

Original Article

Executive pharmaceutical background, R&D investment and corporate innovation performance

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Abstract: Background: In the context of China's innovation-driven economy, the competitive advantage for pharmaceutical companies increasingly depends on their level of innovation. The executives, as the highest decision-makers in the company, directly influence corporate research and development (R&D) investment and innovation performance. Additionally, government subsidies, as an external factor alleviating corporate financial constraints, also impact a company's R&D investment. According to a survey by the *Journal of China Securities*, at the end of 2020, among 119 pharmaceutical companies listed on the A-share market, only 53.3% had Chief Executive Officer (CEOs) with pharmaceutical backgrounds. This study constructs a theoretical model of executive pharmaceutical backgrounds, R&D investment, government subsidies, and corporate innovation performance in pharmaceutical companies, aiming to reveal the mechanism and boundary condition between executive pharmaceutical backgrounds and corporate innovation performance in the pharmaceutical industry. Methods: This study uses Chinese pharmaceutical companies listed from 2015 to 2022 as the research sample. The selected sample was processed as follows: companies with significant issues and risks of Special Treatment (ST) or *ST were excluded, companies with missing data were excluded, and companies for which executive background data could not be obtained were excluded. After these exclusions, the study obtained data for 223 listed pharmaceutical companies over 8 years. Then we constructed a three-stage regression model to test the impact of executive pharmaceutical background on R&D investment, the impact of R&D investment on corporate innovation performance, and the mediating effect of R&D investment. Considering that some scholars raised questions about it, this study simultaneously uses the Bootstrap analysis method in the SPSS PROCESS to test the mediating effect of R&D and the moderated mediating effect of government subsidies. Results: The empirical research results reveal that executive pharmaceutical backgrounds have a significant positive impact on corporate R&D investment. R&D investment contributes to the innovation performance of pharmaceutical companies and plays an intermediary role between executive pharmaceutical backgrounds and corporate innovation performance. Government subsidies act as a moderator in the relationship between executive pharmaceutical backgrounds and R&D investment, and they also moderate the mediating effect of executive pharmaceutical backgrounds, R&D investment, and corporate innovation performance. Conclusions: This study provides insight from a dual perspective of internal and external factors, revealing the internal mechanism and boundary conditions influencing the innovation performance of pharmaceutical companies. In conclusion, pharmaceutical companies should employ executives with pharmaceutical backgrounds to manage the company. This will help increase the company's R&D investment, subsequently improving R&D performance and enhancing the pharmaceutical company's innovation competitiveness. This study not only expands the theories in the fields of executive characteristics, R&D investment, and corporate innovation performance but also has important policy implications for the appointment and selection of executives in pharmaceutical companies.

Keywords: Chinese pharmaceutical listed companies, executive pharmaceutical backgrounds, R&D investment, government subsidies, corporate innovation performance

Introduction

The 2022 Global Pharmaceutical Innovation Ranking released by IDEA Pharma placed Pfizer

at the top. According to the investigation, Albert Bourla, who serves as the CEO of the global pharmaceutical giant Pfizer, holds a Doctor of Veterinary Medicine degree. As a leading com-

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pany in China's new drug R&D and an industry benchmark, Hansoh Pharmaceuticals has gained approval for 15 innovative drugs for listing and is hailed as the "Leader of Chinese new drugs". Its CEO, Sun Piaoyang, also holds a Doctor of Medicine degree. However, when we look at recent pharmaceutical scandals, such as the vaccine falsification incident of China's Changsheng Biotechnology in the year 2018, and the development of drugs of Purdue Pharma in the United States with severe addictiveness leading to patient deaths in the year 2022, it revealed that CEOs of most companies involved in pharmaceutical scandals lack a pharmaceutical background. This leads us to question whether having executives with a pharmaceutical background contributes to improving innovation performance in the pharmaceutical corporates. Do executives with a non-pharmaceutical background exhibit more short-sighted behavior? Is there a correlation between pharmaceutical scandals and CEOs without pharmaceutical backgrounds? According to the investigation by the *Journal of China Securities* as of the end of 2020, among the 119 pharmaceutical companies listed on the A-share market, only 53.3% had a chairman or CEO with a pharmaceutical background.

According to the top management team (TMT) theory, the characteristics of the TMT have a significant impact on a company's R&D investment and overall performance. In a highly competitive market, pharmaceutical companies need to assemble a specialized TMT to increase R&D investments and enhance innovation performance. Research showed that there is a positive correlation between the educational levels of TMT members and strategic changes within a company [1]. Higher educational levels favor strategic decision-making and diversification. Research found that the professional experience of TMT members influences their perception of the environment and engagement in unethical behavior [2]. Since the proposal of the Upper Echelon Theory in the 1980s [3], many scholars have explored the impact of executive background on corporate performance. Although many researchers investigated the promoting effects of executive technical expertise on R&D investment and company performance [4-7], little attention has been given to the influence of executive pharmaceutical backgrounds in pharmaceuti-

cal companies on R&D investment and innovation performance.

Studies indicate that corporate innovation activities are not only influenced by internal factors but also significantly affected by external factors [8, 9]. The pharmaceutical industry, as a high-tech sector, is characterized by high investments, high risks, and high returns. Due to the long R&D cycle, high investments, and low success rates in new drug development, pharmaceutical companies face challenges and a lack of innovation momentum. Thus, strategic decisions regarding R&D investments in pharmaceutical companies are inevitably influenced by financing constraints due to information asymmetry, resulting in reduced innovation investments and diminished innovation intentions [10]. This study aims to explore external factor-government subsidies that reduce corporate financing constraints. Government subsidies are designed to meet the requirements of R&D investments related to technological complexity, partly or fully offsetting the costs of R&D and innovation failures, thus generating cost compensation effects. Specifically, government subsidies can directly provide financial support to companies, reducing the financial cost of innovation and motivating them to engage in innovative activities [11]. In addition, government subsidies serve as a signaling function, increasing external financing for companies [12]. Therefore, examining whether government subsidies, as an external factor, affect the executive pharmaceutical backgrounds, R&D investment, or innovation performance, is beneficial for understanding the boundary conditions in which government subsidies impact R&D investments.

Therefore, this study constructs a theoretical model that examines the relationship among the executive pharmaceutical backgrounds in pharmaceutical companies, government subsidies, R&D investment, and corporate innovation performance. The study aims to uncover the mediating mechanism and boundary condition through executive pharmaceutical backgrounds that affect innovation performance in pharmaceutical companies employing data from Chinese pharmaceutical companies listed from 2015 to 2022. This study makes several contributions. First, it expands the depth of research on the relationship between execu-

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tive characteristics and corporate innovation performance. Existing literature on executive characteristics often focuses on individual characteristics or social characteristics that impact on corporate performance. In contrast, this study delves into the specific context of the pharmaceutical industry, examining how executive pharmaceutical expertise affects innovation performance in pharmaceutical companies. Secondly, the research adopts dual-perspectives, internal and external factors, to study the mechanisms of innovation performance in pharmaceutical companies. Executives in pharmaceutical firms play a crucial role in shaping innovation investment strategies. Government subsidies, as an external factor, provide additional financial and policy support, reducing financing constraints and innovation costs. This is an important boundary condition wherein government subsidies play a significant role in enhancing innovation investments.

Literature review and research hypotheses

Executive pharmaceutical backgrounds and R&D investment

The upper echelons theory posits that company executives with technical backgrounds tend to invest more in innovation activities [13]. They also maintain an open mindset toward the failure of R&D, making them more willing to innovate and more likely to make proactive R&D investment decisions [14]. Managers with technical backgrounds not only possess specialized knowledge but also have a profound understanding of the importance of financial support for R&D activities. Therefore, when allocating resources, they are inclined to increase R&D investment intentionally. Furthermore, they have innovative thinking and an entrepreneurial spirit [15]. They not only bring professional knowledge and experience to corporate strategic decisions but also send motivating signals to technical personnel [16]. Because executives with technical backgrounds are both technical experts and important decision-makers in corporate strategic decisions, they provide professional guidance and recommendations for corporate innovation, influencing the company's innovation investment. Research found that entrepreneurs' technical education backgrounds motivate companies to engage in technological innovation activities

[17]. In the pharmaceutical industry, which is a typical high-tech sector, the development of new products relies on corporate R&D investment. If the executives have relevant pharmaceutical expertise and a deep understanding of the development trends in the industry, they will prioritize technical innovation and product development. This not only increases R&D investment but also enhances the efficiency of R&D investment. So, this study proposes Hypothesis 1:

Hypothesis 1 (H1): Executive pharmaceutical backgrounds are positively related to R&D investment in pharmaceutical companies.

R&D investment and corporate innovation performance

R&D investment is a concrete manifestation of a company's innovation capability and has an impact on innovation performance. First, R&D investment can enhance a company's innovation performance through the cumulative effects of knowledge, technology, capital, as well as economies of scale [18]. Second, R&D investment leads to the creation of new capital or capital upgrades, the introduction of new knowledge, and new technologies, directly promoting corporate innovation [19]. Third, frequent innovation activities and interactions among R&D personnel during training enable the effective use and integration of advanced knowledge from both internal and external sources, facilitating innovation. This, in turn, enhances the ability to absorb and transform innovations, leading to a significant improvement in innovation performance [20]. Finally, the integration of knowledge and technological resources from R&D of the production process generates economies of scale. This promotes production integration and standardization, enhances product market adaptability, and accelerates the realization of results and value creation [21]. Research showed that R&D investment has a significant positive impact on innovation performance [22]. Research by Bae & Han focusing on high-tech enterprises, discovered that enhancing the R&D investment contributes to improving innovation performance [23]. Therefore, when there is a higher level of R&D investment, companies can engage in more innovation activities, leading to an improvement in innovation performance. In other words, R&D investment has a significant

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positive effect on innovation performance. So, this study proposes Hypothesis 2:

Hypothesis 2 (H2): R&D investment has a significant positive impact on innovation performance in pharmaceutical companies.

The mediating effect of R&D investment

According to the resource-based theory, the quantity and structure of R&D are crucial factors influencing a company's innovation performance [24, 25]. Numerous studies have shown that increasing R&D investment can promote the innovation performance [26, 27]. Executives, as the highest decision-makers in the business, directly influence the quantity and structure of R&D investment in the innovation decision-making process. In pharmaceutical companies, executives indirectly affect innovation performance through R&D investment in areas such as drug innovation, technological innovation, and process innovation. Executive pharmaceutical background has a significant positive impact on R&D investment because they have more specialized knowledge in pharmaceutical products and technology. They can leverage their expertise to address issues that the company encounters during its development. Furthermore, they have a deep understanding of the importance of financial support for R&D activities and maintain an open mindset, which makes them more inclined to make positive R&D investment decisions. Therefore, R&D investment has a significant positive impact on innovation performance, and executive pharmaceutical background has a significantly positive impact on R&D investment. R&D investment serves as an intermediate variable between executive pharmaceutical background and innovation performance, playing a "bridging" role. So, this study proposes Hypothesis 3:

Hypothesis 3 (H3): R&D investment mediates the relationship between executive pharmaceutical backgrounds and innovation performance in pharmaceutical companies.

The moderating effect of government subsidies

Government subsidies refer to a series of policy measures taken by the government, such as tax incentives, tax reductions, and financial

subsidies, that provide direct or indirect cash flow support to businesses, thereby reducing the cost of innovation activities, alleviating corporate financing pressure, and encouraging engagement in innovative research and development [28]. Although executive in pharmaceutical companies may formulate strategic decisions to increase R&D investment based on technological and market conditions, external environmental uncertainties can still be obstacles that hinder the company's willingness and capability to innovate [10, 29]. Government subsidies, as a significant source of external resources for companies, can effectively mitigate the adverse impact of environmental uncertainties on businesses [30]. First, government subsidies help companies alleviate cash flow shortages caused by uncertain environments, providing liquidity support [31]. Second, government subsidies play a signaling role in uncertain environments [11]. On the one hand, government subsidies demonstrates the government's recognition of the subsidized projects and companies, which to some extent alleviates management's concerns about R&D uncertainty, boosts their confidence, and fosters innovation enthusiasm [32]. On the other hand, government subsidies send favorable signals to the external market, aiding companies in attracting external financing [33]. Additionally, companies that receive government subsidies are subject to supervision by government agencies, ensuring the effective execution of R&D investments [34]. So, this study proposes Hypothesis 4:

H4: Government subsidies moderate the relationship between executive pharmaceutical backgrounds and R&D investment.

Pharmaceutical companies that receive government subsidies enhance an executive's confidence, and reduce their psychological uncertainties. Government subsidies have a positive impact on R&D investments in terms of external financial support and psychological efficacy. This, in turn, enhances corporate innovation performance. Conversely, when pharmaceutical companies that cannot get government subsidies, following a precautionary principle, this reduces the intensity of R&D investment, lowering R&D performance. Therefore, following the above hypothesis, this study further presents a moderated mediation model and proposes Hypothesis 5:

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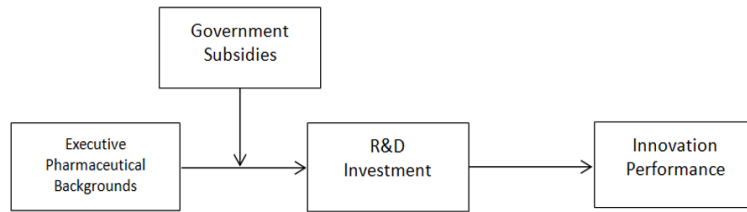


Figure 1. The theoretical model. R&D, research and development.

H5: Government subsidies moderate the mediating effect of executive pharmaceutical background on corporate innovation performance through R&D investment.

The theoretical model for this study is illustrated in **Figure 1**.

Methods

Sample selection and data sources

This study uses listed Chinese pharmaceutical companies from 2015 to 2022 as the research sample. The selected sample was processed as follows: companies with significant issues and risks of ST or *ST were excluded, companies with missing data were excluded, and companies for which executive background data could not be obtained were excluded. After these exclusions, the study obtained data for 223 pharmaceutical listed companies over 8 years. Based on Wind and CSMAR databases, executive resume information was manually collected and organized for all pharmaceutical listed companies from 2015 to 2022 to determine whether the chairman and CEO had a pharmaceutical background. Data on R&D investment and corporate innovation performance mainly came from the CSMAR database. To eliminate the influence of extreme values, this study conducted Winsorization for each variable at the 1% and 99%.

Variable definitions

(1) **Dependent Variable: Corporate Innovation Performance (CIP):** Following the research [35], corporate innovation performance is represented by the number of patent applications in the current year, calculated as the natural logarithm of the number of patent applications plus one.

(2) **Independent Variable: Executive Pharmaceutical Background (EPB):** In this study, executive pharmaceutical backgrounds are con-

sidered to exist if the chairman or CEO of a pharmaceutical company has experience in research or development of new drugs, has studied pharmaceutical-related disciplines, or holds professional titles in the pharmaceutical field such as practicing pharmacist while in office.

(3) **Mediating Variable: Research and Development Investment (R&D):** This refers to the total expenditure on research and development by the company and is obtained from the annual report data of listed companies, transformed into natural logarithms.

(4) **Moderating Variable: Government Subsidies (SUB):** This refers to the total amount of government subsidies recorded in the company's income statement, obtained from the annual report data of listed companies, transformed into natural logarithms.

(5) **Control Variables:** Following the practices of other scholars, this study selects the following variables as control variables: firm value (Tobin-q), current ratio (CR), leverage ratio (Lev), firm size (Size), shareholding ratio of major shareholders (Big 1), executive dual roles (Dual), and the proportion of independent directors (Indp). The definitions of each variable are shown in **Table 1**.

Model construction

This study constructs Model 1 to test the impact of executive pharmaceutical background on R&D investment:

$$R\&D = \alpha_0 + \alpha_1 EPB + \sum \beta_i Controls + \varepsilon \quad (1)$$

This study constructs Model 2 to test the impact of R&D investment on corporate innovation performance:

$$CIP = \alpha_0 + \alpha_1 R\&D + \sum \beta_i Controls + \varepsilon \quad (2)$$

This paper constructs Model 3 to examine the moderating effect of government subsidies on the relationship between executive pharmaceutical background and R&D investment:

$$R\&D = \alpha_0 + \alpha_1 EPB + \alpha_2 SUB + \alpha_3 EPB * SUB + \sum \beta_i Controls + \varepsilon \quad (3)$$

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Table 1. Variables and definitions

	Variable	Abbr.	Definition
<i>Dependent Variable</i>	Corporate Innovation Performance	CIP	Ln(the number of patents +1)
<i>Independent Variable</i>	Executive Pharmaceutical Backgrounds	EPB	Whether the chairman or CEO have a pharmaceutical background (1 for yes, 0 for no)
<i>Mediating Variable</i>	Research and Development Investment	R&D	Ln(Expenditure on R&D)
<i>Moderating Variable</i>	Government subsidies	SUB	Ln(government subsidies)
<i>Control Variables</i>	Firm Value	Tobin-q	(Market Capitalization of Outstanding Shares + Number of Non-Tradable Shares × Net Asset Value Per Share + Book Value of Liabilities)/Total Assets
	Firm Size	Size	Ln(Total Assets)
	Leverage Ratio	Lev	Total Liabilities to Total Assets Ratio
	Current Ratio	CR	Current Assets to Current Liabilities Ratio
	Executive Dual Roles	Dual	Whether the Chairman and CEO are the same person (1 for yes, 0 for no)
	The Proportion of Independent Directors	Indp	Number of Independent Directors to Total Number of Directors
	Shareholding Ratio of Major Shareholders	Big 1	Shareholding of the Largest Shareholder to Total Shares Outstanding

Table 2. Descriptive statistics

Variable	Mean	S.D.	Max.	Med.	Min.	Sample
1. EPB	0.499	0.652	1.000	0.470	0.000	1784
2. R&D	18.259	1.406	21.549	18.262	14.307	1784
3. CIP	4.478	6.901	7.452	3.294	0.000	1784
4. SUB	6.169	8.985	14.668	6.685	0.000	1784
5. Tobin-q	2.394	0.718	15.731	2.259	0.718	1784
6. Size	21.700	0.950	24.360	21.660	19.510	1784
7. Lev	0.360	0.210	1.160	0.340	0.010	1784
8. CR	4.740	10.410	190.870	2.030	0.340	1784
9. Dual	0.320	0.470	1.000	0.000	0.000	1784
10. Indp	0.360	0.050	0.630	0.330	0.250	1784
11. Big 1	0.357	0.147	0.810	0.371	0.110	1784

Where Controls represent the set of control variables, and ε is the error term. Model (1) tests H1, and Model (2) tests H2. To test the mediating effect of Hypothesis 3, this study uses three-stage regression analysis. Considering that some scholars raised questions about it, this study simultaneously uses the Bootstrap analysis method in the SPSS PROCESS to test the mediating effect and the moderated mediating effect [36], and repeats the simulation 2000 times to calculate confidence intervals [37].

Empirical results

Descriptive statistics

Table 2 presents the descriptive statistics results for the variables. It can be seen that the

mean value of corporate innovation performance (CIP) in the pharmaceutical industry is 4.478, with a standard deviation of 6.901. This indicates that the innovation performance level of Chinese pharmaceutical companies is relatively low and there is a certain degree of difference. The mean value of executive pharmaceutical backgrounds (EPB) in pharmaceutical companies is 0.499, suggesting that about half of the executive team members in Chinese A-share pharmaceutical listed companies do not have pharmaceutical backgrounds. The mean value of R&D investment (R&D) is 18.259, indicating that pharmaceutical companies invest significantly in innovation.

Correlation analysis

Table 3 shows the Pearson correlations for the main research variables. From the results of the correlation analysis, the coefficients between EPB and R&D, EPB and CIP, R&D and CIP, SUB and R&D, SUB and CIP are all positive and significant. This indicates that executive pharmaceutical backgrounds are significantly positively correlated with corporate innovation performance, significantly positively correlated with R&D investment, and R&D investment is significantly positively correlated with corporate innovation performance. The results of the correlation analysis are generally consistent

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Table 3. Correlation analysis

	1	2	3	4	5	6	7	8	9	10
1. EPB	-									
2. R&D	0.276***	-								
3. CIP	0.156***	0.541***	-							
4. SUB	0.027	0.621***	0.594***	-						
5. Tobin-q	0.149***	-0.193***	0.286***	-	-					
6. Size	0.003	0.605***	0.652***	0.523***	-					
7. Lev	-0.097	0.028	0.027	0.102	0.086	-				
8. CR	-0.031	0.006	0.036	0.096	0.121	0.627***	-			
9. Dual	-0.105	-0.052	0.042	-0.080	0.139	0.054	0.004	-		
10. Indp	-0.005	-0.031	0.026	0.070	-0.125*	-0.021	-0.041	0.050	-	
11. Big 1	0.226***	0.006	0.110**	0.069	-0.059	-0.051	-0.087	-0.036	0.071	-

Notes: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 4. Regression analysis of the mediating and moderating effect

	R&D			CIP		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
C	9.190*** (6.322)	9.170*** (6.237)	9.094*** (5.967)	30.724 (7.128)	34.173*** (7.725)	37.255*** (7.216)
EPB		0.236*** (7.966)	0.249*** (6.852)			0.214*** (6.159)
SUB			0.026 (0.831)			
EPB*SUB			0.159*** (4.357)			
R&D					0.412*** (4.753)	0.391*** (4.749)
Tobin-q	-0.268*** (-4.690)	-0.299*** (-4.973)	-0.276*** (-4.753)	0.489*** (3.690)	0.415*** (3.658)	0.410*** (3.634)
Size	0.339*** (7.247)	0.321*** (7.959)	0.296*** (6.986)	0.527*** (7.358)	0.486*** (7.257)	0.474*** (7.349)
Lev	-0.039 (-0.977)	-0.168** (-3.142)	-0.109** (-4.142)	0.006 (0.136)	0.013 (1.238)	0.011 (1.236)
CR	-0.012** (-2.530)	-0.016** (2.933)	-0.011** (2.899)	0.107 (3.495)	0.111 (3.530)	0.109 (3.519)
Dual	0.147 (1.092)	0.021 (0.852)	0.019 (0.795)	0.067 (0.293)	0.062 (0.292)	0.059 (0.279)
Indp	-0.015 (0.650)	0.051 (1.006)	0.049 (0.996)	-0.126 (-1.634)	-0.115 (-1.650)	-0.113 (-1.632)
Big 1	0.115** (2.027)	0.117** (2.996)	0.113** (3.001)	-0.013 (-0.036)	-0.015 (-0.027)	-0.017 (-0.030)
F	2.111**	30.714***	33.639***	4.029**	40.606***	52.293***
R ²	0.277	0.405	0.409	0.319	0.483	0.536
Adjusted-R ²	0.250	0.392	0.395	0.302	0.462	0.530
Sample	1784	1784	1784	1784	1784	1784

Notes: ** $P < 0.01$, *** $P < 0.001$. The numbers in parentheses represent robust standard errors.

with the hypotheses and justify further multiple regression analysis.

Regression analysis and hypothesis testing

This study first uses three-stage regression analysis to test hypotheses H1, H2, and H3, as results shown in **Table 4**. In Model 2, it is demonstrated that executive pharmaceutical backgrounds positive significantly influence R&D investment ($\beta = 0.236$, $P < 0.001$), confirming H1. Model 5 showed that R&D investment positively affects corporate innovation performance ($\beta = 0.412$, $P < 0.001$), confirming H2. Model 6 indicated that executive pharmaceutical backgrounds ($\beta = 0.214$, $P < 0.001$) and R&D invest-

ment ($\beta = 0.319$, $P < 0.001$) positively influence corporate innovation performance. This confirms the mediating role of R&D investment in the relationship between executive pharmaceutical backgrounds and innovation performance, thus validating H3. The study further employs the Bootstrap method to verify whether the indirect effect is significant. The results show that executive pharmaceutical background has a positive indirect effect on corporate innovation performance through R&D investment (Indirect Effect = 0.0947, Bootstrap 95% CI = [0.0102, 0.1018]), with the confidence interval not containing zero, indicating that the indirect effect reaches a significant level and further supporting H3.

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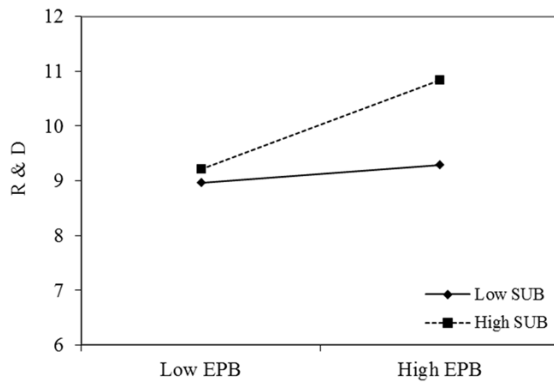


Figure 2. Schematic diagram of the moderating effect of SUB.

Table 5. Mediation effects at different levels of government subsidy

SUB	Indirect Effect	BootSE	Bootstrap 95% CI	
			LLCI	ULCI
Mean - SD (7.184)	0.0543	0.012	0.006	0.055
Mean (12.169)	0.0978	0.015	0.056	0.103
Mean + SD (17.154)	0.1267	0.018	0.094	0.164

To examine whether government subsidies moderate the relationship between executive pharmaceutical backgrounds and R&D investment, the study constructs an interaction term EPB*SUB and tests the significance of its coefficient. Model 3 shows that the interaction term EPB*SUB has a significantly positive regression coefficient on R&D investment ($\beta=0.159$, $P<0.001$), validating H4. Simultaneously, the study visualizes the interaction effect, demonstrating the direction and trend of the moderating variable of government subsidies. Under high government subsidies, the regression slope of executive pharmaceutical backgrounds on R&D investment is relatively steep. Under low government subsidies, the slope is relatively gentle. Therefore, **Figure 2** further illustrates that government subsidies moderate the relationship between executive pharmaceutical backgrounds and R&D investment, confirming H4 visually.

When further examining the moderated mediation effect, the study employs the Bootstrap method. It creates 2, high and low groups of the moderating variable by adding and subtracting one standard deviation from the mean. The study obtains the conditional indirect effect

values for different conditions, as shown in **Table 5**. It is observed that when SUB is one standard deviation below the mean, the conditional indirect effect of executive pharmaceutical backgrounds on corporate innovation performance through R&D investment is 0.0543, with a Bootstrap 95% confidence interval not containing zero. When SUB is at the mean, the conditional indirect effect is 0.0978, with the Bootstrap 95% confidence interval not containing zero. When SUB is one standard deviation above the mean, the conditional indirect effect is 0.1267, with the Bootstrap 95% confidence interval not containing zero. Simultaneously, the Index of Moderated Mediation is 0.0786, with a Bootstrap 95% confidence interval not containing zero. Therefore, government subsidies moderate the mediating effect of executive pharmaceutical backgrounds on corporate innovation performance through R&D investment, confirming H5.

Conclusion and discussion

Conclusion

In the current context of China's strong emphasis on innovation-driven, the competitive advantage of pharmaceutical companies increasingly depends on their level of innovation. As the highest decision-maker in companies, the executive directly influences corporate R&D investment and innovation performance. Additionally, government subsidies, as significant external factors in alleviating corporate financing constraints, also impact a company's R&D investment. This study used data from Chinese pharmaceutical companies listed on the stock market from 2015 to 2022 to explore the relationships among executive pharmaceutical backgrounds, government subsidies, R&D investment, and corporate innovation performance. The findings reveal that executive pharmaceutical backgrounds have a significant positive impact on corporate R&D investment. R&D investment contributes to enhancing the innovation performance of pharmaceutical companies and plays an intermediary role between executive pharmaceutical backgrounds and corporate innovation performance. Government subsidies act as a moderator in the relationship between executive pharmaceutical background and R&D investment, and they also moderate the mediating effect of executive pharmaceutical background, R&D

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investment, and corporate innovation performance [38-40]. This study not only expands the theories in the areas of characteristics of TMT, R&D investment, and corporate innovation performance but also provides valuable policy implications for the appointment and selection of executives in pharmaceutical companies.

Managerial implications

(1) Appointment of Executives with Pharmaceutical Backgrounds. Executive pharmaceutical backgrounds have a positive impact on R&D investment in pharmaceutical companies. Therefore, when appointing executives, pharmaceutical companies need to consider whether candidates have a pharmaceutical background as an important reference criterion. As a typical high-tech enterprise, the pharmaceutical industry relies mainly on the development of new products for its growth. If the management team has relevant pharmaceutical professional backgrounds, a deep understanding of the development trends in the industry, and specialized knowledge, it will be more inclined to promote R&D activity. This will not only increase R&D investment but also improve the efficiency of R&D investment. Specific measures include: First, incorporating executive pharmaceutical backgrounds into executive appointment charters and documents, and prioritizing the appointment of executives with professional technical backgrounds, as such backgrounds are more likely to encourage active engagement in the company's R&D activity, thereby increasing R&D investment. Second, establishing an efficient executive incentive mechanism. This will implement financial incentives, equity incentives, and other measures for executives to motivate them in their work and prevent short-sighted behavior. Finally, from an objective and fair perspective, companies should establish a reasonable executive performance evaluation system [41]. Given the clear characteristics of high technology, high investment, high risk, and high return in pharmaceutical R&D activities, it is necessary to ensure the accuracy and scientific soundness of executive performance assessments so that executives are less likely to consider leaving their positions.

(2) Enhancing R&D Investment in Pharmaceutical Companies. From the perspective of the

feedback effect of the corporate innovation system, R&D investment has a significant impact on improving corporate innovation performance. Therefore, pharmaceutical companies should increase their investment in R&D activities, provide sufficient funds, materials, and other supports for corporate innovation activities, and formulate a detailed policy measures to ensure that funds are reasonably allocated to R&D activities. In addition, companies should ensure the sustainability of R&D investment, allocate R&D funds reasonably, and invest funds in R&D in stages and batches to ensure that companies have the motivation for continuous innovation [42]. Furthermore, from the perspective of the reverse feedback effect of the corporate innovation system, the higher the R&D investment of a company, the easier it is to obtain government subsidies, which further provides sufficient funds for corporate R&D, thereby giving companies the vitality to innovate continuously.

(3) The government can fully leverage the functions of government subsidies by providing fund resources and sending signals to stimulate corporate innovation, guiding external funds towards businesses, thereby encouraging more societal funding to support innovation. Simultaneously, the government must supervise these subsidized companies and ensure the transparency in the subsidy process. This measure aims to effectively regulate the behavior of all parties to ensure the effectiveness of government subsidies. The government should also require companies to enhance their internal governance to prevent negative impacts on subsidies resulting from short-sightedness and agency behavior by corporate management.

Research limitations and prospects

This study has several limitations: First, R&D investment plays a mediating role between executive pharmaceutical backgrounds and corporate innovation performance, but there are likely other mediating variables that need to be further analyzed in future research. Second, due to the difficulty of data acquisition, this study only examined the pharmaceutical backgrounds of chairpersons and CEOs, and the pharmaceutical backgrounds of the entire executive team should be further verified and analyzed in future research. Finally, this study used pharmaceutical listed companies as the

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sample, and future research can select other industry-listed companies as research subjects to enhance the generalizability of the research conclusions.

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Disclosure of conflict of interest

None.

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