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The Impact of Government Subsidies on Technological Innovation in Agribusiness: The Case for China

Liping Wu [1], Kai Hu [1], Oleksii Lyulyov [2,3], Tetyana Pimonenko [2,3,*] and Ishfaq Hamid [4]

1 College of Economics and Management, Jiangxi Agricultural University, Nanchang 310045, China
2 Department of Management, Faculty of Applied Sciences, WSB University, 41-300 Dabrowa Gornicza, Poland
3 Department of Marketing, Sumy State University, 40007 Sumy, Ukraine
4 MICA, The School of Ideas, Ahmedabad 380058, India
* Correspondence: tetyana_pimonenko@econ.sumdu.edu.ua

Abstract: With the implementation of the rural revitalization strategy and the promotion of agricultural and rural modernization, the subsidies enjoyed by agricultural enterprises in China are increasing. As a result, the effectiveness of government subsidies for the technological innovation of agricultural enterprises has attracted more and more attention. Based on the perspectives of the whole industry chain of agriculture, forestry, animal husbandry, fisheries, and of processing, manufacturing, circulation, and service, this paper takes the listed agricultural companies from 2007 to 2019 as a research sample and empirically tests the effects and mechanisms of government subsidies on the technological innovation of agricultural enterprises. The study applies the fixed effect and intermediary effect models. The findings show that government subsidies potentially encourage agricultural enterprises to grow more successfully. Moreover, R&D expenditure is essential for enterprise technological innovation and leads to an intermediate impact. At the same time, government subsidies for the technological innovation of agricultural enterprises have a certain heterogeneity between different industries, state-owned enterprises and non-state-owned enterprises, and large enterprises and small and medium-sized enterprises. Therefore, this study argues that the government should continue to raise subsidies. In addition, the subsidies should be "different from enterprise to enterprise", and government subsidy funds should be better supervised to foster agricultural technological innovation properly.

Keywords: industry chain; government grants; technological innovation in agricultural enterprises; R&D investment

Citation: Wu, L.; Hu, K.; Lyulyov, O.; Pimonenko, T.; Hamid, I. The Impact of Government Subsidies on Technological Innovation in Agribusiness: The Case for China. *Sustainability* **2022**, *14*, 14003. https://doi.org/10.3390/su142114003

Academic Editors: Aaron K. Hoshide and Francesco Caputo

Received: 15 September 2022
Accepted: 24 October 2022
Published: 27 October 2022

1. Introduction

The Chinese government accepted the agricultural and rural modernization plan during the 14th Five-Year Plan period (2021–2025) [1]. In consideration of this, innovation was outlined as the core force for agricultural and rural modernization. The innovations in agricultural development are directed at improving the production of agricultural goods. The innovations in rural development allow the improvement of the production of agricultural goods and the education, health, and social infrastructure of rural areas.

Therefore, agricultural enterprises face several types of risks, such as environmental risks and operations risks [2–4]. In addition, agricultural enterprises face the issue of a lack of financing for the implementation of innovations [5–11]. Consequently, this limits the development of agricultural enterprises. Government subsidies in the form of financial aid have been implemented for a long time in China to modernize agricultural and rural development. In this case, government subsidies for agriculture and rural development may be defined as investments [12–18]. Past studies [14,19–21] outline that government subsidies could guide and motivate enterprises to increase R&D investment to implement technological innovation activities. At the same time, the inefficiency of government subsidies could be caused by the adverse selection of the innovation activities of enterprises for subsidies [14]. Adverse selection results in asymmetric information on available options for government subsidies.

Consequently, it could provoke inequalities and gaps in a company's innovation development and cause a decline in their long-term competitiveness [15]. Past research [16] has proven that information asymmetry between the government and enterprises causes subsidies to have a reverse effect. This could limit the achievement of indicated goals in the plan for agricultural and rural modernization during the 14th Five-Year Plan period (2021–2025) [1]. Thus, it is justifiable to analyze how government subsidies affect the technological innovation of agricultural enterprises and their mechanisms of action. It should be noted that in the ongoing economic open system theory [22], the development of all sectors, including agriculture and rural development, should be analyzed in connection with each other. Thus, agriculture is increasingly closely linked to the secondary and tertiary industries and fails to scientifically reflect the value of the whole industrial chain, such as production, processing, circulation, the service of agriculture, forestry, animal husbandry, and fisheries.

This paper focuses on analyzing the impact of government subsidies on agricultural enterprises' technological innovation from the whole industry chain perspective. Such samples allow the modelling of agricultural enterprises' whole and individual behavior. In addition, they allocate and measure the statistical effects that could not be determined based on the data of the individual enterprises. Regarding the standard of the National Bureau of Statistics' "Statistical Classification of Agriculture and Related Industries (2020)" (Order No. 32 of the National Bureau of Statistics) [23], agricultural enterprises are defined as all economic activities formed in the production, processing, manufacturing, service and other links of agriculture, forestry, animal husbandry, and fisheries, as well as relevant enterprises in the secondary and tertiary industries.

Our research aims to fill the following scientific gaps: (1) to develop a methodology to check the link between government subsidies and the technological innovation of agricultural enterprises; (2) to analyze agriculture from the whole industrial chain, and extend the scope of agricultural enterprises to agriculture, forestry, animal husbandry, fisheries production, processing, manufacturing, circulation, service, and other industries; and (3) to develop a methodology to check whether research and development could extend the innovation among agricultural enterprises. The remainder of this paper is divided into the following sections: Section 2 presents empirical evidence from the literature; Section 3 discusses the methodology and data; Section 4 analyzes the findings; and Section 5 considers conclusions and policy implications.

2. Literature Review

2.1. The Relationship between Government Subsidies and Technological Innovation in Agricultural Enterprises

Past research shows that there has been no consensus on the effect of government subsidies on enterprise technology innovation. A few main views constitute these findings. Government subsidies could incentivize enterprises to innovate technologically [3,22–41]. The late economist Kenneth Arrow [24] suggested that the technological innovation of enterprises has a spillover effect. Moreover, the free-riding behavior of other enterprises has seriously hit the enthusiasm of enterprises for independent innovation. This has provoked an insufficient supply of technological innovation. Subsequent research [25–27] has confirmed that government subsidies positively impact companies' performances. One of these studies [25] analyzed 158 listed energy companies in China. In this case, government subsidies for technological innovations negatively impacted company performance in the short term. At the same time, a positive effect was shown in the long term. Other researchers [26] demonstrated that Chinese government subsidies stimulate innovations in environmental management. However, these types of subsidies did not encourage the rapid growth of technological innovations. It should be noted that carbon-free technological innovation could enhance the performance of companies [27]. However, the effect could be different depending on the time and efficiency of management.

Government subsidies can directly provide financial support to agricultural enterprises. As part of the profits of enterprises, government subsidies directly increase enterprises' funds, alleviate the shortage of funds available to agricultural enterprises, improve their enthusiasm to innovate, and solve the spillovers of innovative results. They also reduce the risk caused by the uncertainty of innovation and encourage enterprises to increase R&D investment in technological innovation [28,33]. Secondly, government subsidies send a positive signal of government recognition and reduce the information asymmetry between enterprises and external investors. An enterprise that enjoys this subsidy shows that the government recognizes their development. This proves that the enterprise has strong R&D innovation ability, good innovation projects, and is more willing and capable of technological innovation [3,28–33]. At the same time, scholars [32,33] confirm that government subsidies should be implemented at all levels, from companies to individuals. In this case, government subsidies could positively impact agriculture.

Government subsidies can improve the ability of enterprises to access resources. They can also improve the ability of enterprises to obtain resources by supplementing their innovation resources and enhancing their recruitment of talented workers. Agribusinesses receiving government subsidies send positive signals of good relations with the government, indicating they have sufficient government resources. The government provides an invisible guarantee for agricultural enterprises to make up for the natural weakness of agriculture and attracts banks, venture capitalists, etc., to increase investment. Furthermore, it also increases the attractiveness of enterprises to prospective employees, which improves the overall level of Research and Development (R&D) personnel, and enhances the technological innovation capabilities of enterprises [34].

Past research [35] on strategic emerging industry enterprises found that the impact of financial incentive policies on innovation conforms to an inverted U-shape. In this case, the scholars confirmed that government subsidies stimulate innovation to a certain point, after which efficiency declines. Thus, the government should control monitoring systems for government subsidies. Other research [36] found no significant positive impact of government subsidies on private R&D for small- and medium-sized firms. In summary, agricultural government subsidies increase funds for production and investment, release positive signals to attract more external financing and outstanding human capital, improve the ability of companies to obtain resources, and promote technological innovation for agricultural producers. Thus, we propose our first research hypothesis:

Hypothesis 1 (H1). *Government subsidies can promote technological innovation in agribusiness.*

2.2. Mechanisms of Government Subsidies for Technological Innovation in Agricultural Enterprises

Enterprises with effective Research and Development (R&D) generate technical knowledge, have certain externalities, are easily learned or reproduced, and suffer from market failure. At the same time, the investment, risk, and uncertainty of these activities provokes issues for enterprises, especially agricultural enterprises, in obtaining funds from the capital markets. Nevertheless, based on the importance of R&D and the solutions to market failures, the government should promote enterprises to carry out such innovation [42].

Based on data from Chinese companies, past research [42–44] finds that government subsidies have an incentive effect on companies' R&D activities. Government subsidies can support agricultural enterprises in increasing investment in three ways: by reducing the cost of R&D, reducing the uncertainty of these types of projects, and dispersing subsequent risks. Thus, government subsidies reduce R&D costs. According to the theory of externalities, the externalities of R&D activities lead to the spillover of knowledge, which to a certain extent discourages the enthusiasm of enterprises involved in such research. Government subsidies, as part of corporate profits, reduce the marginal cost of enterprise R&D and then stimulate agricultural enterprises to increase investment. Furthermore, government subsidies reduce uncertainty about projects [45]. This increases the market demand for a project's results and improves the expected return of the enterprise [45]. At the same time, it can also attract more qualified personnel to participate in projects, reducing their uncertainty. Finally, government subsidies can diversify R&D risks. The government provides subsidies and shares information about the project, which can attract external investors and incentivize them to join, reducing the risk of failure for enterprises to a certain extent [46,47].

According to the new economic growth theory, human capital and investment are important factors in promoting economic growth and technological innovation [42]. Enterprises, through R&D activities, improve the stock of human capital and promote enterprise innovation [41]. R&D activities are the most direct source of technological innovation. Enterprises increase investment in activities, generate new knowledge and information, and directly promote technological innovation. Furthermore, this increase in investment enables enterprises to use existing external knowledge better, enhance their knowledge stock, and indirectly promote their innovation capabilities [46]. Thus, past studies [48,49] emphasize that providing an effective R&D policy allows the development of additional advantages. This could be due to the implementation of transborder strategies on knowledge sharing, geographical changes in research developments and innovations, and the international fragmentation of research activities. It has been demonstrated that competitiveness depends on innovative activities [50]. At the same time, lack of labor and financial resources are the biggest limitations to investing in R&D.

Therefore, an increase in investment in R&D can promote technological innovation. Thus, it can be concluded that government subsidies encourage agricultural enterprises to increase investments by reducing the cost of R&D and project uncertainty, as well as helping to disperse production risk. Therefore, we propose our second hypothesis:

Hypothesis 2 (H2). *Government subsidies encourage both investment and technological innovation.*

3. Materials and Methods

3.1. Sample Selection and Data Sources

Taking the A-share (representing publicly listed Chinese companies that trade on Chinese stock exchanges, such as the Shenzhen and Shanghai Stock Exchanges) of listed agricultural companies from 2007 to 2019 as a research sample, this paper no longer limits agriculture to traditional agriculture, forestry, animal husbandry, and fisheries. Instead, it extends it to the perspective of the whole industry chain to the production, processing, manufacturing, circulation, and service of agriculture, forestry, livestock, and fisheries. Drawing from the practice of [44] and referring to the standards of the Statistical Classification of Agriculture and Related Industries (2020) (Order No. 32 of the National Bureau of Statistics) issued by the National Bureau of Statistics and the Guidelines for the Classification of Listed Companies (Revised in 2012) issued by the China Securities Regulatory Commission, agriculture-related industries include agriculture, forestry (A02), animal husbandry (A01 and A03), fisheries (A04), and services related to these natural resource-based industries (A05). Processing and manufacturing in these industries includes food processing (C13) and the manufacture of food (C14), fertilizers and pesticides (C26), and agricultural machinery (C35). Listed agricultural companies are involved in agriculture, forestry, animal husbandry, and fisheries, as well as enterprises in the secondary and tertiary input sectors whose products are essential for firms within these natural resource-based industries. We narrowed down our sample to 177 listed agricultural companies from 194 after removing 17 companies with serious financial risks. Our non-balanced panel data consisted of 2301 enterprises from these 177 companies. The enterprise patent data used in this article come from the China Research Data Service Platform (CNRDS database) [51]. Some of the missing data were provided by searching on the patent website of the State Intellectual Property Office [52]. The screening of listed agricultural companies was mainly based on analyzing enterprises' main business scopes, such as Hexun Network [53] and

Flush Database [54]. The data for the other variables were collected from the CSMAR database [55].

3.2. Variable Settings

Past studies [45,46] demonstrate that patent applications are one of the incentives for developing and implementing technological innovation at companies. In addition, considering the analytical report of World Intellectual Property Indicators 2021 [56], patents guarantee the authorship protection of innovation. Furthermore, patents allow the obtainment of additional revenue for agricultural companies. Considering this, our research used the patent applications of enterprises as the measure of technological innovation ($Patent_{t+1}$). Considering the time lag of technological innovation, the technology innovation level of t + 1 was measured by adding 1 logarithm to the number of patent applications in the t-period based on the methods outlined in [45,46]. The t-period starts with a value of 0 zero.

Government grants were the explanatory variable we evaluated. There are large differences in the amount of government subsidies distributed based on the size of a natural resource-based enterprise. In order to narrow the absolute difference between the data, the logarithm of the government subsidies received by the company in the current year was taken to measure the explanatory variables. Based on other scholars' work on enterprise technological innovation, our research used six control variables that may affect the technological innovation of agricultural enterprises, such as enterprise size, age, asset–liability ratio, growth potential, proportion of fixed assets, concentration of equity, and salary incentives (Table 1). In order to analyze the impact mechanism of government subsidies on technological innovation, we defined investment as an intermediary variable using the logarithm of the company's investment in the current year.

Table 1. Description of the variables and the calculation formula.

Variable	Symbol	Variable Name	Computational Formula
Explained variable	$Patent_{t+1}$	Number of patent applications	ln(1 + t Number of patent applications)
Explanatory variable	SUB	Governmental subsidy	ln(Government subsidy amount)
Control variables	Size	Enterprise scale	The natural logarithm of the company's total market value
	Age	Enterprise age	Sample year minus the year of company establishment
	Debt	Asset–liability ratio	End Liabilities/End Total Assets
	Growth	Growth ability	Increase the rate of business revenue
	Fixasset	The proportion of fixed assets	Net fixed assets/ending total assets
	Share	Equity concentration	The shareholding of the largest shareholder
	Salary	Compensation incentive	ln(Total annual salary of ending directors, supervisors, and senior executives)
Mediating variables	R&D	Research input	The company's R&D investment was logarithmic

3.3. Model Settings

In order to analyze the impact of government subsidies on the technological innovation of agricultural enterprises, we used a basic econometric model specified as:

$$\text{Patent}_{it+1} = \alpha_0 + \alpha_1 \text{SUB}_{it} + \beta \text{CV}_{it} + \sum \text{Year} + \sum \text{Ind} + \varepsilon_{it} \quad (1)$$

where Patent_{it+1}—technological innovation in the Company's_{t+1} period; α_0—denotes the constant term; SUB_{it}—the government subsidy of the company's t period; CV_{it}—the control variable matrix; ε_{it}—the residual term; i and t—the enterprises and years; and Year and Ind—the fixed effect of the year and industry, respectively.

The two-way fixed-effect model [57] is applied to decrease the impact of the macroeconomic environment and the nature of the industry. However, R&D investment is introduced as the intermediary variable to identify the mechanisms of government subsidies for the technological innovation of agricultural enterprises. Therefore, the following Ordinary Least Square (OLS) econometric models are set up based on model (1) r using methods from [58,59] in order to analyze the intermediary effect of R&D investment.

$$\text{RD}_{it} = \alpha_0 + \alpha_1 \text{SUB}_{it} + \beta \text{CV}_{it} + \sum \text{Year} + \sum \text{Ind} + \varepsilon_{it} \quad (2)$$

$$\text{Patent}_{it+1} = \alpha_0 + \alpha_1 \text{SUB}_{it} + \alpha_2 \text{R\&D}_{it} + \beta \text{CV}_{it} + \sum \text{Year} + \sum \text{Ind} + \varepsilon_{it} \quad (3)$$

where RD_{it} equals the R&D for company i during time period t; SUB_{it} is the government subsidy of the company's t period; and CV_{it} is the control variable matrix with ε_{it} as residual error of the model. Year and Ind are the fixed effect of the year and industry, respectively.

4. Results

4.1. Descriptive Statistics and the Correlation Analysis

The descriptive statistical results of the variables signify that the average number of patent applications is 1.6146, the median is 0.6931, and the maximum and minimum values are 7.3671 and 0 with a standard deviation of 1.3992 (Table 2). Thus, the vast majority of listed agricultural companies have technological innovations but vary greatly. In addition, the average value of government subsidies is 16.3633, the median is 16.4341, the maximum and minimum values are 20.7799 and 8.9227, respectively, and the standard deviation is 1.5357. This suggests that the government subsidies enjoyed by listed agricultural companies are more balanced, but specific differences exist.

Table 2. Descriptive statistical results of the variables.

Variable	Obs	Mean	Standard	Minimum	Median	Maximum
Patent	2301	1.6146	1.3992	0	0.6931	7.3671
SUB	1622	16.3633	1.5357	8.9227	16.4341	20.7799
Size	1680	22.3731	0.9348	19.1148	22.2638	26.3942
Age	2266	14.3350	5.9605	1	14	35
Debt	1697	0.4297	0.2184	0.0084	0.4129	2.0498
Growth	1601	1.2077	37.4913	−0.9913	0.1052	1497.1560
Fixasset	1697	0.3104	0.1619	0.0040	0.2882	0.8491
Share	1697	35.1022	14.2938	4.0800	33.7400	95.9500
Salary	1694	15.0283	0.8552	11.6082	15.0366	17.9634
R&D	1213	16.9112	1.7823	9.6347	17.0643	21.4612

The correlation analysis of the variables is shown in Table 3. Thus, the correlation coefficient between the current government subsidy (SUB) and the next phase of patent applications is 0.423 at the 1% level of significance. The correlation coefficient between the SUB and the intermediary variable for R&D input is significant with a value of 0.384. The correlation coefficient (r) denoting a positive association between R&D and the next phase of patent applications is 0.574, which is also significant at the 1% confidence level. Among the control variable, enterprise size and age are significant and positively correlate with the number of next patent applications.

Table 3. Variable correlation analysis.

Variable	$Patent_{t+1}$	SUB	Size	Age	Debt	Growth	Fixasset	Share	Salary	R&D
$Patent_{t+1}$	1.000									
SUB	0.423 ***	1.000								
Size	0.450 ***	0.441 ***	1.000							
Age	0.327 ***	0.136 ***	0.161 ***	1.000						
Debt	0.115 ***	0.211 ***	−0.053 **	0.012	1.000					
Growth	−0.034	−0.011	−0.031	−0.005	0.000	1.000				
Fixasset	0.028	0.108 ***	−0.004	−0.039	0.121 ***	−0.036	1.000			
Share	−0.112 ***	0.026	0.094 ***	−0.127 ***	−0.110 ***	0.037	0.072 ***	1.000		
Salary	0.534 ***	0.420 ***	0.580 ***	0.252 ***	−0.067 ***	−0.025	0.003	−0.071 ***	1.00	
R&D	0.574 ***	0.384 ***	0.484 ***	0.089 ***	0.039	−0.002	0.007	0.013	0.506 ***	1.000

Note: **, and *** are significant at the 10%, 5%, and 1% levels.

However, equity concentration is significant and negatively correlated (−0.112) with the number of next patent applications. Executive compensation correlates significantly with the number of next patent applications at the 1% significance level with a positive r equal to 0.534. There is a significant correlation between the main variables and further multiple regressions. The absolute value of the correlation coefficient between the main variables is less than 0.5, indicating no limited multicollinearity. Multicollinearity or high degrees of association ($r > 0.7$) between independent variables is problematic since the OLS regression model assumes "independent" impacts of independent variables specified in the model on the dependent variable. Multicollinearity distorts the parameter estimates in the OLS model rendering inferences gleaned from the model results potentially inaccurate.

4.2. Regression Analysis Results

The regression results from empirical tests on the impact of government subsidies on technological innovation in agribusiness using model (1) are shown in Table 4. After the number of patent applications in the current period plus one to take the logarithm and lag one period as the explanatory variable, the enterprise-level variables and the annual and industry fixed effects are gradually controlled. Additionally, the regression coefficient of government subsidies is significantly positive at the 1% confidence level. The findings from column (4) of Table 4 suggest that under the two-way fixed effect of control years and industries, the regression coefficient of SUB is 0.221. The change in government subsidies in the current period is 1%, and the average change in the number of patent applications of enterprises in the next year is 0.221%. This implies that government subsidies promote agricultural innovation, which validates our first hypothesis. Among the other control variables, the regression coefficients of enterprise size, asset–liability ratio, and executive compensation are significantly positive. This indicates that growth in scale results in an increasing level of debt. Furthermore, increases in executive compensation are conducive to increasing patent applications and technological innovation. The regression coefficients of enterprise age and equity concentration are significantly negative. This suggests that the longer the company is established, the higher the equity concentration, the fewer the number of patent applications, and the lower the level of technological innovation.

Table 4. Return results of the impact of government subsidies on technological innovation in agricultural enterprises.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
	Patent$_{t+1}$	**Patent$_{t+1}$**	**Patent$_{t+1}$**	**Patent$_{t+1}$**
SUB	0.464 *** (17.03)	0.209 *** (7.92)	0.201 *** (7.60)	0.221 *** (8.33)
Size		0.299 *** (6.32)	0.352 *** (6.97)	0.402 *** (8.20)
Age		0.011 * (1.70)	−0.006 (−0.72)	−0.016 * (−1.88)
Debt		0.346 * (1.96)	0.459 ** (2.51)	0.306 * (1.70)
Growth		−0.001 *** (−5.70)	−0.001 *** (−3.60)	0.000 (1.47)
Share		−0.009 *** (−3.41)	−0.010 *** (−3.87)	−0.008 *** (−3.13)
Fixasset		−0.215 (−1.00)	−0.096 (−0.45)	−0.332 (−1.34)
Salary		0.664 *** (12.15)	0.576 *** (10.14)	0.431 *** (7.59)
_cons	−5.768 *** (−13.10)	−18.187 *** (−22.77)	−17.769 *** (−21.27)	−17.733 *** (−23.15)
Year	No	No	Yes	Yes
Industry	No	No	No	Yes
N	1549	1460	1460	1460
R^2	0.179	0.358	0.373	0.452

Note: *, **, and *** are significant at the 10%, 5%, and 1% levels.

4.3. Analysis of the Intermediary Affect Test Results

Empirical testing has verified that government subsidies can promote technological innovation in agribusiness. According to the previous analysis, government subsidies may affect the technological innovation of enterprises by influencing their R&D investment. According to [58], the empirical test is carried out through models (1) and (3), and whether the R&D investment plays an intermediary role according to the regression coefficient and significance level of government subsidies and R&D investment.

Column (1) of Table 5 shows the regression results of model (1). The regression coefficient of government grants is 0.221, which is significant at the 1% confidence level. This implies that the basic variable government grant significantly positively affects the number of patent applications for the interpreted variable. Column (2) shows the regression results of model (2), and the regression coefficient of government subsidy is 0.201, which is also significant at the 1% level. Thus, government subsidies appear to have a significant impact on investment in R&D.

Column (3) in Table 5 summarizes the regression results for model (3). The regression coefficient of government subsidy after adding the intermediary variable R&D investment is still significant, but the coefficient drops from 0.221 to 0.212. This indicates that the positive effect of government subsidies on the number of patent applications is partially absorbed by the R&D investment of the intermediary variable. Thus, R&D investment plays a part in the intermediary effect. The proportion of the intermediary effect to the total effect is 27.56%. Moreover, the government subsidy acts on the level of technological innovation of the enterprise by influencing such investment of the enterprise. Therefore, our second hypothesis is also validated.

Table 5. Test of the intermediary effect of government subsidies affecting the technological innovation in agricultural enterprises.

Variable	(1)	(2)	(3)
	Patent$_{t+1}$	**R&D**	**Patent$_{t+1}$**
SUB	0.221 *** (8.33)	0.201 *** (4.90)	0.212 *** (7.05)
R&D			0.304 *** (11.98)
_cons	Yes	Yes	Yes
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	1460	1112	1099
R^2	0.452	0.428	0.548

Note: *** is significant at the 10%, 5%, and 1% levels.

4.4. Analysis of Heterogeneity

In order to investigate the heterogeneity of the samples, this paper conducts empirical tests according to the industry, the nature of the enterprise, and the size of the enterprise. Our research analyzes the production, processing, manufacturing, circulation, and service of agriculture, forestry, animal husbandry, and fisheries from the perspective of the whole industrial chain. The nature of the enterprise is according to whether the actual controller of the enterprise is a government department at all levels. If so, it is a state-owned enterprise; otherwise, it is a non-state-owned enterprise. The size of enterprise is divided into large, small, and medium-sized enterprises. The core criteria are the operating income of the enterprise in the current year. If it exceeds RMB200 million, it is a large enterprise; otherwise, it is a small or medium-sized enterprise.

The group regression results (Table 6) show that from the perspective of the industry, the regression coefficient between the government subsidies for the processing of agriculture, forestry, animal husbandry, and fishery products and the manufacturing industry, the number of manufacturing materials in the manufacturing industry, and the number of patent applications in the next period is significantly positive. At the same time, the regression coefficient between the government subsidies for traditional agriculture, forestry, animal husbandry, and fisheries and the number of patent applications in the next period is not significant. Government subsidies for these natural resource-based industries promote technological innovation by these businesses. At the same time, government subsidies for traditional agriculture, forestry, animal husbandry, and fisheries do not significantly affect enterprises' technological innovation. The reason for this may be that agriculture, forestry, animal husbandry, and fisheries are more susceptible to fluctuations in natural factors and market factors. Therefore, despite government subsidies, these subsidies have not substantially improved enterprises' R&D conditions, and their R&D power is insufficient.

4.5. Robustness Test

In order to test the robustness of the results, we used the number of patent grants instead of the number of patent applications as the agent variable of technological innovation. The regression results (Table 7) show that the regression coefficient of the SUB is significantly positive at the 1% level, which is consistent with the results in Table 4. This confirms that the regression results of Table 4 are stable. The conclusions of this study have passed the empirical test, have strong explanatory power, and can be used to guide and encourage technological innovation in agricultural enterprises.

Table 6. Group regression results by industry, enterprise nature, and size.

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
	Grouped by Industry			**Grouped by Enterprise Nature**		**Grouped by Size**	
	A	**Agr**	**Ag**	**St**	**NSt**	**L**	**S/M**
	Patent$_{t+1}$	**Patent$_{t+1}$**	**Patent$_{t+1}$**	**Patent$_{t+1}$**	**Patent$_{t+1}$**	**Patent$_{t+1}$**	**Patent$_{t+1}$**
SUB	0.006 (0.14)	0.182 *** (4.84)	0.364 *** (7.38)	0.168 *** (4.78)	0.293 *** (7.41)	0.318 *** (7.47)	0.128 *** (3.77)
Age	0.058 *** (4.28)	−0.025 ** (−2.32)	−0.041 *** (−2.71)	−0.059 *** (−4.57)	−0.001 (−0.11)	−0.022 * (−1.89)	−0.007 (−0.62)
Size	0.393 *** (4.67)	0.419 *** (6.32)	0.327 *** (3.59)	0.412 *** (6.99)	0.248 *** (3.71)	0.443 *** (6.36)	0.388 *** (4.04)
Debt	0.715 ** (2.18)	0.378 (1.43)	0.212 (0.68)	1.080 *** (4.59)	−0.444 * (−1.86)	0.832 *** (2.87)	−0.056 (−0.24)
Growth	−0.000 * (−1.87)	−0.016 ** (−2.38)	−0.088 (−0.75)	0.033 (0.41)	0.001 *** (2.97)	−0.135 * (−1.74)	0.000 (0.65)
Share	−0.015 *** (−3.80)	−0.016 *** (−4.41)	0.021 *** (4.36)	−0.011 *** (−3.49)	−0.009 *** (−2.67)	−0.004 (−1.12)	−0.016 *** (−4.33)
Fixasset	0.774 (1.59)	0.913 *** (2.60)	−2.437 *** (−7.50)	−1.435 *** (−4.67)	0.977 *** (2.64)	−0.761 ** (−2.38)	0.026 (0.07)
Salary	0.262 ** (2.33)	0.510 *** (6.73)	0.702 *** (6.27)	0.296 *** (4.04)	0.520 *** (6.32)	0.510 *** (6.62)	0.238 *** (2.88)
_cons	−12.068 *** (−9.44)	−17.696 *** (−16.82)	−21.382 *** (−11.04)	−14.898 *** (−13.83)	−16.777 *** (−15.90)	−22.729 *** (−20.15)	−12.519 *** (−6.60)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	346	674	440	726	734	773	687
R^2	0.308	0.431	0.573	0.611	0.434	0.507	0.298

Note: *, **, and *** are significant at the 10%, 5%, and 1% levels; A: agriculture, forestry, animal husbandry and fisheries; Agr: agriculture, forestry, animal husbandry, and fishery products processing and manufacturing industry; Ag: agriculture, forestry, animal husbandry, and fishery means of production manufacturing industry; St: state-owned enterprises; NSt: non-state-owned enterprises; L: large-lot producer; S/M: medium and small-sized enterprises.

Table 7. Summary of Ordinary Least Squares (OLS) regression parameter estimates for technological innovation and research and development.

Variable	**OLS**	**Variable**	**OLS**
SUB	0.175 *** (6.67)	Fixasset	−0.118 (−0.50)
Age	−0.014 * (−1.66)	Salary	0.382 *** (7.18)
Size	0.369 *** (7.80)	_cons	−16.085 *** (−20.67)
Debt	0.290 * (1.78)	Year Industry	Yes Yes
Growth	0.000 * (1.76)	N	1460
Share	−0.005 ** (−2.02)	R^2	0.432

Note: *, **, and *** are significant at the 10%, 5%, and 1% levels.

5. Discussion

Our model results are consistent with the results of [42,43]. At the same time, the findings underline the necessity of government subsidies for technological innovation in agribusiness in China. Firstly, the study found that government subsidies effectively promote technological innovation in agribusiness. Government subsidies affect the technological innovation of enterprises by influencing their R&D investment; that is, the positive effects of government subsidies on the number of patent applications are partially absorbed by the R&D investment of the intermediary variable. Moreover, R&D investment is an intermediary effect that accounts for 27.56% of the total effect. Thirdly, the effects of government subsidies on the technological innovation of agricultural enterprises have a certain heterogeneity. From an industry perspective, government subsidies for processing agriculture, forestry, animal husbandry, and fishery products and manufacturing promote technological innovation in enterprises. However, government subsidies for traditional agriculture, forestry, animal husbandry, and fisheries do not significantly affect these enterprises' technological innovations. In terms of the nature of the enterprises, government subsidies promote the technological innovation of state-owned and non-state-owned enterprises. Their impact on technological innovation for non-state-owned enterprises is greater than it is for state-owned enterprises. In terms of the size of enterprises, government subsidies promote technological innovation for all sizes of companies. The impact of technological innovation is greater for large enterprises than it is for small and medium-sized enterprises.

The results of this study confirm the assumptions that innovations and digital technologies are the core instruments with which to support the sustainable development of agriculture. These findings are consistent with past research [60–62]. At the same time, innovations and digital technologies require sufficient financial resources from the government subsidies that are available to agricultural companies. However, the government should consider all the effects from innovation projects when making decisions on how to allocate government subsidies to innovative agricultural projects. These subsidized projects can positively and/or negatively impact the environment and society. Past research confirms that innovations in water management can provoke the relocation of local people [63–65]. Other researchers have demonstrated that R&D investments in agriculture positively impact farmers and local communities [66–69]. This suggests that the government should balance agricultural productivity and economic profits with minimizing negative environmental impacts (e.g., soil degradation, water and soil pollution, deforestation, etc.) and promoting societal benefits (e.g., healthy diets, community vibrancy, etc.). The following three policy suggestions are put forward based on the above research conclusions: Firstly, the government should continue to increase subsidies. The rural revitalization strategy needs scientific and technological innovation as a support. The core key to agricultural and rural modernization also depends on scientific and technological innovations, which play a pivotal role in agricultural and rural development. As the main body of technological innovation, agricultural enterprises play an important strategic role in agricultural modernization. Studies have shown that government subsidies effectively promote the technological innovation activities of agricultural enterprises. Moreover, our findings confirm that government subsidies are effective options for stimulating innovation in agricultural enterprises. Therefore, the Chinese government should continue to increase agricultural subsidies, such as direct subsidies, tax incentives, and research and development subsidies. The Chinese government should also account for possible negative externalities of subsidized agriculture, including environmental pollution and the forced relocation of entire communities.

Secondly, government subsidies should "vary from enterprise to enterprise". The impact of government subsidies on the technological innovation of agricultural enterprises varies according to the type of industry, the nature of the enterprise, and its size. Government subsidies have a significant role in promoting technological innovation in the processing and manufacturing of agriculture, forestry, animal husbandry, and fishery products. Their impact on technological innovation for non-state-owned enterprises is greater than it is for state-owned enterprises. The impact of technological innovation is greater for large enterprises than it is for small and medium-sized enterprises. Therefore, government departments should be divided into categories. The government's limited subsidy resources should be invested in enterprises with strong technological innovation capabilities. Thus, agricultural processing and manufacturing companies need to be supported with high-quality resources to invest in agricultural enterprises with a strong willingness to adopt innovative technologies.

Thirdly, government subsidy funds need to be better supervised. Government subsidies affect the technological innovation of agricultural enterprises through R&D investment. Therefore, the government should strengthen the supervision of the use of subsidy funds and improve the performance of the use of funds. It is possible to establish and improve a monitoring system covering the whole process and the whole chain of fund allocation, implementation, and supervision. It is necessary to analyze the efficiency of government subsidies. At the same time, the focus is on supervising agricultural enterprises with low R&D investment levels and on encouraging enterprises to increase their investment in innovative, sustainable technologies and processes.

The efficiency of government policy for supporting the innovation implementations in agricultural companies should become an instrument for improving the export structure of agriculture and achieving sustainable development goals. Thus, the agricultural sector is a crucial element of food security. This involves the rational use of limited resources and the implementation of green technologies and energy efficiency innovations while mitigating adverse environmental and community impacts.

6. Conclusions

From the whole industry chain perspective, this paper extended the agricultural scope to the production, processing, manufacturing, circulation, and service of agriculture, forestry, animal husbandry, and fisheries. It empirically tested the effect and influence mechanism of government subsidies on agricultural enterprises' technological innovation by taking the companies listed from 2007 to 2019 as a research sample. We developed Ordinary Least Squares statistical regression models to test these hypotheses.

Despite the valuable findings and practical recommendations, our research has a few limitations. Our analysis focused on China only. At the same time, the globalization and openness of the economy facilitates potential improvements or declines in the competitiveness and sustainability of companies involved in agriculture and agro-forestry. The competitiveness of agricultural businesses also depends on other internal and external factors and should be studied in future investigations. Internal factors include the social responsibility of companies, the education level of managers, technological innovations, etc. External factors include government corruption and quality, sustainable development pathways in the region, geographic characteristics, etc. Innovative agricultural projects that are subsidized by the government can have a wide range of positive and/or negative economic, ecological, and social impacts which warrant further investigation.

Author Contributions: Conceptualization, L.W., K.H., O.L., T.P. and I.H.; methodology, L.W., K.H., O.L., T.P. and I.H.; formal analysis, L.W., K.H., O.L., T.P. and I.H.; investigation, L.W., K.H., O.L., T.P. and I.H.; writing—original draft preparation, L.W., K.H., O.L., T.P. and I.H.; writing—review and editing, L.W., K.H., O.L., T.P. and I.H.; visualization, L.W., K.H., O.L., T.P. and I.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a grant from the Ministry of Education and Science of Ukraine, 0121U100468, "Green investing: cointegration model of transmission ESG effects in the chain "green brand of Ukraine—social responsibility of business".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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