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Private Equity Investment and Corporate Technological Innovation: An Empirical Examination Based on Chinese Mainboard-Listed High-Tech

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Abstract: Technological innovation is very important to the growth and success of an enterprise, which greatly affects its market competitiveness. There are many known factors that affect the technological innovation of enterprises, and private equity investment is one of the important but often neglected factors. As a country with relatively developed finance, China's laws and systems related to private equity investment are relatively sound. Based on a large number of sample data of high-tech enterprises listed on the main board of China in 2012-2022, this paper studies the influence of private equity investment on technological innovation of enterprises. This paper finds that private equity investment has an obvious positive effect on enterprise technological innovation, and the effect of private equity investment on innovation shows certain differences due to different types of enterprises, which is embodied in the fact that state-owned enterprises or smaller enterprises are more sensitive to private equity investment. The research has both theoretical and practical significance, and can provide some help and suggestions for enterprises and the government in making decisions related to private placement.

Keywords: Private equity investment, enterprise technological innovation, high and new technology enterprises

1. Introduction

1.1. Background

China's private equity investment market started relatively late but has experienced rapid development. After the period of rapid growth from 2007 to 2011, the Chinese private equity market entered a phase of regulated development. Private equity investment activities gradually became more rational, and related policies and laws continued to mature. Private equity investment has assumed an increasingly pivotal role in the process of companies going public. Private equity investment serves as a means to diversify financing sources for companies and aids in enhancing their organizational and management structures. It also provides valuable management advice and methods, significantly augmenting a company's value. In recent years the Chinese private equity funds market have grown rapidly, particularly in the active investment within the field of technological innovation. Private equity funds have evolved into essential institutional investors in the capital market and a crucial

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force within the direct financing ecosystem. As per the latest data, by the end of 2021, private equity funds had contributed equity capital of ¥10.05 trillion to the real economy, thereby effectively facilitating supply-side reforms and fostering innovation-driven growth [Data source: China Securities Investment Fund Industry Association (www.amac.org.cn)].

The development of high-tech enterprises holds significant implications for shaping China's new development paradigm. Due to a later inception, Chinese high-tech enterprises still exhibit certain disparities compared to their counterparts in more developed countries. In recent years, challenges and issues have started to emerge, such as heightened competition and worsening international conditions. Some nations have initiated restrictions on China's access to core technological infrastructure and talent in an effort to impede the progress of China's high-tech industries. Additionally, the substantial funding required for technological innovation poses challenges, especially in times of economic deterioration, leading some companies to face difficulties in securing financing. Consequently, some enterprises may compromise their commitment to research and innovation in pursuit of short-term gains. Therefore, it is of paramount importance to investigate strategies for promoting innovation among high-tech enterprises.

1.2. Research Significance

From a theoretical perspective, private equity investment serves as a mechanism to diversify financing channels and alleviate the financing challenges faced by enterprises. It offers the financial resources necessary for research and development (R&D) and innovation, thereby fostering innovation outputs. Moreover, private equity investment can enhance corporate governance structures and optimize innovation efficiency by judiciously allocating research resources. This study primarily delves into the mechanisms through which private equity investment influences corporate innovation, offering valuable theoretical insights for promoting innovation among high-tech enterprises.

In practical terms, leveraging private equity investment to stimulate innovation output holds far-reaching implications. The resulting innovation may give rise to new industries and technological achievements, thereby contributing to industrial upgrades, enhancing overall productivity, and bolstering the country's comprehensive strength. These considerations can be integrated into national strategic planning. Furthermore, the study's findings offer guidance for both enterprises and government authorities. Enterprises can strategically incorporate private investment to enhance their competitiveness and innovation output, taking into account their unique circumstances. Government entities can acknowledge the role of private equity investment in driving innovation and formulate policies that harness its advantages effectively.

Consequently, this paper employs empirical analysis to illustrate the connection between private equity investment and technological innovation. It establishes a multiple linear regression model to examine and interpret the results. The research also conducts heterogeneity tests based on enterprise size and type. Additionally, robustness checks are performed using various methodologies. The results affirm a positive correlation between private equity investment and enterprise innovation, with small enterprises and state-owned enterprises displaying heightened sensitivity to private equity investment.

2. Literature Review

2.1. Research on Factors Influencing Technological Innovation in Enterprises

Regarding external factors that influence enterprise innovation, Zhang Weijie considers national policies to be a significant determinant. Rational policies can enhance the efficiency of innovation within firms, contributing to the achievement of economic development goals [1]. Li Zuofeng and Zhang Mingshen employ various indicators to gauge innovation efficiency and find that government

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investment in scientific research plays a crucial role as an influencing factor [2]. After examining data from non-listed companies, Chen Yuanyan argues that financial subsidies have a stronger impact on promoting enterprise innovation compared to tax incentives. However, in 2018, he further posited that tax incentives exhibit a more pronounced motivating effect on core technology innovation [3]. Ji Weilin and Liu Bonan, using data from listed companies, discovered that factors such as the proportion of private investments and the state-owned nature of enterprises can stimulate innovation [4]. Yu Minggui and others found that China's industrial policies are closely linked to enterprise innovation [5].

In the study of internal factors, Chi Renyong identified that internal factors, such as internal communication efficiency, significantly influence innovation outcomes [6]. Booyens pointed out that enterprise size has a positive effect on innovation, with larger enterprises being better positioned to provide abundant resources for innovation [7]. Zhang Wei and Zhou Yaodong, taking a human capital perspective, argue that various factors such as different enterprise roles, educational backgrounds, and experiences exert varying degrees of influence on enterprise innovation [8]. Zhang Wenqing subsequently reaffirmed the substantial contribution of human capital to enterprise innovation [9].

2.2. Research on the Relationship between Private Equity and Technological Innovation

As for the connections between private equity investment and technological innovation, a minority of researchers believe that there is no clear correlation between the two: Tan Yi and others, employing a Western paired empirical analysis method and analyzing data from small and medium-sized board-listed companies, contend that private equity investment has no discernible impact on research and development [10]. After their research, Chen Jianli suggests that private equity investment cannot provide resources related to innovation or promote technological innovation within enterprises [11]. However, the majority of scholars support the view that private equity can foster innovation: for instance, after studying American high-tech publicly listed companies, Brown found that private equity has a significant influence on a company's cash reserves and R&D investments, thereby facilitating the company's growth [12]. Tykvova selected German companies as samples and discovered that private equity investment can increase the number of patents, suggesting that private equity enhances enterprise innovation [13]. Wang Linle argues that private equity investment can offer valuable insights for the development and innovation of small and medium-sized companies in China, particularly for high-tech firms [14]. Li Jing posits that private equity investment positively contributes to the bright futures of high-tech companies, mainly by promoting the implementation of product R&D [15]. Zhang Xueyong and Zhang Yeqing employed a two-stage regression method to demonstrate that private equity investment significantly boosts the innovation capacity of enterprises [16].

2.3. Comments

From the above literature review, it is evident that, in the research field of private equity investment and enterprise innovation, the academic community has not reached a unified conclusion. This lack of consensus may stem from differences in research methods and variations in sample data used by different scholars. Considering that China's private equity investment market began its development relatively late and only gradually standardized after 2012, early data may not accurately reflect objective trends. Given the increasingly prominent role of private equity, it is essential to conduct further research while taking into account the specific circumstances of China's private equity investment market.

Compared to previous literature, this paper offers several innovations:

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1. Novel research methods: Previous literature has predominantly focused on studying the relationship between private equity investment and innovation using regression models. In addition to regression analysis, this paper incorporates heterogeneity analysis, allowing for a more detailed reflection of the influence of private investment on enterprise innovation.

2. Fresh research content: Most Chinese scholars have primarily investigated the situations of the small and medium-sized board or the Growth Enterprise Market, with limited examination of the main board market. This paper delves into the situations of enterprises in the main board market, addressing a research gap.

3. Fresh research data: This paper employs data from 2012 to 2022, representing the most up-to-date information currently available and providing a more accurate reflection of real-world conditions.

3. Empirical Design

3.1. Sample Management and Data Sources

In this paper, data from high-tech enterprises showed on the main board between 2012 and 2022 are chosen as the initial sample. The data are subject to several selection criteria, including:

(1) Exclusion of samples with missing data and those listed for less than one year.

(2) Removal of ST, ST*, and delisted enterprises.

(3) Exclusion of sample data from the financial industry.

To account for the influence of outliers, tail-trimming is applied to the data with a trimming parameter set at 1%. Ultimately, the study utilizes a total of 14,875 sample data points from 1,726 high-tech enterprises. All data are sourced from Wind with Stata serves as the statistical software for data analysis and model estimation.

3.2. Description of Variable Selection

3.2.1. Explained Variables

The dependent variable in this paper is "enterprise innovation output," which serves as an indicator of a company's capacity for innovative invention. Due to China's heightened emphasis on protecting intellectual property rights, companies with robust innovation capabilities often apply for a greater number of patents. Consequently, the number of patents serves as a proxy for a company's ability to engage in autonomous innovation. Moreover, patent data is readily accessible and provides strong explanatory power. Hence, following the approach of Sun Ru [17], this paper selects the number of patents granted to companies as the metric for innovation output.

3.2.2. Explanations of the Variables

This research employs the presence of private equity investment (PE) and the total amount of PE (Amount) as explanatory variables. Specifically:

The binary variable PE is used to assess whether a company has private equity participation, with the presence of private equity investment coded as 1 and the absence as 0.

The total amount of private equity investment (Amount) is employed to gauge the extent of private equity investment. It is calculated by aggregating the investments made by private equity institutions among the top ten shareholders of the enterprise.

3.2.3. Control Variables

As control variables, this paper includes enterprise size, enterprise age, and equity concentration, as detailed in Table 1.

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Table 1: Main variables.

Type	Name	Symbol	Calculation
Explained variable	Technological Innovation Output	PAT	Number of patents obtained by enterprises
Explanatory variable	Presence of Private Equity Investment	PE	1 if present, 0 if absent
	Total Private Equity Investment	Amount	Sum of private equity institution investments among the top ten shareholders of the enterprise
Control variable	Enterprise Size	Size	Total assets of the company
	Enterprise age	Age	Age of the enterprise since being established
	Cash Ability	CA	Ratio of quick assets to total assets
	Equity Concentration	TOP10	Sum of the holdings of the top ten shareholders of one enterprise
	Debt-to-Asset Ratio	Lev	Ratio of total liabilities to total assets
	Revenue Growth Rate	Growth	The difference between current income and previous income divided by previous income
	Independent Director Proportion	Indep	Proportion of independent directors in the enterprise
	Year	Year	Fixed year effect
	industry	Ind	Industry fixed effect

4. Empirical Testing and Results Analysis

4.1. Descriptive Statistics of Variables

Descriptive statistics have been conducted on the data to provide insights into some basic information of the variables. The descriptive statistics of the data after processing are showed in Table 2.

Table 2: Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
lnPAT	14875	3.1302	1.5087	0.0000	7.0414
PE	14875	0.2321	0.4222	0.0000	1.0000
lnAmount	14875	4.3837	7.9963	0.0000	21.2178
lnSize	14875	22.2044	1.1344	20.1290	25.5225
Age	14875	19.7408	5.5966	8.0000	36.0000
CA	14875	0.4520	0.1650	0.1146	0.8591
TOP10	14875	0.5801	0.1509	0.2401	0.8949
Lev	14875	0.4078	0.1870	0.0645	0.8667
Growth	14875	0.1440	0.3108	-0.4619	1.7399
Indep	14875	0.3751	0.0528	0.3333	0.5714

As can be observed from the table, the average number of enterprise patents (lnPAT) is 3.1302, with 0.0000 as the minimum value and 7.0414 as the maximum value. This indicates that there may be significant variations in innovation output among different enterprises. The standard deviation is

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less than the mean, suggesting that lnPAT exhibits some fluctuation but not to a severe extent. The mean value of PE is 0.2321, indicating that approximately 23.21% of enterprises have private equity investment participation. The mean value of lnAmount is 4.3837, with a highest value of 21.2178 and a lowest value of 0.0000, with the mean leaning towards the minimum value. The discrepancy between the biggest and smallest values of enterprise size (lnSize) is relatively small. However, since the data has been logarithmically transformed, it is considered that significant differences in size still exist among different enterprises. Due to the presence of large data in PAT, Amount, and Size, their fluctuations have decreased after logarithmic transformation. Given the sufficiently large sample size of 14,875, it is deemed that the study possesses generality.

4.2. Variable Correlation Analysis

Correlation analysis serves as an initial assessment of the relationships between variables. Although it cannot serve as the ultimate regression result, it is beneficial for gaining a fundamental understanding of the interrelationships between variables. The correlation analysis conducted in this paper is presented in Table 3.

Table 3: Correlation test.

Variables	lnPAT	PE	lnAmount	lnSize	Age	CA	TOP10	Lev	Growth	Indep
lnPAT	1									
PE	0.0860***	1								
lnAmount	0.0970***	0.9973***	1							
lnSize	0.5271***	0.1397***	0.1580***	1						
Age	0.1333***	-0.006	-0.0035	0.1908***	1					
CA	0.0546***	-0.0049	-0.0025	-0.1668***	-0.0601***	1				
TOP10	-0.0063	0.0071	0.0076	-0.0091	-0.2087***	0.1240***	1			
Lev	0.2583***	0.0031	0.0072	0.4800***	0.0944***	-0.2065***	-0.1498***	1		
Growth	0.0228***	-0.0225***	-0.0181**	0.0850***	-0.0446***	0.0044	0.0957***	0.0360***	1	
Indep	0.01	-0.007	-0.0065	-0.0044	-0.0136*	0.0061	0.0479***	-0.0123	0.003	1

Note: ***, **, and * respectively indicate significant correlations at the 0.01, 0.05, and 0.1 significance levels.

The correlation coefficient between PE and lnPAT is 0.0860, the figure for that between lnAmount and lnPAT is 0.0970, both of them are significant at the 1% significance level. It is basically determined that enterprises with PE tend to have higher lnPAT. The control variables lnSize, Age, CA, Lev, and Growth all show significant positive correlations with lnPAT. This suggests that most of the control variables have significant relationships with the explained variable, indicating that the selection of control variables in this paper is reasonable.

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Furthermore, this study conducted a VIF test to examine whether there is severe multicollinearity in the model. The VIF test results are showed as the Table 4.

Table 4: VIF test.

	model1		model2	
Variable	VIF	1/VIF	VIF	1/VIF
PE	1.0300	0.9725		
lnAmount			1.0300	0.9663
lnSize	1.4100	0.7102	1.4200	0.7055
Lev	1.3700	0.7313	1.3700	0.7307
TOP10	1.1000	0.9106	1.1000	0.9106
Age	1.0900	0.9168	1.0900	0.9167
CA	1.0600	0.9412	1.0600	0.9411
Growth	1.0200	0.9802	1.0200	0.9804
Indep	1.0000	0.9976	1.0000	0.9976
Mean VIF	1.1300		1.1400	

The VIF values for PE and lnAmount are both 1.0300, which is significantly less than 10. Additionally, all the other variables also have VIF values that are well below 10. This indicates that multicollinearity in the model is very weak and will not have any obvious impact on the results. Therefore, regression analysis can be conducted.

4.3. Relationship between Private Equity Investment and Corporate Technological Innovation

4.3.1. Variable Selection

The variable explained in this paper is enterprise technological innovation (PAT). There are numerous factors that influence enterprise technological innovation, and many of these factors can have a greater impact on technological innovation than private equity investment. Therefore, it is essential to control for these factors. Firstly, the financial condition of a company, which directly affects its innovation output, is influenced by the availability of funds. To reflect the financial condition, this study uses variables such as the asset-liability ratio (Lev), cash capacity (CA), and income growth rate (Growth). Furthermore, the internal organizational structure of a company can influence decision-making and, consequently, innovation output. To account for this, equity concentration (TOP10) and the ratio of independent directors (Indep) are used to represent internal factors. Additionally, some internal characteristics of companies can impact their innovation capabilities. Therefore, this paper includes variables such as company age (Age) and company size (lnSize) as control variables to enhance the precision of the model.

Lastly, to address potential systematic changes, such as economic cycles, dummy variables for years are introduced to control for systematic effects related to time. Similarly, industry dummy variables are included to account for systematic changes related to industry factors.

4.3.2. Model Construction

Based on the analysis in the previous section and taking into consideration the practical context, the regression models are formulated as follows:

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Model 1: A multiple regression model assessing the impact of the presence of private equity investment on enterprise technological innovation.

$$lnPAT_{it} = \alpha_0 + \alpha_1 PE_{it} + CV + \sum Year + \sum Ind + \varepsilon_{it} \quad (1)$$

Model 2: A multiple regression model examining the effect of the amount of private equity investment on enterprise technological innovation.

$$lnPAT_{it} = \alpha_0 + \alpha_1 lnAmount_{it} + CV + \sum Year + \sum Ind + \varepsilon_{it} \quad (2)$$

In these equations, α_0 represents the intercept term, α_i represents the coefficient term, I represents the I-th enterprise, T represents the T-th year, ε_{it} is the random error term, and CV means all the control variable. Year represents a year-based dummy variable, while Ind stands for an industry-based dummy variable, both of which are included to control for the effects associated with time and industry.

4.3.3. Result Analysis

The results of the multiple linear regression model in this paper are presented in Table 5.

Table 5: Regression results.

	(1)	(2)
VARIABLES	lnPAT	lnPAT
PE	0.0972***	
	(3.9961)	
lnAmount		0.0054***
		(4.1333)
lnSize	0.7045***	0.7034***
	(66.8083)	(66.4323)
Age	-0.0023	-0.0023
	(-1.2116)	(-1.2176)
CA	1.5988***	1.5973***
	(23.2143)	(23.1945)
TOP10	-0.0466	-0.0464
	(-0.6975)	(-0.6946)
Lev	0.5569***	0.5586***
	(8.5020)	(8.5249)
Growth	-0.1123***	-0.1125***
	(-3.3007)	(-3.3057)
Indep	0.2780	0.2773
	(1.5403)	(1.5365)
Constant	-15.0751***	-15.0508***
	(-57.1421)	(-56.8848)
YEAR	YES	YES
IND	YES	YES
Observations	14,875	14,875
R-squared	0.4052	0.4052

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Table 5: (continued).

r2_a	0.4039	0.4039
F	299.4245***	299.5770***

Note: * * * indicates significance at the 1% level, * * indicates significance at the 5% level, and * indicates significance at the 10% level. T-values are enclosed in parentheses, as follows.

The results of Model 1 indicate that the impact of the explanatory variable on the explained variable remains relatively stable, regardless of whether year and industry effects are included. The model's goodness of fit is 40.39%, which is considered high for enterprise data. The F-test value is 299.4245, significant at the 1% significance level. The impact of the explanatory variable PE on lnPAT is significant with a coefficient of 0.0972, showing a significant positive effect. In other words, companies with PE of 1 have, on average, a 9.72% higher number of patents compared to those with PE of 0. The impact coefficients of control variables Size, CA, Lev, and Growth are 0.7045, 1.5988, 0.5569, and -0.1123, respectively. An increase in Growth leads to a decrease in lnPAT, while an increase in Size, CA, and Lev leads to an increase in lnPAT.

Similarly, Model 2 also shows a goodness of fit of 40.39% and passes the significance test. The impact coefficient of lnAmount is 0.0054, and it has a significance level of over 99%, meaning that a 1% increase in Amount leads to an average increase of 0.54% in PAT patents. The impact directions of the control variables on lnPAT are consistent with those in Model 1.

In summary, the regression results indicate a significant positive relationship between private equity investment and enterprise innovation output. This suggests that private equity investment plays a significant role in promoting innovation, possibly because private equity investment firms can facilitate enterprise R&D innovation through two main channels: firstly, by providing financial support to meet the capital needs of R&D, and secondly, by intervening in the daily management processes of companies to enhance governance structures and improve innovation efficiency.

4.4. Heterogeneity Analysis

4.4.1. Impact of Enterprise Size

Taking into account the influence of variables on enterprise size, this paper divided the samples into two groups based on the median of each enterprise's size, and investigated whether there were differences in the impact of variables between different-sized enterprises. After grouping, 7435 samples were categorized as small enterprises, while 7440 samples were categorized as large enterprises. Results are presented in Table 6.

Table 6: Heterogeneity analysis (enterprise size).

	small-scale	large-scale	small-scale	large-scale
VARIABLES	lnPAT	lnPAT	lnPAT	lnPAT
PE	0.0897**	0.0730**		
	(2.5695)	(2.1680)		
lnAmount			0.0045**	0.0044**
			(2.3356)	(2.5193)
lnSize	0.6313***	0.6985***	0.6310***	0.6967***
	(25.4728)	(37.7980)	(25.4539)	(37.5763)
Age	-0.0041*	0.0013	-0.0041*	0.0013
	(-1.6562)	(0.4578)	(-1.6544)	(0.4483)
CA	1.0688***	2.1017***	1.0675***	2.0998***

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Table 6: (continued).

	(11.4436)	(20.8682)	(11.4271)	(20.8506)
TOP10	0.2733***	-0.3313***	0.2731***	-0.3302***
	(2.9097)	(-3.4301)	(2.9068)	(-3.4190)
Lev	0.4593***	0.6060***	0.4593***	0.6109***
	(5.3681)	(6.0799)	(5.3682)	(6.1256)
Growth	-0.1097**	-0.0866*	-0.1100**	-0.0862*
	(-2.3833)	(-1.7392)	(-2.3889)	(-1.7321)
Indep	-0.0032	0.4162	-0.0035	0.4150
	(-0.0126)	(1.5754)	(-0.0140)	(1.5709)
Constant	-13.0679***	-15.5235***	-13.0603***	-15.4885***
	(-22.8969)	(-36.8338)	(-22.8792)	(-36.6445)
YEAR	YES	YES	YES	YES
IND	YES	YES	YES	YES
Observations	7,435	7,440	7,435	7,440
R-squared	0.2276	0.3952	0.2275	0.3953
r2_a	0.2241	0.3928	0.2240	0.3929
F	67.9891***	168.4873***	67.9289***	168.6196***

It can be observed that the impact coefficient of PE on lnPAT for small-scale enterprises is 0.0897, and the impact coefficient of lnAmount on lnPAT is 0.0045. For large-scale enterprises, the impact coefficient of PE on lnPAT is 0.0730, and the figure for lnAmount on lnPAT is 0.0044. All of these coefficients are significant at a 5% significance level, indicating a significant positive impact. Both private equity investment participation and the amount of investment have a stronger influence on small-scale enterprises. This could be explained by the fact that small-scale enterprises have significantly less capital than large-scale enterprises. Therefore, an equivalent amount of private equity investment has a larger marginal power on promoting innovation in small-scale enterprises and leads to a more significant increase in innovation output. Similarly, small-scale enterprises often lack the managerial experience that larger enterprises possess, making private equity intervention more effective in addressing this deficiency. These two reasons likely contribute to the heightened sensitivity of small-scale enterprises to private investment.

4.4.2. The Influence of Property Ownership

Taking into consideration the impact of variables on property ownership, this study grouped enterprises based on their property ownership and examined whether there were differences in the effects of variables across different ownership types. After grouping, 4396 samples were categorized as state-owned enterprises, while 10479 samples were classified as non-state-owned enterprises. The results are presented as Table 7.

Table 7: Heterogeneity analysis (enterprise ownership).

	state-owned	Non-state owned	state-owned	Non-state owned
VARIABLES	lnPAT	lnPAT	lnPAT	lnPAT
PE	0.1406***	0.0619**		
	(3.1116)	(2.1356)		
lnAmount			0.0083***	0.0032**
			(3.4811)	(2.0595)

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Table 7: (continued).

lnSize	0.7631***	0.6731***	0.7604***	0.6727***
	(42.2107)	(49.2146)	(41.8429)	(49.0395)
Age	-0.0141***	0.0014	-0.0141***	0.0014
	(-3.8422)	(0.6184)	(-3.8486)	(0.6192)
CA	2.1297***	1.3575***	2.1266***	1.3568***
	(17.4163)	(16.1328)	(17.3994)	(16.1233)
TOP10	-0.3617***	0.0270	-0.3642***	0.0269
	(-2.7657)	(0.3356)	(-2.7859)	(0.3338)
Lev	0.2954***	0.6775***	0.3030***	0.6780***
	(2.6152)	(8.1869)	(2.6784)	(8.1917)
Growth	0.1036*	-0.2008***	0.1040*	-0.2011***
	(1.7228)	(-4.9083)	(1.7295)	(-4.9170)
Indep	0.8850***	-0.0626	0.8814***	-0.0624
	(2.8156)	(-0.2825)	(2.8046)	(-0.2816)
Constant	-16.0287***	-14.7374***	-15.9694***	-14.7282***
	(-38.5255)	(-42.6154)	(-38.2016)	(-42.5103)
YEAR	YES	YES	YES	YES
IND	YES	YES	YES	YES
Observations	4,396	10,479	4,396	10,479
R-squared	0.4975	0.3530	0.4978	0.3530
r2_a	0.4938	0.3510	0.4941	0.3510
F	138.1776***	184.4884***	138.3611***	184.5081***

The influence coefficient of state-owned enterprise PE on lnPAT is 0.1406, and the influence coefficient of lnAmount on lnPAT is 0.0083. The influence coefficient of PE of non-state-owned enterprises on lnPAT is 0.0619, and the influence coefficient of lnAmount on lnPAT is 0.0032, all of which are significant at the 1% or 5% significance level, indicating a significant positive impact. Whether it's PE or lnAmount, the influence coefficients are higher for state-owned enterprises. This could be because state-owned enterprises are more focused on technological innovation compared to private enterprises, which makes them more receptive to management suggestions from private equity institutions.

5. Robustness Test

5.1. Replacement of Sample Period

The COVID-19 pandemic has had certain adverse effects on the company's listing. If the sample data from the worst years of the pandemic (2020 and 2021) are removed and the results remain consistent, then the results can be regarded as stable enough. The results obtained are shown in Table 8.

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Table 8: Robustness test of substitute sample period.

	(1)	(2)
VARIABLES	lnPAT	lnPAT
PE	0.0997***	
	(3.6967)	
lnAmount		0.0056***
		(3.8597)
lnSize	0.6982***	0.6969***
	(56.5973)	(56.2789)
Age	-0.0025	-0.0025
	(-1.1330)	(-1.1378)
CA	1.6807***	1.6790***
	(21.3730)	(21.3543)
TOP10	-0.0510	-0.0506
	(-0.6626)	(-0.6585)
Lev	0.4872***	0.4892***
	(6.4532)	(6.4768)
Growth	-0.0966**	-0.0966**
	(-2.5002)	(-2.5009)
Indep	0.3166	0.3159
	(1.5090)	(1.5056)
Constant	-14.9881***	-14.9603***
	(-48.9784)	(-48.7526)
YEAR	YES	YES
IND	YES	YES
Observations	11,591	11,591
R-squared	0.3889	0.3890
r2_a	0.3873	0.3874
F	258.6060***	259.0403***

From the results, it can be observed that both the influence coefficient of PE and lnAmount on lnPAT are positive and significant. Both factors still have a strong positive impact on enterprise innovation, consistent with the earlier findings. Therefore, it can be concluded that the research results presented in this paper are robust.

5.2. Replace the Explained Variables

Due to the strong correlation between R&D investment and innovation output, they can, to some extent, be used interchangeably. Next, we replace the dependent variable with lnRD (natural logarithm of R&D investment) to conduct a robustness test for the substituted dependent variable. The results are presented in Table 9.

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Table 9: Robustness test of substituting explained variables.

	(1)	(2)
VARIABLES	lnRD	lnRD
PE	0.2701***	
	(6.1100)	
lnAmount		0.0145***
		(6.1422)
lnSize	0.9803***	0.9777***
	(40.2576)	(39.9578)
Age	-0.0262***	-0.0262***
	(-6.7092)	(-6.7155)
CA	1.6220***	1.6183***
	(9.3208)	(9.2985)
TOP10	0.1974	0.1977
	(1.4267)	(1.4287)
Lev	-0.0965	-0.0928
	(-0.6249)	(-0.6013)
Growth	0.0431	0.0424
	(0.4663)	(0.4583)
Indep	-1.1739***	-1.1758***
	(-3.0696)	(-3.0749)
Constant	-6.1600***	-6.1025***
	(-7.6533)	(-7.5725)
YEAR	YES	YES
IND	YES	YES
Observations	14,875	14,875
R-squared	0.3416	0.3417
r2_a	0.3402	0.3402
F	118.8328***	119.0794***

In this case, using lnRD as the dependent variable, the results still demonstrate a highly significant positive correlation between PE, lnAmount, and lnRD. This consistency with the results obtained when lnPAT was the dependent variable indicates that private equity investment participation and private equity investment amount can indeed foster enterprise innovation, regardless of whether R&D investment or patent counts are considered as the dependent variable. This reaffirms the robustness of the research findings.

6. Research Conclusions and Limitations

This study focused on high-tech enterprises listed on the Chinese main board from 2012 to 2022 and elucidated the role of private equity investment in promoting enterprise innovation. The research has led to four main conclusions: (1) Participation in private equity investment can stimulate enterprise innovation. (2) A greater amount of private equity investment leads to increased innovation output for companies. (3) Small enterprises are more responsive to the effects of private equity investment. (4) State-owned enterprises are more responsive to the effects of private equity investment.

However, this study has certain limitations. Firstly, due to the multitude of factors influencing enterprise innovation, this research could only incorporate relatively important variables as control

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factors, potentially overlooking less quantifiable or smaller factors. Secondly, the calculation of PE and lnAmount only considered the top ten shareholders of the companies, neglecting the influence of private equity firms with smaller holdings.

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