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The Mixed Incentive Effect of Government Subsidies and Venture Capital on the Sustainability of Enterprise Innovation in China

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ABSTRACT

The innovation effects of enterprises receiving subsidies remain a widely debated issue in academic research. Using the Control Function (CF) method, this study integrates government subsidies and venture capital into a unified framework to examine their combined incentive effects on the sustainability of firm innovation. Survival analysis is employed to compare the probability of enterprises ceasing innovation under a single-subsidy mechanism versus dual-financing conditions. The findings reveal that the interaction of public subsidies and private capital produces a significant complementary effect, generating stronger and broader stimulation of continuous innovation activities than government subsidies alone. In the technology-intensive industry sample, the synergy of subsidies and venture capital reduces the probability of innovation discontinuation by approximately 6.4%. Results from the Cox proportional hazards model further indicate that determinants of sustained innovation differ depending on enterprises' levels of effective patent output. These empirical results advance the understanding of corporate innovation financing, enrich theoretical perspectives in the field, and provide practical implications by highlighting the importance of combining public and private financing to foster sustainable innovation, thereby supporting China's innovation-driven development strategy.

1. Introduction

Innovation serves as a crucial foundation for building a modernized, powerful country and enhancing international competitiveness. The findings from the 20th National Congress of the Communist Party of China once again underscored the core position of innovation in the overall modernization drive and accelerated the implementation of the innovation-driven development strategy. Authorities such as the State Council, along with the Ministry of Science and Technology and the National Development and Reform Commission, have enacted a suite of policies and actions aimed at promoting the improvement of enterprises' independent innovation capabilities. Especially since 2018, trade friction between China and the US has intensified. The all-round technology

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blockade strategy implemented by Western developed countries, led by the United States, against China has made it extremely urgent for micro enterprises to accelerate the construction of their original innovation capabilities. However, technological innovation has characteristics such as knowledge spillover effects, long investment cycles, and significant risks. It is hard for enterprises to meet the needs of R&D activities with their own funds, so financing has become an indispensable approach.

At present, the number of government subsidies received by listed companies has been growing annually, and the subsidy amounts have also been on the rise. In particular, funding allocated to A-share listed companies by the government increased from 79.28 billion yuan in 2013 to 334 billion yuan in 2021, and the number of subsidized enterprises accounts for 98.45%. Meanwhile, the academic community has been paying close attention to subsidy effects [1-2], but the research conclusions are not entirely consistent. One view is that subsidies serve as financial resources for R&D that can mitigate the capital constraints faced by businesses, and there is a complementary effect between the two [3-4]. However, some scholars believe that government subsidies do not lead to subsequent R&D expenditures by businesses, that their effect on innovation is limited, and that they even reduce the original R&D investment level of enterprises, creating a "crowding-out effect" [5-6]. This may stem from issues like fraudulent claims and opportunistic behavior associated with government subsidies, coupled with the government's inability to adequately monitor companies to ensure the intended use of funds. Some scholars also argue that the relationship between subsidies and business R&D investment is not merely one of crowding-in or crowding-out, but rather exhibits a more intricate nonlinear dynamic [7]. In addition, as another important financing channel for enterprises, venture capital has also given rise to two competing views in existing research. Some argue that venture capital can deeply participate in enterprise management through a series of certification, supervision, technology management consulting, and other methods, thereby playing a pivotal role in fostering business R&D investment and patent generation [4, 8]. Another view holds that the positive correlation between venture capital and business R&D expenditure stems from the screening of investment institutions before investment, and that venture capital often demonstrates short-sighted behavior, which does not improve corporate R&D expenditure [9].

Thus, this paper first demonstrates the necessity of considering both government subsidies and venture capital simultaneously. Secondly, by using the control function method, these two financing methods are incorporated into an integrated analytical paradigm for investigating the mixed effect and cross-effect of their synergy on the sustainability of enterprise innovation. Furthermore, by using the survival analysis method, a comparative analysis is conducted on the differences between a single government subsidy and the coupling of the two types of financing methods in enhancing perpetual firm-level innovation.

The original contributions of this research are threefold: (1) Distinct from prior studies on the single effect of market or administrative means on enterprise innovation, this paper uses the CF estimation framework to incorporate government subsidies and venture capital into the same measurement model, which can effectively solve the endogeneity problems thereby caused, so as to evaluate their mixed incentive effects more scientifically and reasonably. (2) The survival analysis method is introduced to evaluate the effects of different financing methods on the probability of enterprises ceasing innovation, which expands related research in the field of innovation financing. (3) In order to alleviate the controversy in current research regarding the selection of proxy variables for strategic innovation, this paper focuses on innovation sustainability and examines the innovation behaviors of enterprises after obtaining subsidies.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and theoretical background. Section 3 introduces the research methodology, including data description, model setting, variable definitions, and model specifications. Section 4 presents the empirical results, covering benchmark regressions, heterogeneity analysis, survival analysis, and a series of robustness tests. Section 5 discusses the key findings and elaborates on their practical implications. Finally, Section 6 concludes the study and outlines its limitations and directions for future research.

2. Literature review

In recent years, government subsidies to firms have surged significantly [10]. Despite growing academic interest, findings on the impact of subsidies remain inconclusive. While some studies suggest subsidies alleviate firms' financial constraints and stimulate R&D through a complementary effect [11-13], others highlight a crowding-out effect, where subsidies displace internal R&D investment due to opportunistic behavior and weak oversight [14-16]. Recent work further suggests a more nuanced, nonlinear relationship [17]. Parallel debates surround venture capital: some argue it fosters innovation via active involvement and governance [18], while others contend its influence is overstated due to pre-investment screening and short-term orientation [19].

The reasons for the contradictory conclusions in the above studies may be due to the selection of research objects, research periods and proxy indicators. In particular, David *et al.,* [20] pointed out that the possible endogeneity between fiscal incentives and corporate R&D funding was not properly considered as an important reason for the contradictory conclusions of their research. Existing literature has always focused on the incentive effect of direct policies primarily grounded in subsidies provided by the government to firms' R&D expenditure [21], or assessed the influence of private equity on company innovation from a singular viewpoint. There is a scarcity of research that integrates administrative instruments of public funding and market instruments of private equity into a unified analytical framework. Few studies have paid attention to the mixed effect and cross-effect existing between the two, as well as the difference in the impact of comparing the synergy of multiple financing methods and a single channel on enterprise innovation. If the two can be combined, they can achieve complementary advantages [22]. As Busom *et al.,* [23] pointed out, if the composite influences of assorted government innovation initiatives are neglected, it will inevitably lead to an estimation bias of the incentive effect of innovation activities will inevitably be caused.

Furthermore, academics have engaged in thorough debates regarding the tactical innovation initiatives adopted by enterprises after receiving various types of innovation policy funding [24]. However, the proxy indicators related to symbolic behaviors are inconsistent, thus reaching completely contradictory conclusions. Lian *et al.,* [25] identified the behavior of the utility model and design patents as strategic innovation. Meanwhile, substantive innovations were measured by invention patents, and it was perceived that state-owned enterprises exhibited a greater propensity for strategic innovation as opposed to their non-state-owned counterparts. Jiang *et al.,* [26] believed that there were also a lot of symbolic activities in invention patents, so they used invention patents to measure the symbolic innovation of enterprises, and found that private enterprises (as opposed to state-owned counterparts) were more inclined to carry out strategic innovation. In order to provide an effective response to this kind of problem, this paper focuses on the perpetuity of innovation within businesses. This is because if enterprises are motivated by strategic innovation, they will not invest relevant resources based on their internal innovation drive. Only enterprises that carry out substantive innovation will continuously invest R&D resources to ensure the sustainability of innovation output. This is also the original intention of innovation policy design, such as financial subsidies.

In summary, while prior studies have examined the individual effects of government subsidies and venture capital on firm innovation, limited attention has been paid to their combined or interactive impacts within a unified empirical framework. Most existing research fails to account for potential endogeneity in public-private innovation financing, often treating them as isolated mechanisms. Moreover, there is a lack of consensus on appropriate proxies for distinguishing between symbolic and substantive innovation, further complicating the interpretation of innovation outcomes. Notably, few studies have investigated how the synergy between government and market-based financing influences the sustainability of enterprise innovation—an essential but underexplored dimension of long-term innovation behavior. Therefore, this study seeks to fill these gaps by examining the mixed incentive effect and cross-effect of government subsidies and venture capital on firms' continuous innovation efforts, using robust econometric and survival analysis approaches.

3. Methodology

This section begins by describing the data used in the analysis, followed by the model setting and variable definitions.

3.1 Data

The focus of this study encompasses all companies listed on the A-share market between 2015 and 2022. China's technological innovation started from imitation during the initial period following the establishment of the People's Republic of China, and experienced technology introduction, digestion and absorption. In 2015, continuous and comprehensive independent innovation achieved rapid development. Since then, the relevant data on innovation have been relatively complete. The patent information is derived from the incoPat platform. The figures regarding venture capital investments are obtained from the CVSource platform, while government subsidies, financial details of listed companies, and so on, are extracted from the CSMAR database. Furthermore, in accordance with the research requirements, listed companies in the financial sector, insurance industry, and those with abnormal operating conditions (such as ST, PT, SST, etc.) are excluded. Finally, to mitigate the impact of outliers, this study applies a winsorization technique, capping the top and bottom 1% of all continuous variables. It should be observed that the introduction of Accounting Standard for Business Enterprises No. 16 - Government Grants, the sources of government grants are divided into two categories: other income and non-operating income. By checking the item details, it is found that both contain entries related to R&D subsidies. Therefore, when dealing with the data of government subsidies in this paper, both types of sources are included.

3.2 Model setting and variable definition

3.2.1 Model setting

From the perspective of empirical analysis, this section will focus on the influence of governmental financial assistance and venture capital on the sustainability of enterprise innovation, and provide empirical evidence for the subsequent control function methods (CF). In this paper, government subsidies and venture capital are selected as the main explanatory variables, and the explained variable is the sustainability of enterprise innovation. Drawing from the debates concerning the determinants of corporate innovation by Wang *et al.,* [4], the selection and handling of relevant variables are detailed in the index construction section. The following regression equation is constructed:

$$INX_{it} = \alpha + \beta_1 GF_{it} + \beta_2 GF_{it}^2 + \beta_3 VC_{it} + \beta_0 X_{it} + \varepsilon_{it} + \mu_t + \lambda_p \quad (1)$$

$$INX_{it} = \alpha + \beta_1 GF_{it} + \beta_2 GF_{it}^2 + \beta_0 X_{it} + \varepsilon_{it} + \mu_t + \lambda_p \quad (2)$$

Where INX_{it} is the sustainable innovation of enterprise i in year t, GF is the government subsidy and the quadratic term is introduced, VC is the venture capital, X constitutes a suite of control factors, ε_{it} represents the error component, with year and provincial dummies incorporated to account for the influence of time and region. It can be seen from the above model setting that Equation (1) primarily investigates the non-linear effect of government grants on the persistence of innovation. If β_1 is significantly positive and β_2 is significantly negative, it indicates that there exists an ideal extent to which government subsidies influence corporate innovation. Equation (2) mainly analyzes the fluctuations in the non-linear influence of government grants on the ongoing innovation of businesses after the introduction of venture capital.

3.2.2 Variable

(1) Dependent variable. Enterprise innovation sustainability. Current research mainly uses R&D investment and patents to measure enterprise innovation activities, considering the viewpoint of input and output. However, it is an indivisible fact that the input of enterprise innovation activities also includes intangible capital such as technology introduction, innovation talent training and conversion of R&D outcomes. Citing the investigation by Hu *et al.,* [27], the proportion of the growth in intangible assets relative to the overall assets is adopted to measure the innovation persistence. In addition, considering that the innovation activities of businesses are a dynamic progression and the lag of the impact effect of funding activities, the value of patents owned by enterprises within three consecutive years after obtaining both financial subsidies and venture capital is assigned as 1; otherwise, it is 0. The robustness test is carried out.

(2) Independent variables. government subsidies and venture capital. Most of the existing studies directly adopt the data on government subsidies in the CSMAR database [28-29] to examine its impact on innovation activities. However, through the analysis of the notes to the financial statements of listed companies, it can be found that the detailed list of government subsidies contains many items unrelated to innovation activities, such as tax incentives, refund of individual tax fees and subsidies for house purchase promotion activities, etc. There is no doubt that the overall impact of governmental R&D grants on enterprises' innovation activities is overestimated, resulting in biased estimation results. Taking this into account, this study focuses on the innovation subsidy part of the government subsidy, and eliminates the non-innovation-related subsidy items through manual identification, so as to improve the accuracy of the estimation results. Existing studies have almost all assigned values to venture capital variables based on whether the top 10 shareholders of listed companies contain venture capital institutions. However, binary variables cannot reflect the difference in the actual investment level and ignore the heterogeneity of venture capital intensity in promoting innovation. Therefore, this study employs the volume of venture capital as a metric for gauging the VC funding received by listed companies. Furthermore, Wu [30] believed that the capacity for innovation within businesses not only depends on the current R&D investment, but also is affected by the previous R&D expenses. In line with this concept, this study holds that the effect of venture capital on enterprise innovation will also be a long-term process, so the stock of venture capital is used as the index of venture capital. To mitigate the effects of size bias, it is characterized by its proportion of the total operating revenue. Correspondingly, the continuous inventory approach is utilized to determine the stock. The formula is as follows:

$$VCK_{it} = (1-\delta) \times VCK_{i(t-1)} + I_{it} \quad (3)$$

Where, VCK_{it} and $VCK_{i(t-1)}$ are the capital stock of enterprise i in year t and year t-1 accordingly, δ is the depreciation rate, and I_{it} is the venture capital at constant price of enterprise i in period t. Referring to Wu's [30] analysis of the R&D investment stock, the depreciation rate is set at 15%, with 2015 as the base period. The nominal venture capital amount of each enterprise is deflated by the price index of 0.5. In addition, the initial capital stock of venture capital is calculated as:

$$VCK_{i0} = I_{i0}/(g+\delta) \tag{4}$$

Where VCK_{i0} is the capital base during the initial period, I_{i0} is the actual venture capital investment amount in the base period, g denotes the mean growth rate of the tangible venture capital sum in the investigation period (2015-2022).

(3) Control variables. Referring to [3] and [28], this paper adopts firm age, firm size, equity nature, equity balance degree, equity concentration, dual employment, asset-liability ratio and profitability as the control variables of enterprise innovation sustainability from three aspects: basic company information, corporate governance and development. The detailed explanations and summaries of the pertinent variables are presented in Table 1.

Table 1
Definitions of variables and summary statistics

Variable definition			Descriptive statistics		
Symbol	Variable name	Definition / Measurement	Mean	Sd	Obs.
INX	Innovation persistence (qualitative)	Increment intangible assets/total assets	0.005	0.017	6505
INL	Innovation Persistence (quantitative)	Dummy variable: If there is a patent application for three consecutive years after the grant, it is 1; otherwise 0	0.697	0.460	5458
GF	Government subsidy	Government subsidy amount/total operating income	0.007	0.012	6686
VC	Venture capital	Venture capital amount (VCK)/total operating income	0.0338	0.103	6456
DEB	Equity balance degree	Shareholding ratio of the top ten shareholders/shareholding ratio of the largest shareholder	1.836	0.742	6898
STATE	equity nature	Dummy variable: 1 for state-owned enterprises, 0 otherwise	0.399	0.490	6899
ALR	Asset-liability ratio	Total liabilities/total assets	0.440	0.224	6898
SIZE	Firm size	Log of number of employees	7.552	1.344	6893
TGA	Profitability	Growth rate of total assets	0.259	0.917	6899
AGE	Firm age	Current year - Year of establishment	14.80	5.478	6899
OSC	Equity concentration	Herfindahl index of shareholding ratios of top 10 shareholders	1785	1197	6898
PTS	Dual employment	Dummy variable: 1 if the chair is also the CEO, otherwise 0	0.256	0.437	6825

3.3 Model specification

3.3.1 CF estimation

In order to solve the possible endogeneity problem caused by reverse causality between the two types of financial subsidies and enterprise innovation, after testing the Spearman correlation coefficient of government subsidies and venture capital, it was found that its value was 0.064, suggesting that a significant multicollinearity issue was not present between the two variables. Thus, the two types of funding methods can be incorporated into the same measurement equation for estimation. Referring to the design idea of the control function method mentioned by Wooldridge [31], the following estimation framework is adopted to test the combined impacts of the two categories of funding on enterprise innovation sustainability.

$$\begin{cases} INX_{it} = \theta_0 + \theta_1 GF_{it} + \theta_2 VC_{it} + \lambda X + \mu_t + \mu_p + \varepsilon_{it} \\ GF_{it} = \alpha_0 + \eta X + \mu_t + \mu_p + \omega_{it} \\ VC_{it} = \beta_0 + \delta X + \mu_t + \mu_p + \tau_{it} \end{cases} \quad (5)$$

The connotations of each variable in the above-mentioned control function method estimation framework (5) are consistent with those of the regression equation (1); ε , ω and τ , respectively, represent the perturbation terms when the explained variables are INX, GF and VC, and simultaneously control the time and region fixed effects of each core equation.

Firstly, the control function method needs to determine the instrumental variables of government subsidies and venture capital as the dependent variables in the second and third core equations of the above estimation framework (5). To address the potential issue of endogeneity inherent to the government subsidy variable, the initial lag of the government subsidy is adopted as its instrumental variable here. From the regression outcomes presented in Table 2, it is evident that venture capital significantly influences the enduring innovation of businesses.

Table 2
Outcomes of the regression analysis

	(1)	(2)	(3)	(4)
GF	0.078*** (0.026)	0.052** (0.022)		0.024* (0.013)
GF2	0.205* (0.112)	0.073 (0.094)		
VC		0.092*** (0.002)	0.191*** (0.003)	0.196*** (0.003)
VC2			0.092*** (0.002)	0.094*** (0.002)
Control variables	YES	YES	YES	YES
_cons	0.000 (0.002)	0.009*** (0.002)	0.013*** (0.001)	0.014*** (0.001)
Adj-R^2	0.034	0.328	0.471	0.494
N	6289	6241	6383	6241

Note:***, **, and * denote statistical significance at the 1%, 5%, and 10% thresholds, respectively; the figures within parentheses represent robust standard deviation errors; Adj-R^2 is the adjusted R^2; Both time and region fixed effects were controlled. The following table is consistent.

However, this result may be a self-selection problem resulting from venture capital's tendency to invest in enterprises with more innovative capabilities. In order to alleviate this problem, combined with the existing research, the quantity of regional private equity firms (NVC) and the lagged term of venture capital are used as the instrumental variables of venture capital. Regions that consistently have one of the top five highest numbers of local private equity firms throughout the study period are assigned a value of 1 (including Beijing, Guangdong Province, Shanghai, Zhejiang Province and Jiangsu Province), and other regions are assigned a value of 0. The number of venture capital institutions in each province over the years is from the China Venture Capital Yearbook.

Secondly, the instrumental variables are incorporated into the last two equations of the CF estimation framework, in which the explained variables are government subsidies and venture capital, respectively, and the first-stage regression results of the control function method are obtained to analyze the rationality of the choice of instrumental variables.

Finally, on the above basis, by analyzing the residuals of government subsidies and venture capital, the control function is thus formed to enter the first core equation of the CF estimation framework, thereby solving the potential endogeneity problem. Thus, the combined impact of the two factors on the sustainability of corporate innovation is examined.

3.3.2 Survival estimation

Enterprise innovation has dynamic and continuous characteristics. The application of survival analysis methods can track how government subsidies and venture capital transform short-term innovation stimuli into long-term and sustainable innovation activities. To examine the substantive innovation of enterprises, here, whether the enterprise has held valid patents for three consecutive years after obtaining the funding is adopted to judge the sustainability of the innovation. The valid patents of listed companies are derived from the incoPat database as of December 31, 2022. However, it is impossible to observe whether companies have valid patents after 2022. Therefore, there are deleted data (Censoring), and traditional estimation methods cannot effectively estimate this problem. The survival analysis method is applicable to the research of such situations. Its concept was first proposed by Kaplan and Meier [32] and applied in the biomedical field. It mainly studies the analysis of the survival probability of patients by different treatment methods (such as different drugs or intervention methods, etc.). Kiefer [33] further proposed applying survival analysis to issues such as the survival time of enterprises and the durability of products. The survival time of enterprises is similar to the existence and disappearance in the medical field. The innovation sustainability focused on in this article begins with the possession of a patent in the first year after obtaining funding. The survival time is defined as the duration from the beginning year to having a patent for three consecutive years, and the end event is the absence of a patent in any year within three consecutive years.

Acemoglu *et al.,* [34] found that R&D subsidies for existing enterprises may not achieve the goal of technological innovation, as they promote the endurance and growth of less competitive businesses. To avoid this problem, this paper takes technology-intensive sectors between 2015 and 2022 as its subject, and the definition of relevant industries has been mentioned in the above robustness test, so it will not be repeated. It is worth mentioning that the patent index in this part adopts the number of effective patents. On the one hand, patent applications in China need to go through the stages of preliminary examination, substantive examination and authorization, which can guarantee their quality to a certain extent and weaken the phenomenon of strategic innovation of enterprises. On the other hand, there are different views on the definition of enterprise strategic innovation in current research [26, 35], that is, whether the invention patent measures the substantive innovation or strategic innovation of enterprises? And valid patents can alleviate the crux of the contradiction. Analyzing the sustainability of innovation can better depict the substantive innovation activities of enterprises.

Existing studies usually use the Kaplan-Meier product limit method (KM method for short) and Cox proportional hazards model for survival analysis. The former gives an intuitive survival function curve for survival time and analyzes the survival rate and distribution characteristics of enterprise innovation persistence under different conditions. However, as a non-parametric estimation method, KM method cannot control the impact of potential confounding factors on outcome events, while Cox model can effectively solve this problem. If there is no censoring of the data, the survival function is expressed as the proportion of individuals with a survival time longer than t years in the population for estimation:

$$\hat{S}_t = \frac{\text{The number of individual s whose survival time is greater than t}}{\text{Total number of individual s}} \quad (6)$$

Considering the existence of the "knotting" phenomenon in the data, that is, assuming that the event occurs at D strictly distinguished time points $t_1<t_2<... <t_D$, the number di of sustained time periods during which innovation was observed to cease at time ti. Yi represents the number of individuals at risk in time ti, that is, the number of continuous time periods during which innovation may cease in phase i. Then, di/Yi represents the conditional probability that a certain enterprise i continues to innovate just before ti and stops continuous innovation in ti. The expression of the KM method is as follows:

$$\hat{S}_t = \begin{cases} 1, & t < t_1 \\ \prod_{t_1 \le t} \left[1 - \frac{d_i}{Y_i} \right] & t \ge t_1 \end{cases} \quad (7)$$

Further, by incorporating various factors that have a continuous impact on enterprise innovation, the Cox proportional hazards model is presented below:

$$h(t|Z) = h_0(t)c(\beta'Z) = h_0(t)\exp(\sum_k^p \beta_k Z_k) \quad (8)$$

Among them, $h_0(t)$ is an arbitrary baseline risk rate, representing the probability that an individual with a risk vector stops innovating at time t. $\beta=(\beta_1, \ldots, \beta p)'$ is a parameter vector, namely the regression coefficient of the Cox proportional hazards model. Different from the common regression equation, its coefficient is positive (negative), indicating that this variable has an inhibitory (promoting) effect on enterprise sustainable innovation, that is, it reduces (increases) the probability of enterprise sustainable innovation. $Z'=(Z_1,\ldots ,Z_p)$ is the covariate that affects the sustainability of enterprise innovation. According to the influence effect of the above control variables on enterprise innovation, the covariates here are net profit growth rate (NPG), firm age (AGE), sustainable growth rate (SUSG), firm size (SIZE), equity nature (STATE) and market power (MRP), and are represented by the proportion of operating revenue in operating cost. Other relevant data come from the CSMAR database.

4. Results

4.1 Benchmark regression

The initial pair of columns in Table 2 displays the estimation outcomes of regression equations (1) and (2), respectively. Model (1) indicates that both the linear and quadratic term coefficients of government grants (GF) on sustainable firm innovation are statistically significant, but the square term's coefficient is minus. This suggests that the impact effect of government subsidy intensity on firm innovation is inverted U-shaped, that is, there exists an optimal subsidy level. This conclusion is consistent with Liu *et al.,* [36]. After further analysis, it was found that after adding the venture capital variable, the negative impact of the squared component of government grants was no longer significant, and the venture capital coefficient was significantly positive. This indicates that the intervention of venture capital as a market means has improved the utilization level of government subsidies and actively promoted the continuous innovation of enterprises. Similarly, in the relationship between venture capital and innovation sustainability, it can be found that government subsidies also play a similar role. This shows that it is necessary to simultaneously consider two typical financing channels-government grants and venture capital after examining the external funding of enterprises, that is, examining a single funding method may lead to contradictory research results due to potential endogeneity problems.

The above empirical results show that in order to reasonably explain the innovation activities of enterprises after receiving external funding, different types of funding should be incorporated into the same analytical framework. The third section of this paper is based on this.

Table 3 reports the first-stage regression results of the control function method. From Model (1), it is evident that the coefficient for L.GF is notably positive, achieving significance at the 1% level. Similarly, from the regression results of venture capital as the dependent variable, both L.VC and NVC also achieve statistical significance at the 1% level, suggesting that a higher count of venture capital entities in an enterprise's region correlates with greater ease in securing such funding. The regression findings above also indicate that the choice of instrumental variables is justified.

Table 3
First-stage regression results of CF method

Variables	GF (1)	VC (2)
L.GF	0.235*** (0.014)	
L.VC		0.134*** (0.015)
NVC		0.015*** (0.005)
Control variables	YES	YES
_cons	0.011*** (0.001)	0.090*** (0.011)
Adj-R^2	0.327	0.603
N	3849	3743

Note: In the equation where the explained variable is VC, due to the strong collinearity between the dummy variable of the number of venture capital institutions (NVC) and provincial variables, the provincial fixed effect is not controlled in the regression results.

Then, by analyzing the residuals of government subsidies and venture capital and forming a control function, the outcomes from the control function approach are derived, as illustrated in Table 4. GFgr and VCgr in Model (1) respectively represent the generalized residual of GF and VC, that is, the control function. The core explanatory variables of government subsidy and venture capital are significantly positive at different levels, which indicates that both exert a substantial positive influence on the innovation sustainability of businesses. Moreover, the combined motivational impact of the two factors demonstrates a significantly positive effect.

Table 4
CF test and cross effect of the mixed effect of subsidies and venture capital on the sustainability of corporate innovation

Variables	CF test for mixed effects (1)	Cross Effects Test (2)
GF	0.108** (0.051)	0.017 (0.062)
VC	0.108*** (0.007)	0.112*** (0.007)
GFgr	0.007 (0.070)	0.004 (0.070)
VCgr	0.005 (0.008)	0.004 (0.008)
GF_VC		0.539** (0.247)
Control variables	YES	YES
_cons	0.008*** (0.002)	0.012*** (0.002)
Adj-R^2	0.399	0.354
N	3634	3634

In order to further test the possible crowding-in and crowding-out effects of the two funding methods at the micro level, Model (2) of Table 4 shows the test results of including the interaction term of government subsidies and venture capital in the CF estimation framework (5). The results show that the coefficient for GF_VC is notably positive at the 1% significance level, suggesting that the administrative means represented by government subsidies and the market means represented by venture capital have formed a prominent mutual promotion effect. On the one hand, the deep participation of venture investors in enterprise management can effectively alleviate the problems of ineffective supervision and rent-seeking that may be faced in the process of government subsidies [28] and reduce the strategic innovation actions of businesses. On the other hand, the government's innovation subsidy has a certain technology-oriented nature. As a signal of technological advantage, it can increase the support of venture capital for enterprise R&D innovation. Moreover, as a government force, fiscal subsidies can, to a certain extent, avoid the "market failure" problem that may be caused by venture capital. Therefore, a prominent complementary effect is formed between the two.

4.2 Heterogeneity analysis

(1) Analysis of the diversity in ownership rights. Since state-owned enterprises inherently undertake other functions besides the economy, compared with other enterprises, the government has a natural inclination towards state-owned enterprises. Hence, they have a higher probability of securing government subsidies. As a result, the efficiency of innovation within state-owned enterprises has consistently been a topic of intense debate among numerous academics [36-37]. Here, the mixed incentive effects of government subsidies and venture capital in state-owned and non-state-owned enterprises are analyzed. The pertinent findings are displayed in Models (1) and (2) of Table 5. It is evident that VC exerts a notably positive influence on the viability of innovation within state-owned enterprises, whereas GF has a positive influence that is not statistically significant. In non-state-owned enterprises, both of them have shown positive promoting effects on the sustainable innovation of enterprises at the significance level of 1%. From the perspective of the mixed incentive effect, in contrast to state-owned firms, non-state-owned ones experience a more pronounced enhancing effect from government subsidies and venture capital. This finding aligns with the prevailing perspective among scholars that state-owned enterprises tend to have lower innovation efficiency compared to their non-state-owned counterparts. However, it is worth noting that after integrating venture capital, the comprehensive incentive effect of the two financing methods on innovation within state-owned enterprises is notably positive, highlighting the importance of venture capital intervention for companies to undertake innovative endeavors after obtaining financial subsidies.

(2) Heterogeneity analysis of enterprises with different technology levels. The incentive effects of different innovation policies show significant differences among enterprises with different levels of innovation investment. Meanwhile, Acemoglu *et al.,* [34] suggested that enterprises with low productivity should be encouraged to exit, so as to release skilled labor for advanced enterprise R&D. In view of this, the sample is divided into quartiles according to the number of effective patents to examine the marginal effect and holistic motivational impact of government grants and private equity in enterprises' sustainable innovation at different technology levels. The pertinent outcomes are presented in Models (3)-(6) of Table 5. Regarding the marginal impact, GF achieved statistical significance solely within the uppermost tier of technical proficiency (75-100%) at the 5% threshold. This conclusion is consistent with Kang *et al.,* [38]. It is argued that, within the business cycle framework, government subsidies primarily stimulate R&D innovation in mature enterprises. Further

observation shows that its coefficient in the sample with the lowest technology level (0-25%) is negative, although it fails to pass the significance test. To some extent, this provides evidence for the suggestions of Acemoglu *et al.,* [34] At the same time, it also indicates that when implementing subsidy policies, the government should strengthen the intensity of technological review and improve the ability to identify the technological types of enterprises. Try to avoid phenomena such as some enterprises hiring experts and scholars at high salaries for nominal packaging and forging application materials in order to obtain government funding, so as to enhance the effectiveness of subsidy fund utilization. From the perspective of the comprehensive effect, both GF and VC have a positive mixed incentive effect on enterprises with a technological level of more than 25% in the sample. In other words, government subsidies and venture capital have a comprehensive positive promoting effect on the innovation sustainability of 75% of enterprises.

Table 5
Heterogeneity test

Variables	(1) State-owned enterprises	(2) Non-state-owned enterprises	(3) 0-25%	(4) 25-50%	(5) 50-75%	(6) 75-100%
GF	0.018	0.238***	-0.155	0.073	0.400*	0.174**
	(0.065)	(0.084)	(0.167)	(0.077)	(0.209)	(0.087)
VC	0.128***	0.123***	0.061***	0.171***	0.169***	0.106***
	(0.026)	(0.008)	(0.016)	(0.011)	(0.014)	(0.014)
GFgr	-0.008	-0.224**	-0.009	-0.085	0.331*	-0.265**
	(0.074)	(0.106)	(0.154)	(0.096)	(0.176)	(0.120)
VCgr	-0.039*	-0.027**	0.011	-0.028	-0.004	0.003
	(0.022)	(0.011)	(0.020)	(0.019)	(0.019)	(0.020)
Control variables	YES	YES	YES	YES	YES	YES
_cons	-0.007***	-0.017***	-0.012***	-0.011***	-0.012***	-0.013***
	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)	(0.004)
Adj-R^2	0.285	0.456	0.393	0.620	0.492	0.517
N	1517	2132	701	788	831	923

4.3 Survival analysis

Since over 90% of listed companies receive government subsidies, here we adopt two scenarios: Enterprise i only received government subsidies in year j, and simultaneously received government subsidies and venture capital. The samples of high-tech industry enterprises that only received venture capital and no government subsidies were excluded to investigate the heterogeneity of government subsidies, the coupling of the government and the market in the continuous innovation of enterprises. Firstly, utilizing the KM method, a preliminary investigation of the survival curves of enterprise innovation sustainability under a single government subsidy and the mutual synergy of government subsidy and venture capital is shown in Figure 1. It can be found that under both funding models, the survival curves show a downward trend, and the rate of decline gradually increases, indicating that the innovation speed has slowed down in both cases. However, for enterprises that only adopt the government-funded model, the probability of continuous innovation is much lower than that of the model that combines government subsidies and venture capital. It is worth noting that enterprises that only receive government funding have a relatively high probability of early innovation. However, after four years (approximately the authorization period for invention patent applications), the probability of them stopping innovation gradually increases, indicating that after enterprises receive government funding, there may be some strategic innovation phenomena in the later stage. This also initially confirms the importance of the coupling of government subsidies and venture capital.

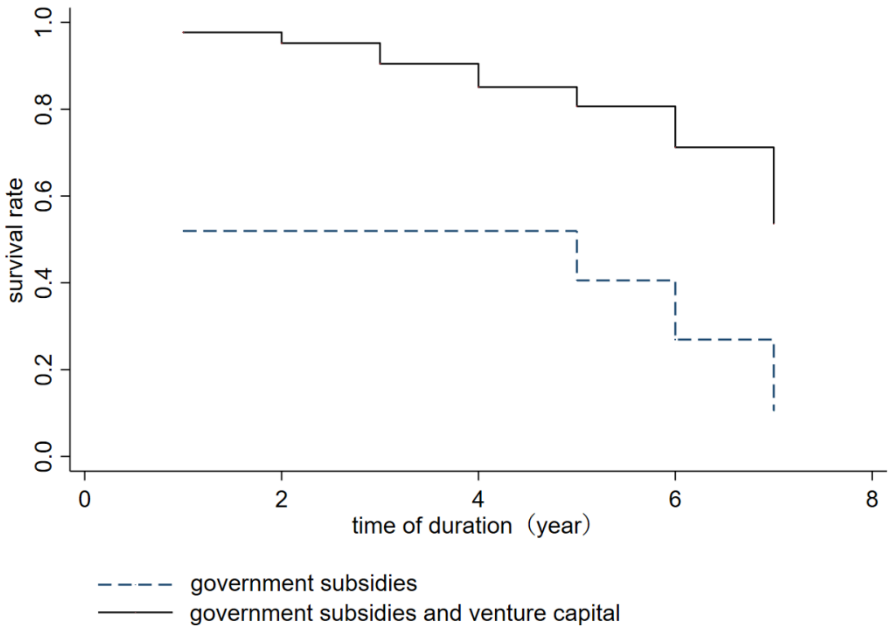

Fig. 1. Kaplan-Meier survival curves of enterprise innovation under the two funding modes

As a non-parametric estimation method, the K-M method cannot control potential confounding factors effect on the failure event. It only preliminarily describes the relationship between the funding model and the sustainability of firm innovation. Other factors, such as enterprise size and equity nature, can also affect the sustainability of firm innovation. Therefore, the Cox proportional hazards model is further used for more accurate estimation. The relevant results are shown in Table 6.

Table 6
Robustness test

Variables	CF test (1)	Cross effects test (2)
GF	0.688*** (0.171)	6.180 (10.249)
VC	0.079** (0.032)	2.343* (1.203)
D_GF_VC		0.321** (0.128)
_cons	0.006 (0.007)	2.987*** (0.397)
Control variables	YES	YES
Adj-R^2	0.511	0.452
N	1084	2863

Column 1 in Table 7 presents the Cox model estimation results of the entire sample. It can be found that the HR value of obtaining the two funding methods (AID) is 0.327 and statistically significant at the 1% threshold. This suggests that after controlling for the corresponding variables that affect the sustainability of firm innovation, the probability of firm receiving both government and venture capital funding to stop innovating is 32.7% of that of enterprises receiving only government funding. That is to say, compared with enterprises that only receive government funding, the probability of enterprises that receive both types of funding simultaneously stopping innovation has decreased by 67.3%, further clarifying the significance of the synergy between administrative and market measures in promoting enterprise innovation. Furthermore, it can be known from the estimation results of covariates that the HR values of enterprise age, sustainable growth rate, equity nature, and market power are all less than 1 and reach the significance level to varying degrees. This indicates that the above variables are all promoting factors for the ongoing innovation of businesses. However, the growth rate of net profit and the enterprise's size fail to meet the statistical significance, that is, they do not constitute independent factors of enterprise sustainable innovation. The reason may be that on the one hand, enterprise innovation is a complicated process. It not only relies on capital investment but also requires the comprehensive coordination of elements such as talents, corporate culture and organizational structure. On the other hand, relevant surveys show that small and medium-sized firms are the main force of active market and technological innovation, while this paper adopts the sample of listed companies, and the scale of businesses is comparatively substantial, so their impact on sustainable innovation is not statistically significant.

Table 7
The Cox proportional hazards model estimation results of enterprise innovation sustainability

Variables	(1) Entire sample		(2) Low effective patent output samples		(3) High effective patent output samples	
	Haz.ratio	Sd	Haz.ratio	Sd	Haz.ratio	Sd
AID	0.327***	0.035	0.374***	0.056	0.310***	0.050
NPG	0.998	0.004	0.985	0.010	1.006	0.008
AGE	0.945***	0.010	0.935***	0.014	0.956***	0.014
SUSG	0.431***	0.139	0.699	0.358	0.366**	0.174
SIZE	0.962	0.048	0.943	0.073	0.900	0.077
STATE	0.687***	0.080	0.652***	0.102	0.709*	0.132
MRP	0.916*	0.046	0.915	0.069	0.929	0.063
Log likelihood	-2801.265		-1229.233		-1186.837	
N	1091		535		531	

Note: Haz.ratio (Hazard ratio) is the risk ratio in exponential form, and Sd (Standard deviation) is the standard error.

Measuring the sustainability of enterprise innovation by whether an enterprise has held patents for several consecutive years cannot mirror the genuine innovation capacity of the business. Moreover, Acemoglu *et al.,* [34] suggested that enterprises with lower productivity should be encouraged to exit and release the skilled labor force for advanced enterprises' R&D. In light of this, the study further categorizes the samples into high and low patent output levels by taking the median of valid patents as the classification basis. The outcomes from the regression analysis of the relevant Cox model are shown in columns 2 and 3 of Table 7. It can be found from this that enterprises obtaining the two types of funding still play a significant promoting role in the continuous innovation of enterprises in the high and low patent output samples. The difference is that the promoting effect on enterprises with high patent output is greater. That is, compared with enterprises that only receive government funding, in the high patent output samples, the probability of enterprises obtaining both types of funding simultaneously stopping innovation is reduced by 69%. However, in the samples with low patent output, it decreased by 62.6%. In addition, compared with the overall sample, the estimated results of each covariate show different degrees of difference in the sub-samples of patent output level, which indicates that enterprises with different levels of patent output need to consider different factors when promoting innovation activities. Taking sustainable growth rate as an example, it is a promoting factor in both high and low patent output samples, but it is not significant in the latter. That is to say, for enterprises with relatively low patent output, whether they can achieve sustainable growth is not an important factor to consider in the innovation process, and they may pay more attention to the breakthrough of a certain technical bottleneck problem at present.

4.4 Robustness test

4.4.1 CF test for mixed effects

Innovation activities are particularly evident in technology-intensive high-tech industries. Here, taking technology-intensive industries as the research sample, the CF test of the combined impact of government grants and venture capital on sustainable innovation is conducted. According to the "Statistical Classification Catalogue of High-tech Industries" issued by the National Bureau of Statistics and relevant documents of the OECD, the technology-intensive industries in the CSRC industry classification (2012) of the sample of this study involve three categories: manufacturing (C), information transmission, software and information technology services (I), and scientific research and technical services (M), including 19 major categories. That is, C25-C41 (excluding C30 in the non-metallic mineral products industry and C33 in the metallic products industry), I63-I65, and M73. The pertinent valuation outcomes are exhibited in Model (1) of Table 6. It is observable that the directions and magnitudes of the influence of the main core explanatory variables, GF and VC, on the sustainable innovation of enterprises are similar to Model (1) in Table 4. That is, whether it is their respective marginal effects or comprehensive effects, each contributes positively to the advancement of corporate innovation, confirming the robustness of the core conclusion of this paper.

4.4.2 Cross effect test

At present, there are numerous discussions on the agency indicators of enterprise innovation. Usually, R&D expense input, R&D personnel input, and patent and paper output are adopted from two aspects: R&D investment and technological output. To validate the reliability of the principal finding of this study, it is different from the aforementioned qualitative use of intangible assets to measure the explained variable, enterprise sustainable innovation. Here, from a quantitative perspective, the quantity of patent applications by businesses (INL) is applied and treated as a dummy variable, that is, whether the enterprise has produced patents for three consecutive years after obtaining the funding. In such a case, it receives a value of 1; if not, it is given a value of 0. Meanwhile, the interaction term between government subsidy and venture capital is replaced by the dummy variable (D_GF_VC). That is, the product of whether government funding is received (yes is 1, no is 0) and whether venture capital is received (yes is 1, no is 0). Since INL is a binary variable, Logit regression is adopted here. The outcomes of the robustness check for the cross-effect are displayed in Model (2) of Table 6. It can be found that the basic core conclusion is consistent with Table 4. The outcomes from the regression analysis of some control variables are slightly different, which may be caused by the use of different numbers of enterprise samples.

5. Discussions and implications

The principal findings of this study are summarized below: (1) Preliminary empirical evidence shows that the entry of venture capital weakens the negative effect of government grants and improves the level of capital utilization (the value at the inflection point increases). The integration of government subsidies has a similar effect on venture capital. (2) The synergy between government subsidies and venture capital exerts a notably positive overall and interactive stimulus on the sustainable innovation of businesses. This finding is consistent across multiple robustness checks, such as changing the dependent variable, replacing the measurement method of the interaction term and focusing on technology-intensive industries. (3) Heterogeneity analysis shows that when contrasted with state-owned firms, the combined motivational impact of government grants and venture capital is particularly pronounced in non-state-owned businesses. In particular, government subsidies notably influence the sustained innovation of businesses only in the range of 75%-100% in the sample. In addition, the mixed effect of the two is significantly positive at different technological levels. (4) From the Kaplan-Meier survival curve, compared with only having government subsidies, enterprises that receive both financial subsidies and venture capital have a lower probability of stopping innovation. Moreover, the former maintains a relatively high probability of innovation approximately in the first four years after receiving subsidies, but then the rate of decline accelerates. Furthermore, the Cox proportional hazards model indicates that the synergy of financing methods can reduce the probability of enterprises stopping innovation by 69% in samples with high patent output, while this figure is 62.6% in samples with low patent output.

Thus, several practical implications are produced. Firstly, the single funding method has many deficiencies. Only when the government and the market work together can the sustainable innovation of firms be effectively promoted. In the future, multiple financing channels should be comprehensively utilized as much as possible to maximize the comprehensive incentive effect of financing channels on the technological innovation of firms. Secondly, the government should enhance its ability to identify the technological level of businesses, accurately implement the management system of fiscal special funds, enhance the effectiveness of subsidy fund utilization, and provide dual guarantees of funds and systems for the key core technology breakthroughs of high-tech enterprises. Finally, it is encouraged that enterprises with low technological levels strive to seek opportunities for industrial transformation, freeing up innovative resources for the technological innovation of high-tech enterprises. At the same time, it is necessary to clarify the effects of various factors among enterprises with different technological levels, and achieve "tailoring measures to the specific conditions of each enterprise" to increase the probability of their sustainable innovation and establish a solid foundation for innovation in building a world-class science and technology power.

6. Conclusions

Utilizing data from Chinese A-share listed companies, this study examines the impact of government subsidies and venture capital on the sustainability of enterprise innovation. Firstly, empirical findings substantiate that the coupling of government subsidies and venture capital significantly contributes to fostering business innovation. Secondly, according to the logic of China's reality, the control function method (CF) is constructed to explore the two types of financing into the same analytical framework and test the marginal effect, mixed effect and cross effect of the two financing methods. Finally, in order to investigate the dynamic continuous process of enterprise innovation, the survival analysis method, an important research method in the field of biomedical science, is used to further compare and analyze the differences between the synergy of the two financing methods and the single government subsidy in the continuous innovation of enterprises, and the empirical findings are different from those of previous studies.

Despite the novel insights and empirical evidence provided in this study, several limitations should be acknowledged. Firstly, the study is based solely on data from Chinese listed enterprises, which may limit the generalizability of the findings to other institutional contexts with different innovation and financing environments. Future research could explore the applicability of the mixed incentive framework in cross-country or emerging market comparisons. Secondly, although this study employs the control function method to mitigate endogeneity concerns, potential biases arising from unobserved heterogeneity or measurement errors in innovation performance may still exist.

Subsequent studies may incorporate panel data techniques or instrumental variable approaches with richer firm-level data to improve causal inference. Lastly, the interaction mechanisms between government subsidies and venture capital are treated in aggregate; further investigation into the heterogeneity across different subsidy types, venture capital structures, or governance models would offer a more nuanced understanding of their joint effects.

Author Contributions

The author conducted all aspects of the research, including conceptualization, methodology, experiments, data analysis, and writing of the manuscript.

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Data Availability Statement

For patent information, this study refers to the incoPat platform, available at incoPat Database(https://www.incopat.com/). Venture capital investment figures are sourced from the CVSource platform, accessible at CVSource Database(https://www.cvsource.com.cn/). Government subsidies and financial data of listed companies are retrieved from the CSMAR database, which can be found at CSMAR Database(https://data.csmar.com/).

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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