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Government Subsidies, Green Innovation, and Firm Total Factor Productivity of Listed Artificial Intelligence Firms in China

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Abstract: The world is being reshaped under global economic development driven by new advances in information technology. Artificial intelligence, an essential potential technology, will play a vital role in technological change and industrial upgrades. Exploring the relationship between government subsidies, green innovation, and total factor productivity will help us analyze government decisions' effects and better promote artificial intelligence's technological innovation process. Based on data from China's listed artificial intelligence companies from 2011 to 2020, this study uses the Levinsohn–Petrin method to measure the total factor productivity of companies and analyzes the impact of government subsidies on the total factor productivity of AI companies, the mediating effect of green innovation, and the moderating effect of intellectual property protection intensity. The research results show that (1) government subsidies can promote the total factor productivity of AI enterprises; (2) green innovation capabilities play a mediating role between government subsidies and enterprise total factor productivity, and government subsidies can indirectly promote green innovation to promote the improvement of total factor productivity effectively; (3) in the AI industry, the promotion effect of government subsidies on total factor productivity is more significant among state-owned enterprises, while the impact mechanism of government subsidies on private enterprises is not significant; and (4) the intensity of intellectual property protection has played a positive moderating role in the impact of government subsidies for artificial intelligence enterprises on total factor productivity. However, the current intensity of intellectual property protection remains unable to promote improvements in enterprise total factor productivity by stimulating green innovation. The research results will help us better understand the relationship between government subsidies and the development of corporate economic benefits and promote more scientific and effective government decision-making.

Keywords: artificial intelligence firms; government subsidies; green innovation; total factor productivity; LP methodology

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1. Introduction

The world is being remodeled under global economic development driven by a new round of information technology. Artificial intelligence, as one of the most important potential technologies, has a crucial role to play in technological change and industrial upgrades. As one of the most influential and promising industries today, AI technology and industrial robotics have been subject to accelerated R&D investments and innovation research in various countries and regions [1]. Over the past 20 years, the AI industry has experienced exploration and growth phases due to the rapid development of the Internet and continuous technological advancements. Currently, Chinese AI enterprises are developing rapidly, with the total number of enterprises increasing each day, and the scale of the industry is expanding; these developments have made essential contributions to the high-quality development of China's economy. According to statistical data from the China ICT Academy, the scale of China's AI industry began to proliferate in 2019, with the industry scale reaching CNY 508 billion in 2022 and CNY 578.4 billion in 2023.

As a measure of production efficiency, total factor productivity (TFP) is an important channel connecting technological progress and high-quality economic development [2]. From a financial perspective, as China's "demographic dividend" gradually fades and the "pull effect" of factor investments on economic growth diminishes, the future economic growth in China will increasingly rely on the expansion of TFP [3]. Thus, increasing the productivity in AI firms is crucial for driving innovation-led industrial development and facilitating the transition to a more advanced economic growth model.

As an important factor affecting the production and development of enterprises, government subsidies are an inherent requirement for compensating and perfecting the market adjustment mechanism and represent an important policy tool for the Chinese government to implement an innovation-driven strategy and promote the development of high-tech industries [4,5]. Against this background, can government subsidies promote TFP growth among AI enterprises? What is the specific impact mechanism of government subsidies? What role does green innovation play in this process? What is the difference in the impact on heterogeneous firms? Answering these questions will help us assess the implementation effects of government subsidies more scientifically and provide new ideas for the government to implement relevant policies accurately.

Considering the above considerations, this paper aims to gain a deeper understanding of the connection between government subsidies for environmental protection and the development of environmentally friendly innovations by enterprises. By examining the correlation between government environmental subsidies and enterprises' green innovation, effective strategies can be implemented to enhance the capabilities of enterprises in this area. Understanding these elements would enable the high-quality advancement of China's AI sector. To achieve this goal, the present study employs a sample set of Chinese AI companies using data from listed companies in China, following the industry classification standards of the State Securities Regulatory Commission (SSRC). We acquired this information through literature research, theoretical analysis, and empirical testing. The TFP of AI companies is measured using the Levinsohn–Petrin method (referred to as the LP method). Additionally, we systematically investigate the impact of government subsidies on the TFP of enterprises, considering the heterogeneous effects of these subsidies. At the same time, green innovation and the intensity of intellectual property protection (IPP) are incorporated into the analytical framework, and both mediating and moderating effect models are established to analyze the mechanisms of government subsidies on the TFP of AI enterprises, thereby providing new perspectives for understanding the interaction between macroeconomic policies and micro-enterprise behaviors.

2. Literature Review

For this study, we conducted a literature review based on existing research. This review focused on four aspects: measuring enterprise TFP and its influencing factors, understanding the impact mechanisms of government subsidies on TFP, examining the impacts of government subsidies on green innovation, and exploring the transmission of effects between these three aspects.

2.1. Evaluation Study on the Measurement of TFP of Enterprises and the Factors Affecting It

As AI is a dual-intensive industry encompassing both knowledge and technology, improving the TFP of AI is critical to enhancing competitiveness in the sector [6]. Specifically, TFP evaluation research elucidates the development level of the AI industry, enabling us to propose targeted solutions for any weaknesses. To date, academics have conducted few studies on evaluating TFP among AI enterprises, primarily focusing on studying the TFP of enterprises at the macro, regional, and micro levels [7]. For example, Tian [8] assessed

China's aggregate enterprise total factor productivity (TFP) using macro panel data from Chinese industrial companies between 1998 and 2007. This study focused specifically on listed Chinese manufacturing enterprises.

Enterprise TFP is measured using different entry points at home and abroad. The stochastic frontier production function proposed by Aigner [9] decomposes the total production function into non-efficiency terms. Kumbuakar [10] further decomposed the TFP and obtained specific indexes such as technological progress and technological efficiency, thereby explaining the influencing factors of TFP growth in more detail. The results emphasized the critical role of optimizing the institutional structures of enterprises, improving management capacity, and accumulating human capital, such as knowledge in the production process for improving enterprise efficiency. Charnes and Cooper [11] proposed Data Envelopment Analysis (DEA) using multiple input and output units to achieve effective productivity assessments within the same sectors. This method can simplify the calculation process and reduce the errors that other methods are prone to. Therefore, this method has been adopted by many scholars for empirical research. Fare [12] used the DEA–Malmquist productivity index and decomposed the index into technical efficiency and changes in production technology. As research on measuring TFP shifted from the macro to the micro level, more scholars began using semi-parametric methods. The current mainstream measurement methods are the LP and OP methods. Lin and Zhang used the LP method to measure the TFP values of new energy companies [13]. Guan and Zhang used the Porter Hypothesis (PH) framework and the OP method to explore the impact of environmental taxes on the innovation and ecological total factor productivity of heavily polluting manufacturing companies [14].

TFP might be influenced by financial restrictions and other variables when considering external factors, such as tax policy, government subsidies, environmental regulations, the business environment, and the legal system [15]. Howell [16] argued that lax tax policies benefit the efficiency of enterprise capital allocation, which is conducive to TFP. Simultaneously, based on empirical analysis, tax policy can affect enterprise TFP through the two mediator variables of technological innovation and investment efficiency. Cai [17] found that environmental regulations can affect enterprise TFP by influencing enterprise innovation efficiency, and Kasman [18] observed that a favorable business climate has a beneficial impact on TFP. Additionally, the presence of an active market mechanism, a high concentration of talented individuals, and the smooth movement of capital contribute to positive economic expansion. Additionally, internal variables such as research and development investments, debt structure, enterprise size, enterprise ownership, and executive management capabilities exert varying degrees of influence on the TFP of enterprises [19]. An analysis of listed companies' financial index data found that R&D investments and TFP are positively correlated and that capital investments have the potential to enhance the productivity and innovation capabilities of empowered businesses, thereby improving TFP. According to previous research, there is a positive correlation between the scale effects of firms and the growth trends of enterprise TFP [20].

2.2. Government Subsidies and TFP

As the most common and direct type of government industrial policy, government subsidies are one of the important factors affecting TFP. As an important policy tool to promote industrial development, government subsidies serve as a "helping hand" [21]. For this reason, the actual impacts and effects of government subsidies on manufacturing and enterprise functionality have become the focus of many scholars.

Scholars have carried out considerable empirical research and numerous theoretical analyses on such effects, but the results of this research are variable. The current academic community has two diverging conclusions: (1) government subsidies have a positive incentivizing effect and (2) government subsidies have a negative effect. From a theoretical perspective, government subsidies can provide financial incentives for firms to engage in production and operational activities that have significant external effects. However, the real impacts of such incentives may vary during the operational process.

According to certain academics, government subsidies have a positive incentivizing effect on the TFP of enterprises. Xu [22] examined statistics from publicly traded companies in China's Shenzhen Stock Exchange and discovered that government subsidies for R&D have a notable and favorable impact on the R&D investments made by businesses. This outcome, in turn, leads to an improvement in the innovation performance of these enterprises and positively affects their overall productivity. Liu [23] argued that government subsidies perform an essential function in compensating for market failures and supporting enterprise development and that such subsidies are effective and efficient in improving the productivity of enterprises. Using a cross-sectional comparison of different government relief methods, Nishimura [24] discovered that government subsidies significantly increase the TFP of subsidized companies. Kumbhakar [25] argued that financial subsidies considerably reduce the marginal costs of production, which serves as a critical factor for fiscal subsidies to incentivize TFP improvement.

Additionally, several experts have argued that government subsidies adversely influence enterprise TFP. Due to the uncertainty enterprises face in R&D activities and the inherent defects of market mechanism regulation and other factors, the government subsidizes specific types of enterprises, sometimes based on their R&D expenditures, to produce a "crowding-in effect". Espinosa [26] noted that rent-seeking behavior can weaken the actual effects of government subsidies, destroy the mechanism of equal competition in the market, and seriously damage enterprise business performance. Such behavior can also diminish the willingness of businesses to allocate resources to research and development endeavors. At the same time, Bos [27] argued that information asymmetry exists between policymakers and enterprises. When applying for government subsidies, enterprises may intentionally exclude important information and provide false information, resulting in a mismatch of government subsidy resources. In these situations, government subsidies may contribute negatively to the development of the enterprise, potentially with inhibitory consequences.

Overall, most consider government subsidies to play a positive role in the TFP of enterprises. However, due to the manufacturing and functioning of enterprises, R&D and innovation are long-term processes that incentivize certain non-linear characteristics. Hence, it is imperative to investigate further the influence of government subsidies on enterprises' TFPs.

2.3. Government Subsidies and Green Innovation

With green development becoming the primary development trend and vision of industrial production, domestic and international experts have focused their research on the correlation between government subsidies and green innovation capabilities. Martens [28] argued that, due to the "externalities" of "innovation", government subsidies can narrow the disparity between the social and economic benefits of enterprises to improve the motivation of active innovation and research and development. Wang [29] conducted an empirical study using data from listed businesses and discovered that government subsidies can successfully address the issue of market failure, strongly incentivizing enterprises to engage in green innovation. The types of government subsidies and subsidy objects are strictly categorized according to their signaling mechanisms. Research has shown that subsidies for environmental protection and innovation positively impact the actual output of green innovation by companies. However, other forms of subsidies do not substantially affect a company's capacity for green innovation.

Some scholars, however, consider such subsidies to have a negative effect. Dimos [30] applied the categories of "market-oriented" and "far-from-market" green innovations. The findings indicated that subsidies have a beneficial impact on "far-from-market" innovations and a "crowding-out effect" on "market-oriented" projects. Luo [31] researched a sample of high-tech industry enterprises in a province, revealing that government subsidies have a detrimental influence on corporate innovation, with a more pronounced impact on non-SOEs. There exists a disparity in the flow of information between the government and enterprises [32], resulting in the irrational allocation of funds and overinvestments. Enterprises may also speculatively adopt "strategic green innovation" as part of their financing, seriously affecting the role of government subsidies in supporting green innovation.

Some scholars have also found that government subsidies and green innovation have a non-linear relationship, with a U-shaped effect [33]. In this way, the government provides subsidies to achieve a specific magnitude to foster the advancement of environmentally friendly innovation, reflected explicitly in the innovation efficiency and quality. Conversely, a crowding-out effect will occur when government subsidies increase beyond a certain scale.

2.4. Government Subsidies, Green Innovation, and Firm TFP

Few scholars have explored green innovation as an entry point to examine the correlation between government subsidies, green innovation, and enterprise TFP. Most studies begin by examining the correlation between government subsidies, R&D investments, and enterprise TFP [34] or discuss the relationship between government subsidies and enterprise TFP and the impact of government subsidies on technological innovation.

2.5. Commentary on the Literature

Further examination is required to assess the effect of government subsidies on the TFP of firms, as there is currently no scientific consensus on this matter [35]. First, it would be worthwhile to conduct further empirical testing to measure TFP based on the micro subject of AI enterprises and analyze the effects of government subsidies in China on this basis. Second, most scholars have focused on R&D capital investments when studying the mediating impact of government subsidies and the TFP of enterprises. Whether green innovation can facilitate the process by which government subsidies affect the TFP of AI enterprises deserves further empirical experimentation. Third, the existing literature on the moderating effects of government subsidies and enterprise TFP mostly analyzes this topic from the perspectives of enterprise size, the nature of property rights, and financing constraints. Few scholars have introduced the moderating variable of "IPP" to explore the relationship between government subsidies, IPP, and enterprise TFP. Scholars have also not yet investigated the correlation between government subsidies, the level of intellectual property protection, and the TFP. To what extent the intensity of intellectual property protection, an important legal policy variable affecting the technological innovation of AI enterprises, affects the policy incentives of government subsidies on the TFP of enterprises deserves further empirical testing.

3. Theoretical Analysis and Research Hypotheses

3.1. Concept Definition

3.1.1. Government Subsidies

Government subsidies refer to policy funds provided free of charge by the government to enterprises in order to achieve specific social and economic goals [36–38]. They are an important measure to adjust market failures under the socialist market economy and are one of the main sources of R&D investment for enterprises. It can effectively influence the research and development, decision-making, and operating activities of enterprises over the long term, help enterprises to enrich their capital flow and increase their actual income, and promote the optimal allocation of resources. The leading parties in government subsidies are the central government, the local government, and policy-based state-owned enterprises, which are highly timely and controllable. However, if the scope of the subsidy is too broad and the subsidy is unreasonable, it can easily cause negative impacts.

3.1.2. Firm Total Factor Productivity

Total factor productivity includes the utilization efficiency of all production factors such as labor, knowledge, and capital [39]. It comprehensively considers various factors that promote economic growth, helps reflect the authenticity of economic activities, and comprehensively considers the contribution of various factors to economic growth [40]. TFP has gradually become a comprehensive indicator that reflects the transformation of enterprises' production and development methods and higher-quality development. The measurement of enterprise total factor productivity starts from the production function and is measured by the input–output ratio, which then affects enterprise production efficiency, operating efficiency, and performance management. When other conditions remain unchanged, resources and inputs are certain; the higher the technical level, the higher the efficiency, and the greater the output. With the development of digitalization and the application of digital technology, enterprises have also formed a large number of data resources in the process of production and operation. As data become a factor of production, the application of digital technology can increase the synergy and permeability of data and other factors, promoting enterprises to achieve endogenous growth.

3.1.3. Green Innovation

Green innovation refers to innovation that takes ecological priority as the principle, takes into account economic and environmental benefits, and achieves goals such as energy conservation and emission reduction, low-carbon recycling, and clean production [41–43]. The concept of green innovation was initially defined as "environmental protection innovation", which focused on the impact of an enterprise's production and operation activities on the environment, while paying less attention to the realization of enterprise economic benefits [44]. However, as a profit-making entity, one of the purposes of enterprise innovation is to obtain economic benefits and thereby realize commercial value [45]. Therefore, green innovation is derived from environmental innovation and emphasizes the unity of corporate environment and economic benefits. In recent years, the academic community has used the concept of "green innovation" more frequently and recognized it more frequently, so this article adopts the concept of "green innovation". The initial definition of "green innovation" mainly refers to easing ecological and resource pressures through technological upgrading. Later scholars continued to expand its connotation. The current definition includes green products, processes, and management innovation. That is, innovations with the purpose of protecting the environment can be included in green innovation.

3.2. Research Hypotheses

3.2.1. Government Subsidies and TFP of Enterprises

The impact of government subsidies on total factor productivity can be analyzed through externality theory, resource-based theory, and signaling theory. The processes of innovation activities among AI enterprises entail significant capital investments, substantial risk, and uncertain returns. These factors necessitate government intervention to foster firm development through policy measures, with government subsidies being the most prevalent form of support. First, according to externality theory [46], the government should take measures to eliminate the impact of externalities. During the enterprise R&D investment stage, government subsidies can help enterprises reduce R&D costs and encourage innovation. In the output stage, government subsidies can enhance the total factor productivity of artificial intelligence enterprises by reducing innovation uncertainty and easing financing constraints. Second, according to resource-based theory [47], the risk of innovation uncertainty can be spread and mitigated by government subsidies, thereby encouraging R&D and innovation activities and enhancing the competitive advantages of enterprises in their manpower, technology, and capital. Moreover, the signaling effect of government subsidies can alleviate the financing constraints of enterprise R&D [48]. The core resources of AI enterprises are "knowledge" and "talent". Obtaining government subsidies is an important signal for the development potential of an enterprise and its industry.

In this way, AI enterprises can obtain more financing support for technological research and development and expand their production scale, thus enhancing their technological efficiency and innovation quality.

Based on the above analysis, we contend that the advantageous effects of government subsidies are the most significant factor for the TFP of AI enterprises. Consequently, Hypothesis 1 is proposed:

Hypothesis 1. *Government subsidies can potentially enhance firms' TFP.*

3.2.2. Mediating Effects of Green Innovation

Enterprise green innovation capacity is a critical factor that cannot be ignored when studying government subsidies and the TFP of AI firms. The contributions made by innovation inputs to enterprise TFP primarily manifest through the improvement of resource allocation efficiency. At the macro level, resources are transferred from high-pollution or energy-intensive production sectors to low-pollution or knowledge-intensive sectors. The same phenomenon is reflected in the flux of factors at the micro level, such as manpower and capital, between different production sectors of the enterprise until the level of factor allocation reaches an optimal level, which further improves the TFP of the enterprise. One aspect related to the transmission chain of mediating effects is the correlation between corporate green innovation and government subsidies. Today, green and low-carbon development has gradually become a new direction of innovation in wind technology. Government subsidies in this area can alleviate the problems of market externalities such as malfunctions and lag, promote enterprise green innovation, and enhance the motivation of businesses to invest in environmentally friendly innovation. There is also a relationship between enterprise green innovation and enterprise TFP. In Schumpeter's theory of innovation, innovation is defined as integrating a novel production function into an existing production process and is essential for achieving long-term economic growth [49]. Enterprises continue to develop high-value-added, high-technology, high-environmental-intensity, and low-pollution AI products or services to form core competitiveness. This way, enterprises can find their foothold within intense market competition and promote high-quality, sustainable economic development.

Based on the analysis above, Hypothesis 2 is proposed:

Hypothesis 2. *Government subsidies can increase enterprise TFP by advocating for enhancing enterprise green innovation. Green innovation has a mediating effect between government subsidies and TFP.*

3.2.3. Heterogeneity Analysis of Firms

The concept of ownership is critical in determining the TFP of enterprises. Enterprises with different ownership systems differ significantly in terms of their natural endowment, internal operations, and governance structures, leading to different strategic behaviors for resource procurement, signal transmission, and principal–agent performance. Compared to non-state-owned enterprises (non-SOEs), state-owned enterprises (SOEs) have inherent advantages, mainly reflected in financing constraints, government–enterprise relations, access to information, and closer interactions between SOEs and the government. These factors help SOEs actively respond to the government's calls to intensify green innovation, thus enhancing the TFP of enterprises [50]. Private enterprises face inherent property rights challenges, leading to distortions in the factor market due to rent-seeking activities. These distortions hinder the effective implementation of government subsidies to mitigate the imbalance of information between businesses and investors, thereby weakening non-SOEs' innovation efforts.

According to the above analysis, Hypothesis 3 is proposed:

Hypothesis 3. *The promotion effects of government subsidies on the TFP of enterprises are more substantial among SOEs.*

3.2.4. Moderating Effects of IPP

Technological progress is the only avenue to support the growth of TFP. Technology represents a key competitive advantage for AI enterprises, and a sound intellectual property system provides a strong guarantee of technological progress. Additionally, the infringement of intellectual property rights will inevitably dampen a firm's enthusiasm for innovation and affect enterprise innovation development. Enhanced intellectual property protection is a deterrent against activities like the unauthorized disclosure of knowledge and copying of technology. On the other hand, a lower level of IPP will increase the risks and costs of AI R&D endeavors, reduce the willingness to engage in research and development activities, and weaken the influence of R&D investments on innovation performance, thereby impacting the economic efficiency of enterprises [51]. A low level of IPP will increase the expenses and risks of enterprise R&D activities and decrease the willingness and likelihood of businesses to carry out R&D activities. Conversely, a high level of IPP can stimulate enterprises to develop their innovation abilities and improve their innovation efficiency.

Based on the above analysis, Hypothesis 4 is proposed:

Hypothesis 4. *The intensity of IPP can strengthen the effects of government subsidies on the TFP of AI firms.*

4. Study Design

4.1. Data Sources

According to the "Artificial Intelligence Standardization White Paper", artificial intelligence enterprises offer artificial intelligence chips, sensors, cloud computing, data collection and processing, and other technologies or the use of deep learning frameworks, underlying algorithms, general algorithms, and development platforms as their main products and services. Since the scope of artificial intelligence technology is extensive, this study is based on the latest industry classification standards of the China Securities Regulatory Commission, and 164 companies were selected from the artificial intelligence concept stocks of China's Shanghai and Shenzhen A-share markets as initial research samples. Based on our research needs, data screening sought to reduce interference in the empirical research and ensure the continuity of the data, numerical integrity of the variables, and accuracy of the results using the following principles:

(1) We eliminated listed artificial intelligence companies with incomplete data on government subsidies, green patent applications, corporate total factor productivity, etc.
(2) After screening and excluding ST and *ST listed companies, 145 research samples were obtained. Based on the above principles for screening data, balanced panel data on these companies from 2011 to 2020 were selected for analysis, and 1022 observation data were ultimately obtained.

Data on R&D personnel and R&D investments were all obtained from the WIND database. The financial statements of the listed companies all came from the Guotai Junan database. The number of regional patent authorizations and regional patent applications were obtained from the corporate yearbook published by the National Bureau of Statistics. Data on technology market turnover and GDP were all obtained from the China Statistical Yearbook. All of the above data processing processes used STATA for statistical analysis and the winsorize method to process variables.

4.2. Definition of Variables

(1) Explanatory variable: Government subsidies (SUB)

This article uses government subsidies as explanatory variables. The government can subsidize enterprises by allocating special funds for innovation and R&D, tax incentives, financial subsidies, patent funding, etc. As the most common method of subsidy, most scholars start with the financial statements of enterprises and the government subsidy funds disclosed in the statements as research target [52]. Based on the accuracy and availability of data, this article uses the value of government subsidies after logarithmic processing as the core explanatory variable of this article.

(2) Explained variable: Total Factor Productivity of Firms (TFP_FE)

Total factor productivity is a relative concept and cannot be directly observed like capital and labor. It is the additional production efficiency after excluding the output of capital, labor, and other factor inputs. It is the additional production efficiency of the total output except factor inputs. The remaining explanation reflects the improvement in enterprise technological progress, the improvement in production organization and coordination capabilities, the improvement in management capabilities, and the improvement in allocation efficiency. The main methods for measuring enterprise total factor productivity from the micro level are the OP method and LP method. Each method has its own unique advantages and limitations. Based on the literature review in the second part, the OP method and the LP method were analyzed, and considering the availability of data and the reliability of the calculation [53], the empirical test part of this article uses the static total factor productivity of enterprises calculated under the LP method as the explained variable. The LP method is used to measure the total factor productivity of enterprises. This method can effectively solve the problem of simultaneity deviation caused by enterprises choosing output and capital stock at the same time.

(3) Mediator variable: Green innovation (lngreen)

The manifestation of corporate green innovation capabilities cannot be measured directly, and patents are usually used as a measure of innovation capabilities or innovation performance in the literature. Patents have the advantage of containing a wealth of information about a technology, invention, and inventor, and are relatively easy to obtain. Additionally, agency patent filing, examination, and grant regulations are generally consistent across regions across the country, making patent data comparable. Since there is a period of time between the filing and granting of a patent, the number of patent applications is used as a measure of innovation performance. Similarly, the number of green patent applications can be used to measure green innovation performance [54]. Therefore, this article uses the total number of green patent applications of listed artificial intelligence companies to measure corporate green innovation indicators. The total number of patent applications is the sum of invention patents, utility model patents, and appearance patents.

(4) Moderator variable: Intensity of intellectual property protection (IPP)

As patent authorization is a direct indicator of a region's capacity for scientific and technological innovation, according to the approach of Xu et al. [55], this study uses a logarithmic formula to evaluate the extent of regional intellectual property protection by calculating the annual patent authorization of the provincial administrative region where the enterprise is enrolled.

(5) Control variables

The following elements are considered control variables in this study to avoid changing our interpretations. In this paper, the control variables selected mainly cover the enterprise's basic conditions and financial status. Fundamental indicators include the size of the board of directors (Board) and the proportion of independent directors (Indep), which are expressed by the total number of formal members of the board of directors at the end of the year and the ratio of the number of independent directors to the total number of board members. Financial status includes asset–liability ratio (Lev), operating income growth rate (Growth), and Tobin Q value (TobinQ). Among them, the asset–liability ratio (Lev) is expressed by the ratio of the company's total liabilities to total assets, the operating income growth rate (Growth) is represented by the ratio of the company's operating income growth this year to the previous year's operating income, and Tobin Q value (TobinQ) is represented by the enterprise Tobin Q value in the financial statements of the listed companies [56–58].

The definitions and measurement methods for the aforementioned variables are presented in the form of a table, as shown in Table 1.

Table 1. List of variable definitions and corresponding measurements.

Variable Type	Variable Name	Variable Meaning	Methods of Measurement
Explanatory variable	SUB	Government grant	Natural logarithm of government grants
Explained variable	TFP_FE	TFP of enterprises	TFP as measured by the LP methodology
Mediator variable	Ingreen	Green Innovation	Numerical value of total green patent applications by companies
Moderator variable	IPP	Intensity of intellectual property protection	Natural logarithm of the annual number of patents granted in the place of business registration
Control variable	Lev	gearing	Total liabilities/total assets of the enterprise
	Growth	Revenue growth rate	Growth in business revenue of the enterprise in the current year/business revenue of the previous year
	Board	Board size	Numerical value of the total number of regular members of the Board of Directors at the end of the year
	TobinQ	Tobin's Q	Tobin's Q for firms
	Indep	Percentage of independent directors	Number of independent directors/total number of board members

4.3. Model Construction

4.3.1. Analysis of Intermediation Effects

The primary components of our research model are twofold. First, we test the direct impact of government subsidies on enterprise TFP and the mediating effect of enterprise green innovation. Model 1 is the regression model for the impact of government subsidies on enterprise TFP, as shown in Equation (1). GPAT in the model denotes enterprise green innovation, SUB denotes government subsidies, and ε denotes the random error term. Model 2 is the regression model for the impact of government subsidies on enterprise green innovation, where the variable in green denotes enterprise green innovation, as shown in Equation (2). Based on model 1, model 3 adds the variable of enterprise green innovation to test the impact of government subsidies and green innovation on enterprise TFP, as shown in Equation (3).

β in Equation (3) represents the standardized regression coefficient value, which is mainly used to compare the magnitude of different explanatory variables' effects on the explained variables:

$$\text{TFP\_FE} = \beta_0 + \beta_1 SUB + \beta_2 \text{Board} + \beta_3 \text{Growth} + \beta_4 \text{Indep} + \beta_5 \text{Lev} + \beta_6 \text{TobinQ} + \varepsilon \quad (1)$$

$$\text{lngreen} = \beta_0 + \beta_1 SUB + \beta_2 \text{Board} + \beta_3 \text{Growth} + \beta_4 \text{Indep} + \beta_5 \text{Lev} + \beta_6 \text{TobinQ} + \varepsilon \quad (2)$$

$$\text{TFP\_FE} = \beta_0 + \beta_1 SUB + \beta_2 \text{Board} + \beta_3 \text{Growth} + \beta_4 \text{Indep} + \beta_5 \text{Lev} + \beta_6 \text{TobinQ} + \beta_7 \text{lngreen} + \varepsilon. \quad (3)$$

4.3.2. Analysis of the Moderating Effect

We add IPP to models 1, 2, and 3 and set models 4 and 6 with government subsidies and green innovation, respectively, to test the moderating role of IPP in the mediation process of "government subsidies–enterprise green innovation–enterprise TFP" and distinguish between the direct moderating effect and mediating moderating effect. Next, we add IPP to models 1, 2, and 3 and establish models 4, 5, and 6 to test the moderating role of the intellectual property protection level in the mediation process of "government subsidies–enterprise green innovation–enterprise TFP" and distinguish between the direct moderating effects and mediating moderating effects. This process yields cross-terms with government subsidies, green innovation, SUB∗IPP, and lngreen∗IPP. All other control variables remain constant:

$$\text{TFP\_FE} = \beta_0 + \beta_1 SUB + \beta_2\text{IPP} + \beta_3 SUB * \text{IPP} + \beta_4\text{Board} + \beta_5\text{Growth} + \beta_6\text{Indep} + \beta_7\text{Lev} + \beta_8\text{TobinQ} + \varepsilon \quad (4)$$

$$\text{lngreen} = \beta_0 + \beta_1 SUB + \beta_2\text{IPP} + \beta_3 SUB * \text{IPP} + \beta_4\text{Board} + \beta_5\text{Growth} + \beta_6\text{Indep} + \beta_7\text{Lev} + \beta_8\text{TobinQ} + \varepsilon \quad (5)$$

$$\text{TFP\_FE} = \beta_0 + \beta_1 SUB + \beta_2\text{IPP} + \beta_3\text{lngreen} + \beta_4 SUB * \text{IPP} + \beta_5\text{lngreen} * \text{IPP} + \beta_6\text{Board} + \beta_7\text{Growth} + \beta_8\text{Indep} + \beta_9\text{Lev} + \beta_{10}\text{TobinQ} + \varepsilon. \quad (6)$$

5. Results

5.1. Descriptive Statistics and Correlation Analysis of Variables

In total, 1022 observations were collected in this paper. Table 2 presents the results for the descriptive statistics of the variables. The results show that the mean value of TFP_FE is 11.242, with a significant difference between the maximum (15.372) and minimum values (7.952), which indicates a significant difference in TFP_FE between different firms. Moreover, some firms have a lower TFP_FE. The range of SUB after taking the logarithm of government subsidies is 11.871–21.779, which shows that most of the listed firms have received financial support from the government. These data illustrate the government's development orientation and support for enterprises. The minimum and maximum value of green innovation (lngreen) among enterprises is 0.693 and 6.477, respectively, which indicates a clear green innovation gap between different enterprises and that some enterprises do not properly consider green innovation.

Table 2. List of descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
TFP_FE	1022	11.242	1.324	7.952	15.372
SUB	1022	16.722	1.425	11.871	21.779
lngreen	1022	1.988	1.143	0.693	6.477
Board	1022	2.117	0.186	1.386	2.708
Growth	1022	0.54	9.956	−0.74	317.3
IPP	1019	0.044	0.06	0.001	0.175
Indep	1022	37.595	5.879	25	71.43
Lev	1022	0.379	0.186	0.014	0.868
TobinQ	1022	2.166	1.405	0	22.15

Table 3 presents the preliminary degree of correlation between the variables. Based on the results of the correlation coefficient test, SUB is significantly positively correlated with TFP_FE, with a coefficient of 0.703 significant at a 1% level of significance, which is consistent with Hypothesis 1. lngreen has a correlation coefficient of 0.552 with TFP_FE, which indicates that green innovation is significantly positively correlated with the TFP_FE of the enterprise at a 1% level. The correlation analysis provides only a rough indication of the degree of interconnectedness between the variables. The specific relationships must be empirically examined in depth using regression analysis.

Table 3. List of descriptive statistics results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) TFP_FE	1.000								
(2) SUB	0.703	1.000							
	0.000								

Table 3. *Cont.*

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(3) lngreen	0.552	0.502	1.000						
	0.000	0.000							
(4) Board	0.172	0.127	0.158	1.000					
	0.000	0.000	0.000						
(5) Growth	0.029	0.009	−0.026	−0.008	1.000				
	0.349	0.767	0.402	0.801					
(6) IPP	0.080	0.045	0.011	−0.056	−0.020	1.000			
	0.011	0.148	0.717	0.073	0.521				
(7) Indep	0.087	0.093	−0.065	−0.467	−0.002	0.081	1.000		
	0.005	0.003	0.037	0.000	0.962	0.010			
(8) Lev	0.600	0.372	0.327	0.084	0.048	−0.082	−0.020	1.000	
	0.000	0.000	0.000	0.007	0.128	0.009	0.518		
(9) TobinQ	−0.219	−0.082	−0.109	−0.112	−0.015	0.041	−0.012	−0.257	1.000
	0.000	0.008	0.000	0.000	0.623	0.192	0.710	0.000	

5.2. Mediating Effect Test

In Table 4, models 1 to 3 show the process of conducting stepwise tests on mediation effects. In model 1, the coefficient of SUB is 0.497 and passes the significance test at a 1% level. This result suggests that SUB facilitates TFP_FE. Among geothermal energy companies, a higher SUB corresponded to a higher TFP_FE. Thus, Hypothesis 1 is verified. Model 2 mainly tests the effects of SUB on green innovation. The coefficient of SUB is 0.357 and passes the significance test at a 1% level. This result indicates that SUB facilitates green innovation with an increase in subsidies, leading to improvements in the level of green innovation among enterprises. In model 3, the coefficient of SUB is 0.414, which is significant at a 1% level of significance. This coefficient represents the direct effect of SUB on firms' TFP_FE. The coefficient of green innovation is 0.232, which is significant at a 1% level. This result indicates that the effect of firms' green innovation on TFP_FE is also positive and significant.

Table 4. List of the mediating effect test results.

	TFP_FE	lngreen	TFP_FE
Variables	**Model 1**	**Model 2**	**Model 3**
lngreen			0.232 ***
			(9.38)
SUB	0.497 ***	0.357 ***	0.414 ***
	(25.92)	(15.29)	(20.29)
Board	0.780 ***	0.288	0.714 ***
	(5.04)	(1.52)	(4.80)
Growth	0.001	−0.004	0.002
	(0.34)	(−1.43)	(0.78)
Indep	0.022 ***	−0.016 ***	0.025 ***
	(4.44)	(−2.69)	(5.39)
Lev	2.680 ***	0.922 ***	2.467 ***
	(18.04)	(5.09)	(17.08)
TobinQ	−0.061 ***	−0.025	−0.055 ***
	(−3.32)	(−1.10)	(−3.13)
Constant	−0.415	−4.292 ***	0.580
	(−0.84)	(−7.16)	(1.20)
Observations	1022	1022	1022
R-squared	0.644	0.290	0.672

t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Accordingly, green innovation has a mediating effect through subsidies on firms' TFP. Specifically, government subsidies can either directly promote an increase in enterprises'

TFP or indirectly promote an increase in enterprises' TFP by improving enterprises' green innovation. As a result, Hypotheses 1 and 2 are verified. Ultimately, green innovation acts as a mediator between government subsidies and enterprise TFP.

5.3. Tests for Firm Heterogeneity

As shown in Table 5, the results of model 1 indicate that there exists a substantial positive link between TFP_FE and government subsidies for both non-SOEs and SOEs. The coefficients for SOEs and non-SOEs are 0.582 and 0.425, respectively, both of which pass the significance test at a 1% level. This result indicates that government subsidies have a direct promoting effect on TFP_FE among both non-SOEs and SOEs, with a stronger effector for SOEs. The results of model 2 indicate a significant positive correlation between green innovation and government subsidies among both non-SOEs and SOEs. The coefficient of SOEs is 0.519, which passes the significance test at a 1% level, and the coefficient of non-SOEs is 0.217, which passes the significance test at a 1% level. These results indicate that government subsidies play a substantial role in fostering green innovation in both categories of businesses, with the influence being more pronounced in SOEs. Model 3 incorporates green innovation as a mediating variable. For both non-SOEs and SOEs, green innovation and TFP_FE are significantly and positively correlated. The coefficient for SOEs is 0.288, which is statistically significant at a 1% level. Similarly, the coefficient for non-SOEs is 0.169, which is also statistically significant at a 1% level. This result suggests that green innovation can enhance TFP among both types of organizations, with a greater impact for SOEs.

Table 5. List of test results for firm heterogeneity.

	Model 1		**Model 2**		**Model 3**	
	SOEs	**Non-SOEs**	**SOEs**	**Non-SOEs**	**SOEs**	**Non-SOEs**
lngreen					0.288 ***	0.169 ***
					(6.39)	(5.60)
SUB	0.582 ***	0.425 ***	0.519 ***	0.217 ***	0.433 ***	0.388 ***
	(14.75)	(17.77)	(9.27)	(7.88)	(10.06)	(15.94)
Board	−0.511	1.186 ***	−0.019	0.184	−0.505 *	1.155 ***
	(−1.59)	(6.45)	(−0.04)	(0.87)	(−1.72)	(6.40)
Growth	0.402 **	0.001	0.341	−0.004	0.304 **	0.002
	(2.56)	(0.51)	(1.53)	(−1.48)	(2.10)	(0.81)
Indep	0.015 *	0.027 ***	−0.026 **	−0.015 **	0.023 ***	0.029 ***
	(1.82)	(4.39)	(−2.14)	(−2.13)	(2.91)	(4.88)
Lev	2.680 ***	2.569 ***	0.738	0.971 ***	2.468 ***	2.405 ***
	(7.97)	(15.72)	(1.55)	(5.17)	(7.97)	(14.75)
TobinQ	−0.142 ***	−0.046 **	−0.023	−0.035	−0.136 ***	−0.040 **
	(−2.90)	(−2.39)	(−0.33)	(−1.58)	(−3.02)	(−2.11)
Constant	1.346	−0.314	−5.938 ***	−1.862 **	3.054 ***	−0.000
	(1.36)	(−0.48)	(−4.24)	(−2.48)	(3.23)	(−0.00)
Observations	213	809	213	809	213	809
R-squared	0.679	0.545	0.343	0.160	0.732	0.563

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

Therefore, Hypothesis 3 is verified.

5.4. Moderating Effect Test

In Table 6, Model 4 tests the moderating role of IPP between SUB and TFP_FE. The coefficient of the cross-multiplier term SUB∗IPP is −0.311, which fails to meet the criteria for statistical significance, indicating that the moderating role of IPP does not hold between SUB and TFP_FE. Model 5 tests the moderating role of IPP between SUB and green innovation. The coefficient of the cross-multiplier term SUB∗IPP is 0.815, which passes the significance test at a 5% level. This result indicates that the positive moderating effect of IPP between SUB and green innovation is significant. Here, the higher the IPP, the stronger the facilitating effect of SUB on green innovation. Model 6 tests the moderating role of IPP between green innovation and TFP_FE. The coefficient of the cross-multiplier term lngreen∗IPP is 0.170, which does not pass the significance test. This result indicates that the positive moderating effect of IPP between green innovation and TFP_FE is not significant. The above result indicates that the positive moderating effect of IPP only remains in model 5. The increased level of IPP gives stronger incentives to enterprises' green innovation behaviors and technological innovation projects with strong innovation willingness. However, insufficient economic benefits mitigate the risk of enterprises in carrying out technological innovation under an increased level of IPP. Under the concept of green development, regions can continuously increase their level of IPP and ultimately realize the healthy and sustainable operation of enterprises, effectively improving their green innovation.

Table 6. List of test results for moderating effects.

	TFP_FE	lngreen	TFP_FE
Variables	**Model 4**	**Model 5**	**Model 6**
lngreen			0.232 ***
			(9.47)
SUB	0.492 ***	0.347 ***	0.411 ***
	(25.58)	(14.69)	(20.21)
Board	0.795 ***	0.312 *	0.720 ***
	(5.16)	(1.65)	(4.86)
Growth	0.001	−0.004	0.002
	(0.41)	(−1.41)	(0.83)
Indep	0.020 ***	−0.015 ***	0.024 ***
	(4.16)	(−2.60)	(5.10)
Lev	2.753 ***	0.965 ***	2.529 ***
	(18.58)	(5.30)	(17.56)
TobinQ	−0.064 ***	−0.020	−0.059 ***
	(−3.52)	(−0.87)	(−3.36)
IPP	1.982 ***	0.241	1.928 ***
	(4.79)	(0.47)	(4.86)
SUB*IPP	−0.311	0.815 **	−0.577 *
	(−1.15)	(2.46)	(−1.84)
lngreen*IPP			0.170
			(0.43)
Constant	−0.411	−4.233 ***	0.583
	(−0.84)	(−7.05)	(1.21)
Observations	1019	1019	1019
R-squared	0.653	0.294	0.681

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

Therefore, Hypothesis 4 is verified.

6. Conclusions and Recommendations

6.1. Conclusions

In this study, we examined the implications of government subsidies on firms' TFP and the mediating role of green innovation. We also explored the heterogeneity of this impact using data from listed Chinese AI firms. The research results are as follows.

First, government subsidies will significantly promote the improvement of total factor productivity among artificial intelligence enterprises. This conclusion remained unchanged after using the two-stage least squares method to eliminate the endogeneity of variables and changing the productivity measurement method for robustness testing. Government subsidies not only help alleviate the financial pressure on enterprises in R&D and innovation, but also encourage enterprises to increase their investments in R&D, improve their technological and innovation capabilities, and promote improvements in total factor productivity.

Second, green innovation has an intermediary effect between government subsidies and enterprise total factor productivity. That is, government subsidies encourage enterprises to increase their investments in green innovation, improve the quantity and quality of their green innovation, and ultimately help improve enterprise total factor productivity. Therefore, government subsidies play a positive role in promoting the green development of enterprises and help guide enterprises to achieve a win–win situation of economic and environmental benefits.

Third, the impact of government subsidies on total factor productivity is significantly different for different types of artificial intelligence companies. From the perspective of ownership, government subsidies have a more significant incentive effect on state-owned artificial intelligence companies. This result may be related to the advantages that state-owned enterprises have in resource acquisition, policy support, and market position. However, government subsidies also remain important for non-state-owned enterprises. The government should further optimize its subsidy policies to ensure that enterprises of all ownership types can enjoy policy dividends fairly.

Fourth, the stronger the intensity of intellectual property protection, the more significant the positive incentive effect of government subsidies on the total factor productivity of artificial intelligence enterprises. This impact occurs because strong intellectual property protection can reduce the risk of imitation and misappropriation of corporate innovations, and intellectual property protection provides strong support for government subsidies, which will stimulate the innovation enthusiasm of enterprises and, thus, enhance total factor productivity. However, the effect of intellectual property protection intensity on green innovation is not significant. Because green innovation involves multiple fields and technologies, excessive intellectual property protections may limit cooperation and exchange between enterprises in different fields. In addition, the acceptance of green innovative products is limited in the current market. Protection fails to act as a catalyst, thereby hindering the progress of green innovation.

6.2. Recommendations

6.2.1. Government Adjusts the Level of Subsidies to Increase the Effectiveness of Spending Funds

Due to the lack of precision among subsidies, situations of "flooding", and the absence of monitoring mechanisms, funds cannot be fully utilized. At the same time, for an enterprise, after obtaining a government subsidy, there is no sufficient motivation to maximize the efficiency of its use in R&D inputs because the pertinent policy serves as more of a principle. The use of green technology development subsidies in other business areas is commonplace, leading to current government subsidies that poorly increase the technical levels of enterprises and do not ameliorate the negative status quo. Hence, in its capacity as a financier, the government must increase its financial assistance, refine the precision of its subsidies, and oversee the allocation of enterprise funds. The government uses "big data" and other tools to build a new cloud database for enterprise subsidy fund management through multi-departmental linkages, joint finances, taxation, and industry and information technology departments. The government also adopts different financial and tax policies for enterprises in different growth cycles. For example, for large AI enterprises, cloud databases can be used to assess the progress of fund disbursements, project implementation, and other information in real-time. Such systems adopt special subsidies in a targeted manner, enabling policies to be applied according to the materials and prescribe the right solution.

Government subsidies for private AI enterprises should be increased, and the synergistic growth of economies with multiple proprietors should be encouraged. China is undergoing a crucial transition phase in its development mode, enhancing its economic structure and modifying its growth trajectory. The pace of monetary expansion is slowing down, the demand structure is changing rapidly, and the pressure on some private enterprises to achieve high-quality development is increasing. The government should increase its support for key regional private enterprises, ease the pressure of enterprise financing, and help private enterprises improve their scientific and technological innovation. Simultaneously, government departments can help private artificial intelligence enterprises establish industrial technology research institutes, advanced technology research institutes, industrial research institutes, and other new research and development organizations through project funding, post subsidies, social capital, and government cooperation. The government can also collaborate with higher education institutions, integrate the strengths of all parties and the advantages of their resources, optimize their resource allocation, and promote the in-depth integration of industry, academia, and research, thus providing a better solution for AI enterprises. These measures would provide the talent necessary to develop groundbreaking technology.

6.2.2. Government Plays a Policy-Oriented and Regulatory Role and Establishes a Sound Intellectual Property Protection System to Support the Innovative Activities of Enterprises

The government should enhance its role in improving patent quality among high-tech enterprises and improving the effectiveness of its policy implementation. In its subsidy policies, the government should establish a classification management and process supervision mechanism, as well as incorporate patent conversion rates, international patents, and other indicators reflecting the quality of patents in the evaluation; enhance the guiding effect of government subsidies on the technological innovation of enterprises; and avoid the problem of enterprises emphasizing innovation quantity over innovation quality for the sake of obtaining subsidies. When developing IPP policies, government departments should meticulously select suitable IPP policies that align with the technological capacities and economic foundations of enterprises in the region. Additionally, governments should enhance IPP enforcement by balancing enforcement costs and effectively protecting the interests of R&D institutions and personnel. These measures will facilitate independent investments in R&D within the AI industry. The design of the intellectual property system should not adopt a one-size-fits-all approach. With the rapid change in digitalized industrial products, the government should build and improve mechanisms for safeguarding intellectual property rights and improve the protection of property rights for artificial intelligence technology in the context of the digital economy.

7. Contributions and Limitations

7.1. Contributions

Utilizing pertinent literature, this study quantified the TFP of Chinese AI companies. We examined how government subsidies can affect the TFP of AI firms and explored the impact magnitude of government subsidies on AI firms, considering factors such as green innovation and firm ownership. Firstly, through research, we analyzed the impact of government subsidies on enterprises' TFP and explored theoretically and empirically whether government subsidies can offer positive or negative incentivizing effects. We also studied the mechanisms of such impacts on TFP. To a certain extent, these results fill research gaps in improving the provision of government subsidies and the growth of enterprises.

To conclude, this study explored various dimensions, such as green innovation, ownership, and IPP, to explain the role of financial subsidies in TFP. This work aimed to further investigate how government subsidies can assist enterprises in overcoming challenges and provide a theoretical foundation for enhancing relevant policies. The present results provide theoretical foundations for further exploring the effects of government subsidies in helping enterprises alleviate their difficulties and improve their policies.

7.2. Limitations

When analyzing the mediating role and heterogeneity, we considered only the factors of green innovation and the nature of enterprise ownership. However, other types of heterogeneity may yield different results, which this paper did not capture. In future research, we will continue to explore enterprise trends in artificial intelligence and the implementation effects of government subsidies to provide more comprehensive theoretical study and empirical analyses and contribute to the advancement of a high-quality economy.

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