moderate financing constraints may force enterprises to optimize resource allocation and improve the efficiency of R&D investment [45]. Specifically, financing constraints can impose financial discipline on corporate management, suppress excessive investment and agency problems, and encourage enterprises to allocate limited capital more prudently, thereby enhancing capital utilization efficiency [45]. For agricultural listed companies, agricultural enterprises generally face structural financing difficulties such as a high proportion of fixed assets, unstable collateral values, and mismatch between production cycles and capital recovery cycles, resulting in relatively limited external financing channels [44]. In this context, financing constraints are not only a restriction on external fund acquisition for agricultural enterprises but also constitute an endogenous resource allocation constraint mechanism. Moderate financial pressure may compel agricultural enterprises to evaluate green investments more cautiously, prioritize projects with shorter payback periods and relatively mature technologies, and thereby improve the allocation efficiency of limited funds. Therefore, this paper chooses to measure corporate green innovation from the dimension of financing constraints, so as to depict the funding constraints faced by agricultural listed companies in the green transformation process and empirically test its impact on profitability.

Accordingly, the following hypothesis is proposed:

H1b: Financing constraints have a positive impact on corporate profitability.

2.2 The Mediating Role of Green Patents

Green patents, as the core intellectual property output of corporate green innovation activities, play an important transmitting role between green innovation and corporate profitability [21,22]. For agricultural listed companies, green patents hold particularly special significance. Agricultural technologies are characterized by highly context-specific applications, long commercialization cycles, and deep integration with natural resource endowments. These features make the acquisition and utilization of green patents a critical link connecting R&D investment and corporate profitability. Existing studies still lack systematic examination of the mediating transmission mechanism of green patents, and their specific pathways and boundary conditions remain to be further revealed [23,24]. Based on this, the present study takes green

patents as a mediating variable and systematically examines its mediating effect in the processes through which R&D intensity and financing constraints respectively influence corporate profitability.

R&D intensity reflects the level of resource investment by enterprises in green technological innovation and serves as the fundamental guarantee for carrying out green innovation activities. Enterprises with higher R&D intensity are more likely to produce high-quality green technological achievements, which need to be protected through patent applications and then commercialized [21]. R&D investment has a significant positive impact on green patent output, while the accumulation of green patents can enhance enterprises' market competitiveness and profitability through channels such as technology licensing and product differentiation [22]. From the perspective of the underlying mechanism, R&D intensity first promotes substantive breakthroughs in green technology through capital investment and talent allocation; the key output of this process is green patents. As the legal embodiment of corporate technological capabilities, green patents not only prevent knowledge spillovers from being freely exploited by competitors, but also signal the enterprise's genuine capabilities in green technology to external investors, thereby alleviating information asymmetry [23]. On this basis, enterprises can obtain technology revenues through patent licensing or enhance product pricing power through differentiation advantages formed by patent protection, ultimately converting innovation inputs into economic returns [46]. This series of linkages reveals that the impact of R&D intensity on profitability is not entirely direct, but is partially transmitted through the intermediate link of green patents [47].

Accordingly, the following hypothesis is proposed:

H2a: Green patents play a mediating role in the relationship between R&D intensity and corporate profitability.

Financing constraints reflect the degree of funding restrictions faced by enterprises in carrying out green innovation activities. When financing is constrained, enterprises' ability to engage in green innovation is restricted, and the output of green patents may also decrease accordingly. However, green patents, as signals of corporate innovation capability, can convey competitive advantages in green technology to the market, helping to alleviate information asymmetry and attract external financing [22]. The acquisition of green patents can, to a certain extent, break through the constraints imposed by financing restrictions on corporate innovation activities: on the one hand, enterprises possessing green patents are more likely to gain recognition from external investors and broaden their financing channels; on the other hand, improved financing conditions in turn provide further financial support for enterprises to carry out green innovation, forming a virtuous cycle. On this basis, the accumulation of green patents can improve enterprises' financing conditions, reduce financing costs, and thereby create greater profit margins for enterprises [23].

Accordingly, the following hypothesis is proposed:

H2b: Green patents play a mediating role in the relationship between financing constraints and corporate profitability.

3. Research Design

3.1 Variable Measurement

Table 1 reports the definitions and measurement methods of the main variables used in this study. The dependent variable is the corporate comprehensive profitability score, the independent variables are R&D intensity and financing constraints, the mediating variable is green patents, and company size, listing age, and the proportion of independent directors are selected as control variables.

Table 1: Variable Measurement

Variable Type	Variable Name	Symbol	Description and Calculation
Dependent Variable	Corporate Comprehensive Profitability Score	Score1	Comprehensive score calculated by objectively weighting seven financial indicators—current ratio, quick ratio, debt-to-asset ratio, accounts receivable turnover, total asset turnover, return on equity (ROE), and gross profit margin—using the entropy weight method.
Independent Variables	R&D Intensity	Research	R&D expenses / Total expenses
	Financing	WW	Financing constraints measured by the WW index constructed by

Variable Type	Variable Name	Symbol	Description and Calculation
	Constraints		Whited and Wu. It is a linearly weighted index based on six indicators: corporate cash flow, dividend payout, leverage level, firm size, industry sales growth rate, and the firm's own sales growth rate.
Mediating Variable	Green Patents	EP	Natural logarithm of (1 + total number of invention patents, utility model patents, and design patents) divided by ln(1 + R&D expenditure)
Control Variables	Company Size	Size	Natural logarithm of total assets at the end of the year
	Listing Age	Age	Natural logarithm of (listing years + 1)
	Proportion of Independent Directors	Indep	Number of independent directors / Total number of board members

(1) Dependent Variable

The dependent variable in this study is the corporate comprehensive profitability score. Existing studies have mostly measured corporate profitability from a single dimension, such as solvency, operational capability, or profitability. Compared with a single financial indicator, the comprehensive profitability score can more fully reflect the overall financial condition and operating results of an enterprise [25]. As a multidimensional comprehensive evaluation indicator, the comprehensive score contains richer financial information and can effectively measure the overall financial performance of the enterprise. Referring to the methods of existing studies [25], this paper selects seven financial indicators—current ratio, quick ratio, debt-to-asset ratio, accounts receivable turnover, total asset turnover, return on equity (ROE), and gross profit margin—and applies the entropy weight method for objective weighting [26] to obtain the corporate comprehensive profitability score.

(2) Independent Variables

One of the independent variables in this study is R&D intensity. R&D intensity is an important way for enterprises to acquire core competitiveness and innovation advantages. Especially for knowledge-intensive enterprises, R&D activities constitute the primary means of technological innovation [27]. Existing studies have mostly measured R&D intensity as the ratio of R&D expenditure to operating revenue [28-30], while some scholars directly use the amount of R&D investment [31]. For agricultural enterprises, R&D activities are characterized by long cycles, high risks, and strong influence from natural conditions; thus, the measurement of R&D investment needs to take into account the overall operating scale of the enterprise. Following the approach of existing studies [27], this paper adopts the ratio of R&D expenses to total expenses as the measure of R&D intensity for agricultural listed companies. A higher ratio indicates a greater relative intensity of R&D investment, which can better reflect the degree of resource allocation toward technological innovation by agricultural enterprises.

The other independent variable in this study is financing constraints. Financing constraints refer to the significant difference between the costs of internal and external financing, which makes it difficult for enterprises to raise funds to support their investment activities [32]. Existing studies mainly adopt multi-indicator composite index methods to measure financing constraints, among which the KZ index [33] and the WW index [18] are two widely used indicators in academia [34,35]. Compared with the KZ index, the WW index is constructed based on a structural investment model and includes multiple dimensions such as corporate cash flow, dividend payout, long-term debt, firm size, industry sales growth, and firm sales growth. It can more comprehensively reflect the degree of external financing constraints faced by enterprises [18]. Therefore, this paper uses the WW index as the measure of financing constraints for agricultural listed companies. A higher WW index indicates a higher degree of financing constraints faced by the enterprise.

(3) Mediating Variable

The mediating variable in this study is green patents. Green patents are an important output of corporate green innovation activities and reflect an enterprise's technological innovation capability in the fields of environmental protection and sustainable development [22,36]. For agricultural listed companies, the measurement of green patents is particularly critical because the application of agricultural technologies has strong regional dependence and ecological sensitivity. Green patents not only embody technological

breakthroughs but also reflect the enterprise's adaptability to regional resource endowments and environmental protection requirements. Existing studies mainly use the number of green patent grants or applications as proxy variables [22,36]. Considering the differences in firm size and innovation investment levels, simply using the number of green patents cannot accurately measure green innovation efficiency. Referring to the approach of existing studies [22], this paper adopts the ratio of green patent quantity to R&D expenditure to measure green innovation efficiency. The specific measurement of green patents is as follows: first, take the natural logarithm of (1 + total number of green patent grants), and then divide it by the natural logarithm of (1 + R&D expenditure). A higher ratio indicates higher green patent output per unit of R&D investment and thus higher green innovation efficiency.

(4) Control Variables

To mitigate omitted variable bias, this paper draws on existing studies and selects listing age, firm size, and the proportion of independent directors as control variables. Agricultural listed companies generally feature longer establishment periods, special asset structures, and relatively traditional governance models, which make the above organizational characteristic variables particularly meaningful in explaining the profitability of agricultural enterprises. Existing studies have shown that listing years have a significant impact on board structure and constitute an organizational characteristic variable that cannot be ignored in firm-level research [37]. Therefore, this paper uses the natural logarithm of (listing years + 1) to measure listing age. Sewpersadh confirmed in an empirical analysis of South African listed companies that firm size has a significant impact on both capital structure and financial performance [38]; accordingly, this paper uses the natural logarithm of total assets at the end of the year as the measure of firm size. Koufopoulos et al. pointed out that the proportion of independent directors is a key indicator for measuring board independence and plays an important role in corporate strategic decision-making [39]. Therefore, this paper defines it as the number of independent directors divided by the total number of board members.

3.2 Model Construction

To verify the impact of green innovation on the profitability of agricultural enterprises, i.e., research hypothesis H1, this paper draws on existing research methods [40,41] and constructs multiple regression models for empirical testing. As an important strategy for enterprises to achieve sustainable development, green innovation has received widespread attention from academia in recent years. Theoretically, green innovation may affect corporate financial performance by optimizing resource allocation, improving production efficiency, and reducing environmental costs [42]. At the same time, financing constraints, as a key factor restricting corporate innovation activities, may also influence corporate profitability [35]. To accurately identify the direction and magnitude of the effects of R&D intensity and financing constraints on corporate profitability, this paper incorporates firm age, firm size, and the proportion of independent directors as control variables to mitigate potential estimation bias caused by omitted variables. The specific model specifications are as follows:

$$Score1_{i,t}=\alpha_0+\alpha_1 Research_{i,t}+\alpha_2 Age_{i,t}+\alpha_3 Size_{i,t}+\alpha_4 Indep_{i,t}+\varepsilon_{i,t} \quad (1)$$

$$Score1_{i,t}=\alpha_0+\alpha_1 WW_{i,t}+\alpha_2 Age_{i,t}+\alpha_3 Size_{i,t}+\alpha_4 Indep_{i,t}+\varepsilon_{i,t} \quad (2)$$

where $Score1_{i,t}$ is the dependent variable, representing the profitability of firm i in year t; the independent variable $Researchi,t$ represents the green innovation level of firm i in year t, and its coefficient α_1 indicates the impact of R&D intensity on corporate profitability; the independent variable $WW_{i,t}$ represents the green innovation level of firm i in year t, and its coefficient α_1 indicates the impact of financing constraints on corporate profitability. $Age_{i,t}$, $Size_{i,t}$, and $Indep_{i,t}$ are control variables such as firm age, firm size, and the proportion of independent directors, respectively. $\varepsilon_{i,t}$ is the random error term.

On the basis of Model (1), to test the mediating effect of green patents between R&D intensity and corporate profitability, this paper further introduces the mediating variable green patents and constructs the following recursive model. According to the resource-based view, R&D intensity, as an important input into corporate green innovation, may not exert a completely direct effect on corporate profitability; instead, part of its effect may operate through the intermediate output of green patents [22]. Therefore, incorporating green patents into the model helps reveal the internal transmission mechanism through which R&D intensity affects corporate profitability. The specific model is specified as follows:

$$Score1_{i,t}=\alpha_0+\alpha_1 Research_{i,t}+\alpha_2 EP_{i,t}+\alpha_3 Controls_{i,t}+\epsilon_{i,t} \quad (3)$$

where $EP_{i,t}$ represents the green patent level of firm i in year t, reflecting the green innovation output per unit of R&D investment. $Controls_{i,t}$ is a set of control variables, including firm age, firm size, and the proportion of independent directors. This model aims to examine whether the direct effect of R&D intensity on corporate profitability changes after controlling for green patents, thereby determining whether green patents play a mediating role.

On the basis of Model (2), to test the mediating effect of green patents between financing constraints and corporate profitability, this paper further introduces the mediating variable green patents and constructs the following recursive model. As an important indicator of a firm's external financing environment, moderate financing constraints can encourage enterprises to optimize resource allocation and improve capital utilization efficiency, thereby exerting a positive impact on profitability [23]. Specifically, firms facing higher financing constraints tend to select green innovation projects more prudently, concentrating limited resources on high-return innovation activities, and thus enhance their competitive advantage and financial performance through the output of green patents. The specific model is specified as follows:

$$Score1_{i,t}=\beta_0+\beta_1 WW_{i,t}+\beta_2 EP_{i,t}+\beta_3 Controls_{i,t}+\epsilon_{i,t} \quad (4)$$

where $WW_{i,t}$ represents the degree of financing constraints faced by firm i in year t, and $EP_{i,t}$ represents the green patent level of firm i in year t.

To examine the mediating role of green patents in the relationship between R&D intensity and corporate profitability, as well as between financing constraints and corporate profitability, this paper draws on the mediation effect testing procedure proposed by Baron and Kenny [43] and adopts a two-step approach. The first step is to test the impact of the independent variable on the mediating variable, i.e., to examine whether the regression coefficient of R&D intensity on green patents is significant. The second step is to include both the independent variable and the mediating variable in the model simultaneously and test whether the impact of the mediating variable on the dependent variable is significant. If the regression coefficients in both steps are significant, the mediating effect is considered to hold. This testing method can effectively identify whether green patents play a mediating role between R&D intensity and corporate profitability by progressively verifying the transmission pathways among variables.

3.3 Data Sources

This paper selects A-share agricultural listed companies from 2016 to 2024 as the research sample. To ensure the completeness and accuracy of the data, the initial sample is screened from the following two aspects: ST and *ST firms are excluded; firms in their first year of initial public offering are removed. To mitigate the influence of outliers, all continuous variables in the research sample are winsorized at the 5% and 95% levels. Among them, data on green innovation variables are sourced from the CNRDS database, while firm-level financial data and industry characteristic data are mainly obtained from the CSMAR database and the WIND database.

4. Empirical Analysis

4.1 Descriptive Statistics

Table 2 reports the descriptive statistics of the main variables. The dependent variable, corporate comprehensive profitability score, has a mean of 2.949, a standard deviation of 2.736, a minimum value of 0.564, and a maximum value of 11.508, indicating significant differences in profitability among the sample firms. Regarding the independent variables, the mean of R&D intensity is 0.234, with a standard deviation of 0.193, a minimum of 0.010, and a maximum of 0.667, suggesting considerable variation in R&D investment levels across sample firms, with some enterprises exhibiting a relatively high proportion of R&D expenditure. The mean of financing constraints is -0.996, with a standard deviation of 0.059, a minimum of -1.079, and a maximum of -0.903, indicating that the sample firms generally face a certain degree of financing constraints, though the overall variation is relatively small. The mediating variable, green patents, has a mean of 0.115, a standard deviation of 0.076, a minimum of 0.000, and a maximum of 0.226, suggesting that the overall level

of green patent output among the sample firms is relatively low, with some enterprises having yet to generate any green patent output.

Table 2: Descriptive Statistics

VarName	Obs	Mean	SD	Min	Median	Max
EP	117	00.115	0.076	0.000	0.127	0.226
Size	117	3.527	0.828	2.076	3.477	5.176
Age	117	2.606	0.523	1.386	2.708	3.258
Indep	117	0.176	0.038	0.125	0.167	0.273
WW	95	-0.996	0.059	-1.079	-1.012	-0.903
Research	117	0.234	0.193	0.010	0.147	0.667
Score1	117	2.949	2.736	0.564	2.116	11.508

4.2 Baseline Regression Results

To examine the impact of R&D intensity on corporate comprehensive profitability, this study constructs baseline regression models for empirical testing. The baseline regression results are reported in Table 3, which reveal the effect of firms' R&D intensity on comprehensive profitability. When control variables are not included, R&D intensity shows a significant negative correlation with corporate comprehensive profitability. After incorporating control variables such as firm age, firm size, and the proportion of independent directors, the regression coefficient of R&D intensity remains significantly negative at the 1% level. This result indicates that the current R&D investments of the sample firms have not yet produced a positive effect on profitability. R&D activities may face difficulties in achieving commercialization in the short term, or the efficiency of R&D resource allocation requires further improvement. In the agricultural sector, constrained by external factors such as natural conditions and biological cycles, technological achievements require longer validation periods and higher adoption thresholds from R&D to practical application. Consequently, the negative impact of R&D investment on current-period profitability is particularly pronounced.

Table 3: Baseline Regression Results

Variable	(1)	(2)
Research	-4.332***	-3.874***
Control Variables	NO	YES
Age	-	-0.404
Size	-	0.137
Indep	-	-11.084*
N	117	117
R^2	0.094	0.128

** p < 0.1, ** p < 0.05, *** p < 0.01*

The impact of financing constraints on corporate profitability is presented in Table 4. As shown in Column (1), when only financing constraints are considered, the WW index exhibits a significant positive correlation with comprehensive profitability, with a coefficient of 13.617 that is significant at the 1% level. In Column (2), after further including control variables such as firm age, firm size, and the proportion of independent directors, the coefficient of financing constraints increases to 23.589 while maintaining the same level of significance. Overall, financing constraints do not act as an obstacle to corporate profitability. Instead, moderate external financing pressure may encourage firms to optimize internal capital allocation, thereby enhancing profitability performance.

Table 4 Baseline Regression Results

Variable	(1)	(2)
WW	13.617***	23.589***
Control Variables	NO	YES
Age		-1.081**
Size		0.832
Indep		-9.031
N	95	95
R2	0.076	0.157

** p < 0.1, ** p < 0.05, *** p < 0.01*

4.3 Robustness Tests

To ensure the reliability of the research findings, this study employs two methods for robustness testing: (1) replacing the dependent variable and (2) replacing the control variables. Specifically, when replacing the dependent variable, the core dependent variable in the original model is substituted with a similar alternative indicator to test whether the estimation results of the core independent variables are affected by the measurement method. When replacing the control variables, some control variables in the original model are replaced with other factors that may influence the dependent variable, thereby excluding potential interference caused by the choice of control variables. The results of the two robustness tests are presented in Table 5.

Table 5: Robustness Tests

Variable	Original Model	Replace Dependent Variable	Replace Control Variables
Research	-4.332***	-11.779***	-4.332***
	(-3.451)	(-4.297)	(-3.451)
WW	13.617***	48.386***	13.617***
	-2.755	-4.901	-2.755
Size	Controlled	Controlled	Controlled
Age	Controlled	Controlled	Controlled
Indep	Controlled	Controlled	—
ROA	—	—	Controlled
constant	3.961***	9.104***	3.961***
	-10.423	-10.971	-10.423
N	117	117	117
Adi.R2	0.086	0.131	0.086

** p < 0.1, ** p < 0.05, *** p < 0.01*

(1) Replacing the Dependent Variable. In the robustness test, this study adopts Score2, a comprehensive score calculated by objectively weighting seven financial indicators—current ratio, quick ratio, debt-to-asset ratio, return on equity (ROE), total asset turnover, net profit margin, and gross profit margin—using the entropy weight method. Score2 replaces the original dependent variable Score1, and the models are re-estimated. As shown in Table 5, after replacing the dependent variable, the coefficient of Research is -11.779, which is significantly negative at the 1% level; the coefficient of WW is 48.386, which is significantly positive at the 1% level. The significance and direction of the core independent variables remain consistent with the original model, indicating that the conclusions of this study are robust.

(2) Replacing the Control Variables. To further confirm the reliability of the conclusions, this study replaces the control variables Indep, Age, and Size with ROA, Age, and Size, and re-estimates the models. As shown in Table 5, after replacing the control variables, the coefficient of Research remains -4.332, which is significantly negative at the 1% level; the coefficient of WW remains 13.617, which is significantly positive at the 1% level. The significance and direction of the core independent variables are consistent with the original model, and the conclusions align with the baseline regression results.

5. Further Analysis

5.1 Mediating Effect

To examine whether green patents play a mediating role between R&D intensity and corporate profitability, this study follows the stepwise testing paradigm proposed by Baron and Kenny [43]. It sequentially tests the effect of the independent variable on the mediating variable and the effect of the mediating variable on the dependent variable. The results are presented in Table 6.

The regression coefficient of R&D intensity on green patents is 3.529, which is significantly positive at the 1% level, indicating that an increase in R&D investment significantly promotes the output of green patents. The regression coefficient of green patents on corporate profitability is 0.464, which is significantly positive at the 5% level, indicating that green patent output makes a significant positive contribution to profitability. Both coefficients reach statistical significance, satisfying the judgment criteria of the stepwise

testing method. This confirms that green patents play a significant mediating role between R&D intensity and profitability.

Further analysis of the sign relationship between direct and indirect effects reveals that, without the mediating variable, the direct effect of R&D intensity on profitability is -5.509, showing a significant negative relationship. After including the mediating variable, the indirect effect of R&D intensity through green patents is 1.635. This indicates that the impact of R&D intensity on profitability consists of two coexisting paths: on the one hand, R&D expenditures are directly recorded as costs in the current period, exerting a negative squeezing effect on profitability [5,10]; on the other hand, R&D investment promotes green patent output, which in turn makes a positive contribution to profitability [48,49]. The two paths have opposite directions, and green patents play a positive mediating role.

Table 6: Mediating Effect of the R&D Intensity Path

Path	Coefficient	Standard Error	t-value	p-value	95% Confidence Interval
Path a: Research → EP	3.529	0.697	5.06	0	[2.147,4.911]
Path b: EP → Score1	0.464	0.179	2.06	0.011	[0.109,0.817]
Direct effect: Research → Score1	-5.509	1.461	-3.77	0	[-8.404,-2.615]
Indirect effect	1.635	-	-	-	-

** $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

This study adopts the stepwise testing procedure proposed by Baron and Kenny [42] to explore the mediating mechanism of green patents between financing constraints and corporate profitability. The test results are shown in Table 7.

The regression coefficient of financing constraints on green patents is -0.436, which is significantly negative at the 5% level, indicating that an increase in the degree of financing constraints significantly inhibits the output of green patents [19,45]. The regression coefficient of green patents on corporate profitability is -8.520, which is significantly negative at the 5% level, indicating a significant negative association between green patent output and profitability [35,50].

Without the mediating variable, the direct effect of financing constraints on profitability is 19.870, showing a significant positive relationship. After including the mediating variable, the indirect effect of financing constraints through green patents is 3.715. It can be seen that the net effect of financing constraints on profitability consists of two parts: in terms of the direct effect, moderate financial pressure can stimulate enterprises to improve internal operational efficiency, forming a positive driving force [45,48]; in terms of the indirect effect, financing constraints weaken the enterprise's potential profit space to a certain extent by inhibiting green patent activities [49,51]. Since the positive contribution of the direct effect exceeds the negative drag of the indirect effect, financing constraints still exert an overall positive impact on profitability, and green patents play a negative mediating role.

Table 7: Mediating Effect of the Financing Constraints Path

Path	Coefficient	Standard Error	t-value	p-value	95% Confidence Interval
Path a: WW → EP	-0.436	0.217	-2.01	0.047	[-0.867,-0.006]
Path b: EP → Score1	-8.52	3.922	2.17	0.032	[-16.312,-0.727]
Direct effect: WW → Score1	19.870	8.237	2.41	0.018	[3.502,36.238]
Indirect effect	3.715	-	-	-	-

** $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

5.2 Heterogeneity Analysis

(1) Based on the Division between Northern and Southern Regions

Considering the significant differences between northern and southern China in terms of economic development level, degree of marketization, and institutional environment [11], existing studies indicate that, compared with the south, the northern region experiences a higher degree of government intervention and a larger proportion of state-owned enterprises. Differences in the institutional environment have become an important reason for the widening economic gap between northern and southern China during the transformation of China's development model, with green innovation capability serving as a key mechanism through which the institutional environment affects this north-south economic disparity. As the foundational industry of the national economy, agriculture is particularly strongly influenced by resource endowments and

institutional environment. The northern region of China is dominated by plains, where agricultural production features a higher degree of scale and mechanization and relies more heavily on government-led farmland water conservancy infrastructure and agricultural subsidy policies. In contrast, the southern region consists largely of mountainous and hilly areas, where agricultural operations are more dispersed and the degree of marketization is higher, with agricultural enterprises tending to allocate resources through market mechanisms. These differences in agricultural resource endowments and business models between the north and south make the impact of the institutional environment on green innovation of agricultural enterprises particularly pronounced. Based on this, the present study further divides the full sample into southern and northern enterprises and examines the impact of regional heterogeneity on the relationship between core variables through group regression. The results are shown in Table 8.

The regression results show that in the southern sample, the coefficient of R&D intensity on profitability is -1.683, which is significantly negative at the 1% level, while the coefficient of financing constraints is 2.973, which does not reach conventional significance levels. In the northern sample, the coefficient of R&D intensity is -5.975, which is significantly negative at the 1% level, and the coefficient of financing constraints is 55.379, which is significantly positive at the 1% level. Comparing the two subsamples, the effects of both R&D intensity and financing constraints on profitability exhibit stronger significance and larger coefficient magnitudes in the northern sample.

The above differences are likely closely related to the institutional environment disparities between the north and south. The northern region features a higher degree of government intervention and a larger share of state-owned enterprises, with the role of market mechanisms being relatively constrained. Under such an institutional environment, the efficiency with which enterprises convert R&D investment into profitability is lower, resulting in a more pronounced negative effect of R&D intensity. At the same time, the "forced mechanism" triggered by financing constraints is more significant, prompting enterprises to allocate internal resources more prudently and thereby exerting a stronger positive impact on profitability. In contrast, the southern region has a higher degree of marketization, with resource allocation relying more on market mechanisms and higher innovation transformation efficiency. Consequently, the negative effect of R&D intensity is smaller, and the role of financing constraints is also insignificant.

Table 8: Regional Heterogeneity Test Results

Variable	Southern Sample	Northern Sample
Research	-1.683***	-5.975*
	(0.341)	(3.379)
WW	2.973	55.379**
	(2.244)	(23.897)
Control Variables	YES	YES
N	45	72

** p < 0.1, ** p < 0.05, *** p < 0.01*

(2) Based on the Division between Pre- and Post-Epidemic Periods

Considering the profound impact of the COVID-19 outbreak in 2020 on corporate operating environments and innovation activities [25,44], relevant studies show that the pandemic not only exerted a sustained "long-term effect" on corporate innovation investment [44] but also caused a significant shock to the output of green invention patents [12,13]. For agricultural listed companies, the impact of the pandemic is particularly distinctive. Agricultural production is characterized by strong seasonality, long supply chains, and vulnerable biological assets. Issues such as logistics disruptions, shortages of agricultural materials, and restricted labor mobility caused by the pandemic directly disrupted the normal production and operation of agricultural enterprises. Meanwhile, agricultural technology R&D relies on field trials and on-site promotion; pandemic lockdown measures extended the transformation cycle from R&D achievements to application, posing greater challenges to green innovation activities of agricultural enterprises. Based on this, the present study divides the full sample into two periods—before 2020 and 2020 onward—and examines the moderating role of temporal heterogeneity on the relationship between core variables through group regression. The results are shown in Table 9.

From the regression results, in the pre-2020 sample, the coefficient of R&D intensity on profitability is -2.762, which is significantly negative at the 10% level, while the coefficient of financing constraints is 9.399,

which fails the significance test. In the 2020 and post-2020 sample, the coefficient of R&D intensity is -9.471, which is significantly negative at the 1% level, and the coefficient of financing constraints is 60.748, which is significantly positive at the 1% level. The comparison between the two subsamples shows that the effects of both R&D intensity and financing constraints on profitability are more pronounced in the post-epidemic period, with a significant increase in the absolute values of the coefficients.

This difference reflects the reshaping effect of the COVID-19 pandemic as an external shock on corporate operating logic [44]. After the outbreak, shrinking market demand and supply chain disruptions led to a decline in the short-term return rate of R&D activities, amplifying the negative effect of R&D investment. At the same time, the narrowing of external financing channels forced financially constrained enterprises to strengthen internal capital allocation efficiency, making the "forced mechanism" of financing constraints more evident during the pandemic. In addition, the advancement of the "dual carbon" strategy after the epidemic further strengthened the strategic position of green innovation, exerting a profound influence on corporate innovation decisions [25].

Table 9: Temporal Heterogeneity Test Results

Variable	Pre-2020	2020 and After
Research	-2.762*	-9.471***
	(1.588)	(2.727)
WW	9.399	60.748***
	(7.242)	(20.029)
Control Variables	YES	YES
N	52	65

** p < 0.1, ** p < 0.05, *** p < 0.01*

6. Conclusions and Suggestions

6.1 Research Conclusions

This study takes Chinese A-share agricultural listed companies from 2016 to 2024 as the research sample. As special entities connecting natural ecosystems and market economies, agricultural enterprises' green innovation activities possess both technological and ecological attributes and exhibit high dependence on resource endowments and the external environment. Drawing on the resource-based view and innovation theory, this study constructs multiple regression models to systematically examine the impact of green innovation on corporate profitability and introduces green patents as a mediating variable to reveal its internal transmission mechanism. Furthermore, from the perspectives of regional heterogeneity and temporal heterogeneity, this study explores the influence of north-south institutional differences and the COVID-19 shock on the main effects. The main conclusions are as follows:

First, R&D intensity has a significant negative impact on corporate profitability, while financing constraints have a significant positive impact on corporate profitability. The baseline regression results show that R&D intensity is significantly negatively correlated with the comprehensive profitability score at the 1% level, indicating that the current R&D investments of the sample firms have not yet been effectively converted into improvements in profitability. This may be due to low R&D efficiency or long commercialization cycles of R&D achievements. Financing constraints are significantly positively correlated with the comprehensive profitability score at the 1% level, indicating that firms facing higher degrees of financing constraints actually exhibit better profitability, as such constraints encourage enterprises to allocate internal resources more prudently and improve capital utilization efficiency.

Second, green patents play a positive mediating role between R&D intensity and profitability, and a negative mediating role between financing constraints and profitability. The mediation effect test results show that R&D intensity has a significant positive impact on green patents, and green patents have a significant positive impact on profitability; thus, R&D intensity indirectly enhances corporate profitability by promoting green patent output. In contrast, financing constraints have a significant negative impact on green patents, and green patents also show a significant negative association with profitability; therefore, financing constraints indirectly weaken corporate profitability by suppressing green patent output. Further analysis reveals that financing constraints have a direct positive effect on profitability, but the indirect negative effect

generated through the suppression of green patents partially offsets the direct effect, resulting in an overall net positive effect.

Third, the impact of green innovation on corporate profitability exhibits significant regional heterogeneity and temporal heterogeneity. The division based on northern and southern regions shows that in the northern sample, both the negative effect of R&D intensity and the positive effect of financing constraints are much stronger than in the southern sample. This indicates that the institutional environment in the northern region—with higher government intervention and a larger share of state-owned enterprises—leads to lower efficiency in converting innovation into profitability, while the "forced mechanism" of financing constraints is stronger. The division based on pre- and post-epidemic periods shows that in the 2020 and post-2020 sample, both the negative effect of R&D intensity and the positive effect of financing constraints are much stronger than in the pre-2020 sample. This indicates that the COVID-19 pandemic, as a major external shock, increased the difficulty of converting R&D investment into profitability, while firms facing higher financing constraints allocated internal resources more prudently during the pandemic, thereby exerting a greater positive impact on profitability.

6.2 Policy Suggestions

Based on the above research conclusions, this study offers the following suggestions for the business practices of agricultural listed companies:

First, optimize R&D investment management mechanisms and improve the efficiency of innovation resource transformation. The baseline regression results indicate a significant negative correlation between R&D intensity and corporate profitability, reflecting that the sample firms' R&D investments have not yet formed effective profit contributions. Agricultural enterprises should establish a closed-loop management system covering the entire process of innovation activities. In the project initiation stage, it is necessary to strengthen the strategic alignment between R&D projects and core business, giving priority to applied technologies with shorter transformation cycles, such as precision agriculture, stress-resistant breeding, and smart irrigation, to avoid excessive dispersion of R&D resources. In the process control stage, phased achievement evaluation nodes should be set to dynamically review technical feasibility and market prospects, and to adjust or terminate inefficient projects in a timely manner. In the achievement transformation stage, collaboration barriers between R&D departments and production departments should be removed, and a rapid response mechanism should be established from technological breakthroughs to field application or product launch. Relying on industry-university-research cooperation platforms to introduce external scientific research forces can help share R&D risks and improve capital utilization efficiency.

Second, leverage the forcing function of financing constraints and strengthen internal resource allocation capabilities. The baseline regression results show a significant positive correlation between financing constraints and corporate profitability, indicating that moderate financial pressure can motivate enterprises to optimize internal management. Agricultural enterprises should transform financing constraints into a driving force for improving operational efficiency. At the investment decision-making level, a strict capital expenditure approval system should be established to conduct refined benefit evaluations for various investment projects, giving priority to projects with stable cash flows and shorter payback periods, such as cold-chain logistics facility upgrades and deep processing production lines for agricultural products. At the capital operation level, internal funding pools can be established, accounts receivable management strengthened, and inventory turnover optimized to improve capital utilization efficiency and reduce dependence on external financing. At the strategic layout level, the impulse for diversified expansion should be moderately controlled, with a focus on core businesses and the concentration of limited resources on key operational segments, so as to cope with changes in the external financing environment with a sound financial structure.

Third, build green patent transmission pathways and open channels from innovation investment to profitability transformation. The mediation effect test results indicate that green patents play a positive mediating role between R&D intensity and profitability, and a negative mediating role between financing constraints and profitability. This finding highlights the critical bridging role of green patents between innovation activities and corporate performance. In the patent creation stage, a dedicated patent management department should be established to coordinate the entire process from R&D project initiation to

achievement transformation. In the patent layout stage, focus should be placed on key areas such as agricultural green production, resource recycling, and low-carbon technologies to form competitive patent portfolios. In the patent utilization stage, a hierarchical evaluation system should be established to prioritize the allocation of industrialization resources to green patents with commercialization potential, and to explore various transformation methods such as patent licensing, technology transfer, and equity investment, thereby converting technological advantages into economic returns.

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