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Research on the impact of university innovation output on provincial innovation output

Yitong Huang

School of Literature and Journalism, Yantai University, Yantai, China
1306163208@qq.com

Abstract:

Using panel data from 31 provincial-level administrative regions in China between 2014 and 2023, this study adopts literature review and empirical analysis methods to explore the impact of university innovation output on provincial innovation output. The results demonstrate that, when controlling for other factors, university innovation output has a significantly positive promoting effect on provincial innovation output across all regions, including the eastern, central, and western areas. Moreover, the robustness test further confirms the reliability of the research conclusions. This study provides a theoretical basis for universities and governments to formulate relevant innovation policies and optimize the allocation of innovation resources.

Keywords: Innovation in universities, Provincial innovation, Innovation output, Panel data

1. Introduction

Since the 18th National Congress of the Communist Party of China, technological innovation has been established as a strategic priority at the national level. The report from the 20th National Congress emphasizes that education, science and technology, and talent form the foundational and strategic pillars for achieving modernization. In the new era, provincial-level innovation, which is an essential part of the national innovation system, has become a critical force in driving high-quality regional economic growth and advancing modernization. According to the World Intellectual Property Organization's "Global Innovation Index Report 2024," China ranks 11th globally in terms of innovation performance, being the only middle-income economy among the top 30 economies and showcasing the fastest growth in innovation over the past decade. However, compared to developed countries, provincial innovation in China still faces challenges such as uneven distribution of innovation resources, insufficient capabilities, and an environment requiring further improvement. Therefore, analyzing the factors influencing provincial innovation output, particularly the role of university-driven innovation, is of great importance for enhancing provincial innovation capacity.

In the key phase of innovation-driven development, China places significant emphasis on strengthening its innovation capabilities. Universities, as major contributors to knowledge production, play a central role. The commercialization of their innovative outcomes is crucial for improving provincial innovation capabilities. However, there are existing gaps in the transformation of university innovations and the deep

integration of industry, academia, and research. There is an urgent need to enhance the innovation capabilities and output levels of universities while promoting coordinated development between universities and provincial innovation systems. Against this backdrop, exploring the interaction between university innovation achievements and provincial innovation outcomes, understanding their dynamic relationship, and providing guidance for formulating provincial innovation policies and optimizing resource allocation becomes a pressing task.

Although previous studies have extensively investigated innovation at both university and provincial levels, most have focused on individual regions or cross-sectional data, with limited exploration into the relationship between the two. This study employs literature analysis and empirical methods, considering the influence of regional economic development (measured by per capita GDP) and research and development investment (R&D funding). It uses the number of patent applications filed by universities in each province as an indicator of university innovation output and the number of patent applications in each province as a representation of provincial innovation output. An in-depth examination of the relationship between these two variables is conducted. Additionally, the study utilizes the number of valid patents and the number of universities in each province as quality indicators for robustness testing, exploring how the heterogeneity of university innovation output affects provincial innovation. The findings of this study hold significant theoretical and practical implications for optimizing the allocation of university innovation resources, enhancing innovation capabilities, and ensuring the efficient operation of provincial innovation systems.

2. Literature Review

Universities have historically played a pivotal role in fostering knowledge creation and nurturing talent, making their innovation outcomes a focal point for academic exploration. A university's research strength is commonly evaluated through key indicators such as the quantity of patent applications, granted patents, and published scientific articles. Scholars both domestically and internationally concur that university innovation output is influenced not only by internal factors like research funding and faculty expertise but also by external elements, including regional innovation ecosystems and policy frameworks. Li Hongjin et al. (2019) [1] explored the spatial distribution and spillover effects of innovation output in Chinese universities. Their study revealed pronounced spatial clustering in university innovation output, which positively affects neighboring regions. Additionally, they underscored a non-linear relationship between innovation inputs and outputs, suggesting that optimizing input allocation can enhance output efficiency. Wang Haiyan and Su Boqian (2023) [2] utilized the entropy weight TOPSIS method to assess the comprehensive index of scientific and technological innovation in universities. The findings indicated that while the integration and coordination between university innovation and regional innovation capabilities have shown an upward trend overall, the overall level remains relatively low, highlighting potential for universities to further amplify their role in driving regional innovation.

Provincial innovation serves as a critical driver of regional economic growth and constitutes a highly intricate system shaped by various factors, including governmental policies, corporate investments, and collaborations between universities and research institutions. Studies consistently demonstrate that R&D investment and economic development are primary determinants of provincial innovation. Zhang Pei et al. (2023) [3] analyzed provincial panel data from 2013 to 2020 to evaluate the coupling coordination between provincial innovation infrastructure and innovation output levels. The results exhibited significant spatial heterogeneity, with the highest coupling coordination observed in the eastern region, followed by the central, northeastern, and western regions. Wu Mingjie and Fang Dachun (2024) emphasized that the intensity of technological innovation investment, economic conditions, and educational expenditures significantly influence the spatial correlation of the "four chains" within provinces. Furthermore, factors such as urbanization and governance capabilities play a crucial role in ensuring balanced development between provincial innovation infrastructure and output levels. This underscores that provincial innovation development relies not only on local innovation investment but also on broader regional economic and social contexts.

University innovation and provincial innovation are closely interconnected. As a primary source of knowledge and technology, universities substantially contribute to provincial innovation output. Guo Quanen and Sun Bindong (2017) employed spatial econometric analysis to illustrate that knowledge spillovers from universities have a significant positive impact on innovation in high-tech industries. Wang Xiaohong et al. (2024) [4] examined the influence of industry-university collaboration on university innovation performance from two perspectives: organizational and cross-provincial levels. Their findings demonstrated that cross-provincial collaborations significantly enhance university innovation performance. This suggests that partnerships between universities and provincial enterprises can effectively promote the commercialization of university innovations and boost provincial innovation

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output. Moreover, the spatial spillover effects of university innovation output can provide essential knowledge and technological support for provincial innovation, facilitating the harmonious development of regional innovation systems.

In conclusion, university innovation constitutes a foundational element of provincial innovation systems. The outcomes of university innovation not only directly enhance their own research quality and talent cultivation but also significantly propel provincial innovation through knowledge diffusion and technology transfer mechanisms. Nevertheless, the integration and coordination between university innovation and provincial innovation still require further refinement. Enhancing collaborative efforts among universities, enterprises, and local governments, as well as optimizing the allocation of innovation resources, are critical steps to improve the overall efficiency and effectiveness of provincial innovation systems.

3. Theoretical Basis and Hypothesis Proposal

3.1 Innovation ecosystem theory

The Innovation Ecosystem Theory (Miller, Hancock, Rowan, 2002) [5] underscores the interactive relationships among innovation actors and their synergistic influence with the external environment. In this context, universities function as key players that not only enhance their internal research capabilities but also contribute to the development of provincial innovation capacities through mechanisms such as knowledge spillovers and technology transfer. For example, university innovations can be transformed into tangible productivity via collaboration with industries, thereby stimulating provincial economic growth. As a result, universities serve as essential bridges in the innovation ecosystem, connecting scientific research with industrial practices and promoting a sustainable feedback loop within the provincial innovation framework.

3.2 Knowledge spillover effect

According to the knowledge spillover effect (Romer, 1990) [6], the innovation achievements of universities can promote provincial innovation through knowledge spillover effects. The knowledge innovation output of universities is not limited to within the campus, but can also spread to surrounding enterprises and society through academic exchanges, technical training, scientific research cooperation, and other means. This knowledge spillover effect has a certain degree of locality in geography, that is, in the surrounding areas of universities, the impact of knowledge spillover is more important. In this study, the knowledge spillover effect of universities is an important link between university innovation and provincial innovation, which can provide technical support and innovation inspiration for enterprises within the province, thereby promoting the overall improvement of provincial innovation level.

3.3 Industry university research cooperation innovation

Collaborative innovation among industry, academia, and research institutions plays a vital role in enhancing the innovation capabilities of provinces. According to the theory of industry-university-research cooperation [7], the collaboration among universities, enterprises, and governments enables the effective integration of resources, thereby strengthening provincial innovation capacities. By establishing robust cooperation mechanisms, universities can transform scientific research achievements into practical productivity, enterprises can leverage the technological and talent advantages offered by universities to enhance their innovation capabilities, and the government can support the smooth progress of industry-university-research cooperation through policy guidance and resource allocation.

Based on the preceding theoretical analysis, this study constructs a theoretical framework for the mechanism by which university innovation output affects provincial innovation output (as shown in Figure 1) and proposes the following hypotheses:

H0: Under the control of other factors, university innovation output does not have a significant positive effect on provincial innovation output.

H1: Under the control of other factors, university innovation output has a significant positive effect on provincial innovation output.

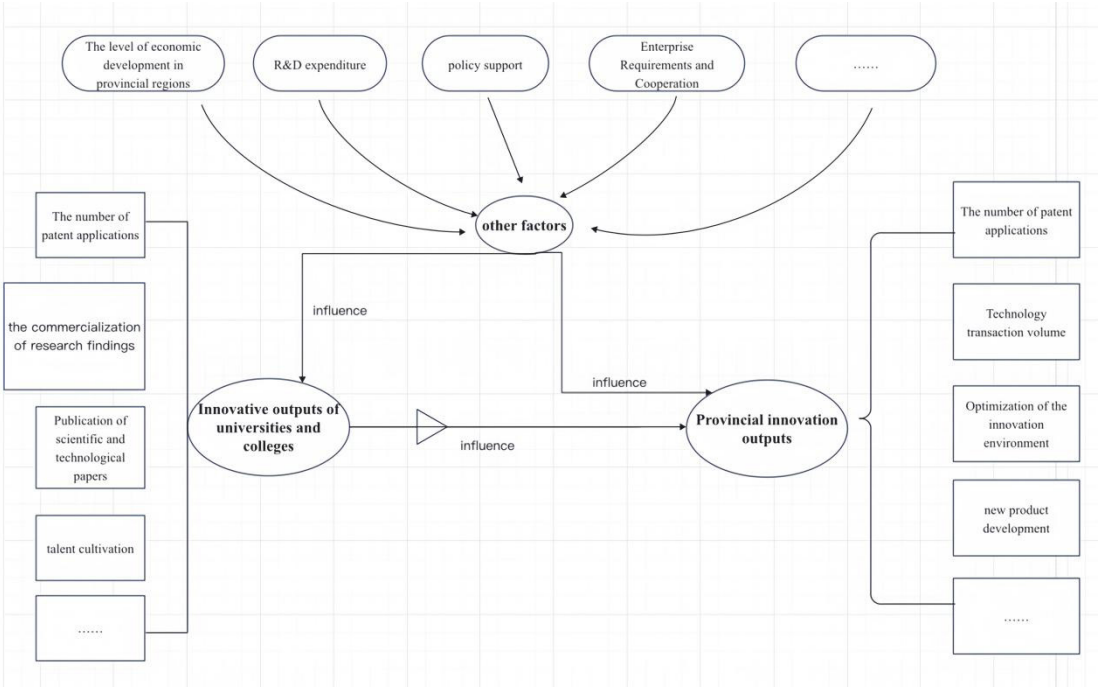

Figure 1. Theoretical framework for the mechanism of the influence of university innovation output on provincial innovation output.

4. Research Design

4.1 Bidirectional fixed effects model

This study used a bidirectional fixed effects model to control for unobservable heterogeneity over time (year) and individuals (province). The model settings are as follows:

(1) $y_{it} = \alpha + \beta_1 x_{1it} + \beta_2 x_{2it} + \sum_{j=1}^{n} \gamma_j d_{jt} + \sum_{k=1}^{m} \delta_k e_{it} + \mu_i + \lambda_t + ?_{it}$

Among them:

y_{it} Representing the provincial innovation output of the i-th province in the t-th year (using the number of provincial patent applications as a proxy variable);

α lis a constant term;

x_{1it} Representing the innovation output of universities in the i-th province in the t-th year (using the number of university patent applications as a proxy variable);

x_{2it} Representing the regional economic development level and R&D investment of the i-th province in the t-th year (using per capita GDP and R&D funding as proxy variables);

d_{jt} Representing other factors that change over time but are not included in the model;

e_{it} Other omitted variables that vary with individuals and time;

μ_i Fixed effects for provinces, controlling for provincial heterogeneity that does not change over time;

λ_t for the fixed time effect, control for the time-varying factors that all provinces face together;

$?_{it}$ is a random error term.

4.2 Variables and Data Sources

This study is based on a panel dataset established in 31 provincial-level administrative regions in China from 2014 to 2023. Because of significant data gaps in Hong Kong, Macau, and Taiwan, it is not possible to meet the integrity and consistency requirements for research. So as to ensure the accuracy and credibility of the analysis results, the data of the above three regions are excluded from the empirical analysis, and the analysis only stems from the data of Chinese Mainland.

1. Independent variable: Innovation output of universities. Referring to previous research [8] Journal of Management Science, Tsinghua University 2023, using the number of patent applications from universities to measure innovation output, and conducting robustness tests using the number of valid patents, the data is sourced from the China Education Statistical Yearbook and the China Science and Technology Statistical Yearbook.

2. Dependent variable: Provincial innovation output. Reference to previous research [9], the number of patent applications was used to measure regional innovation output,

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and robustness tests were conducted using the number of valid patents. The data was sourced from the China Statistical Yearbook and the China Science and Technology Statistical Yearbook.

3. Control variables: regional economic development level and R&D investment. Referring to previous research [10], the per capita GDP and R&D expenditure of each province were used to measure the level of regional economic development and R&D investment, respectively. The data was sourced from the China Statistical Yearbook.

To eliminate the impact of inflation on regional per capita GDP and R&D funding, this study extracted the Consumer Price Index (CPI) of each province from the China Statistical Yearbook from 1949 to 2023, with 1978 as the base year, and adjusted the per capita GDP and R&D funding of each province. In addition, this study further took the natural logarithm of all adjusted comparable price data to reduce the heteroscedasticity of the data and enhance the explanatory power of the model. The formula for calculating comparable prices is as follows:

$$(2)\ Comparableprice = \frac{Actualprice}{Consumerpriceindex(CPI)} \times 1\,00$$

All calculations are uniformly in units of yuan, specifically:

$$(3)\ \text{Comparable price of per capita GDP} = \frac{\text{Real GDP per capita in a year}}{\text{Consumer price index based on1978(CPI)}} \times 1\,00$$

$$(4)\ \text{Comparable price of R \& D funds} = \frac{\text{Actual R \& D expenditure in a year}}{\text{Consumer price index based on1978(CPI)}} \times 1\,00$$

Through the above processing, this study standardized the price levels for each year to ensure comparability of data.

4. Replace variables: quality and sustained impact of innovative achievements. This article uses the number of valid patents in each province and its universities to measure the quality and sustainability of innovation achievements, and uses them to replace independent and dependent variables for robustness testing. The data stems from the "China Education Statistical Yearbook" and the "China Science and Technology Statistical Yearbook".

Table 1: Variables and Their Related Concepts

	Variable code	variable definition	variable description
Independent variable	X1	Innovation output of universities	number of patent applications filed by universities
Dependent variable	Y1	provincial innovation output	provincial patent applications
control variable	Pgdp	Regional economic development level	Logarithmic of per capita GDP in the province
	R&D	R&D investment	Logarithmic R&D investment in provincial R&D

5. Empirical Result Analysis

5.1 Descriptive statistical analysis

This study gathers panel data from 31 provincial-level administrative regions in China, spanning the years 2014 to 2023, and generates a total of 310 data points. The descriptive statistical analysis demonstrates that the mean provincial innovation output (Y1) is 130,517.61, with a standard deviation of 176,945.4, ranging from a minimum of 248 to a maximum of 993,480. Regarding university innovation output (X1), the average value is 9,482.542, accompanied by a standard deviation of 9,246.5, with values extending from 7 at the lowest to 55,433 at the highest. The regional economic development level (Pgdp) has an average of 10,216.322, with a standard deviation of 4,686.113, varying between 4,253.131 and 28,287.854. Lastly, the innovation investment level (R&D) averages 1,054,673.1, with a standard deviation of 1,241,615.8, and ranges from 3,535.235 to 6,783,356.

There are significant differences in innovation output, provincial innovation output, regional economic development level, and innovation investment level among universities in different provinces of China.

Table 2: The outcomes of descriptive statistical analysis for each variable are presented.

Variable	Obs	Mean	Std.Dev.	Min	Max
Y1	310	130517.61	176945.4	248	993480

X1	310	9482.542	9246.5	7	55433
pgdp	310	10216.322	4686.113	4253.131	28287.854
R&D	310	1054673.1	1241615.8	3535.235	6783356

5.2 Correlation analysis

The outcomes of the correlation analysis indicate that the correlation coefficient between the innovation output of universities (X1) and that of the province (Y1) amounts to 0.828. The correlation coefficient between the level of regional economic development (Pgdp) and Y1 reaches 0.529. Moreover, the correlation coefficient between the level of innovation investment (R&D) and Y1 is 0.937. And all three are significant at the 0.01 significance level. Thus, it can be initially discerned that there exists a pronounced positive correlation among the variables: Y1 and X1, Pdgp, as well as R&D.

Evidently, a remarkable positive correlation is observed between the innovation output of universities and that of the province. Additionally, a conspicuous positive correlation also exists between the level of regional economic development, innovation input, and the innovation output of the province.

Table 3: The correlation results of each variable are shown.

Variables	(1)	(2)	(3)	(4)
(1)Y1	1.000			
(2)X1	0.828***	1.000		
(3)pgdp	0.529***	0.589***	1.000	
(4)R&D	0.937***	0.862***	0.693***	1.000

5.3 Benchmark regression analysis

This study utilized a two-way fixed effects model in benchmark regression analysis to investigate the impact of university innovation output on provincial innovation output. To account for potential heterogeneity, fixed effects were controlled at both the provincial and yearly levels. The results of the benchmark regression are presented as follows:

In the absence of control variables (column (1)), the coefficient of X1 is estimated at 14.579 and is statistically significant at the 0.01 significance level. This indicates that, when other factors are not considered, university innovation output exerts a markedly positive and stimulating influence on provincial innovation output.

Upon including control variables (column (2)), the coefficient of X1 decreases to 5.738 but remains significant at the 0.01 level. This demonstrates that after adjusting for factors such as regional economic development and innovation investment levels, university innovation output still plays a significantly positive role in promoting provincial innovation output. More precisely, for each one-unit increase in the number of university patent applications, the average number of provincial patent applications increases by 5.738 units.

Table 4: The benchmark regression results for each variable are shown.

	(1)	(2)
	Y1	Y1
X1	14.579***	5.738***
	(14.429)	(6.123)
pgdp		-10.160***
		(-5.890)
R&D		0.116***
		(16.734)
_cons	-7727.197	58027.918***
	(-0.785)	(3.648)

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N Province fe Year fe	310 YES YES	310 YES YES
R^2	0.955	0.978

5.4 Robustness test

In the research process, two critical measures were taken to ensure the robustness of the benchmark regression results. Firstly, replace the number of provincial and university patent applications with the number of valid patents and conduct regression analysis again; Secondly, considering the potential bias that samples from municipalities directly under the central government may bring to the overall analysis results, as well as the interference of data from epidemic years (2020, 2021) on research conclusions, robustness tests were conducted by removing samples from municipalities directly under the central government and data from epidemic years to strengthen the reliability of research results. The specific robustness test results are as follows:

In the test after excluding samples from municipalities directly under the central government (column (1)), the X1 coefficient is 6.073, which is significant at the 0.01 significance level. This result is consistent with the benchmark regression, indicating that under the control of factors such as regional economic development level and innovation investment level, the innovation output of universities has a significant positive promoting effect on provincial innovation output.

In the test after excluding samples from the epidemic year (column (2)), the X1 coefficient is 6.686, which is also significant at the 0.01 significance level. This result is also consistent with the benchmark regression, once again confirming that after controlling for relevant factors, the innovation output of universities has a significant positive promoting effect on provincial innovation output, further verifying the robustness of the benchmark regression results.

In summary, the robustness test results show that the innovation output of universities does have a positive promoting effect on provincial innovation output significantly. This indicates that the benchmark regression results mentioned above are relatively reliable, providing strong support for hypothesis H1, which holds that when controlling for other factors, the innovation output of universities has a greatly active impact on provincial innovation output.

Table 5: The robustness results of each variable are shown.

	(1)Exclude municipalities directly under the central government	(2)Excluding the year of the epidemic
	Y1	Y1
X1	6.073***	6.686***
	(5.884)	(6.474)
pgdp	-11.052***	-8.838***
	(-4.358)	(-4.958)
RD	0.116***	0.104***
	(15.785)	(14.869)
_cons	61848.694***	45937.399***
	(2.899)	(2.837)
N Province fe Year fe	270 YES YES	248 YES YES
R^2	0.979	0.978

5.4 Heterogeneity analysis

To delve deeper into the disparities in the promotional impact of university innovation output on provincial innovation output across diverse regions, this research categorized the sample into three regions in accordance with the classification standards of the National Bureau of Statis-

tics: the eastern, central, and western regions, for the purpose of conducting heterogeneity analysis. Columns (1), (2), and (3) respectively present the regression outcomes for the eastern, central, and western provinces, as detailed below:

The coefficient of X1 in the eastern region (column (1)) amounts to 7.637, the coefficient of X1 in the central region (column (2)) is 3.019, and the coefficient of X1 in the western region (column (3)) is 2.023. All of these coefficients are statistically significant at the 0.01 significance level. Evidently, the promotional effect of university innovation output on provincial innovation output is present in the eastern, central, and western regions.

Table 6: Division of the 31 provincial administrative regions into eastern, central and western regions by the National Bureau of Statistics

Eastern (11)	Shanghai, Beijing, Tianjin, Shandong, Guangdong, Jiangsu, Hebei, Zhejiang, Fujian, Liaoning, Hainan
Central (8)	Heilongjiang, Hunan, Hubei, Henan, Jiangxi, Shanxi, Anhui, Jilin
Western (12)	Yunnan, Inner Mongolia, Sichuan, Ningxia, Guangxi, Xinjiang, Gansu, Xizang, Guizhou, Chongqing, Shaanxi, Qinghai

Classification source: National Bureau of Statistics

Table 7: The heterogeneity analysis results of each variable are shown.

	(1)East	(2)Central	(3)Western
	Y1	Y1	Y1
X1	7.637***	3.019***	2.023***
	(4.299)	(2.696)	(3.451)
pgdp	-12.961***	0.898	0.717
	(-4.441)	(0.428)	(0.503)
RD	0.117***	0.058***	0.024***
	(9.201)	(4.582)	(3.220)
_cons	89309.237**	10115.731	19228.753*
	(2.349)	(0.677)	(1.845)
N Province fe Year fe	110 YES YES	80 YES YES	120 YES YES
R^2	0.978	0.969	0.977

6. Conclusion and Discussion

6.1 Conclusion

This study conducted a comprehensive empirical analysis to explore the influence of university innovation output on provincial innovation output. The results demonstrate that, after controlling for other factors, university innovation output has a significantly positive effect on provincial innovation output, providing strong evidence in support of Hypothesis H1. This conclusion is consistent across eastern, central, and western regions, highlighting the pivotal role universities play in promoting the construction and development of provincial innovation systems. Additionally, the study found that regional economic development and R&D investment are critical determinants of provincial innovation performance. Specifically, sufficient R&D investment lays a solid foundation for innovative activities, while advanced regional economic development creates an enabling environment for the effective transformation and application of innovation outcomes.

6.2 Policy recommendations

Strengthening the construction of innovation capabilities in universities, promoting industry university research cooperation, and optimizing the provincial innovation environment are important measures to promote the development of provincial innovation, and have profound

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significance for enhancing the overall competitiveness of the province.

In terms of importance, as a key source of knowledge innovation, the enhancement of innovation capabilities in universities is of great significance for provincial innovation. There are two main focuses in promoting the improvement of innovation capabilities in universities. On the one hand, the government needs to strengthen support for scientific research investment in universities, expand the budget scale of scientific research funds, optimize resource allocation patterns, and improve the efficiency of fund utilization. On the other hand, universities themselves need to strengthen scientific research management, improve incentive mechanisms, motivate teachers and students to actively engage in innovative research, cultivate innovative talents with high literacy, and lay a solid talent foundation for provincial innovation.

To accelerate the transformation of scientific research achievements in universities, industry-university collaboration represents an effective strategy. In this process, the government needs to design and enhance relevant policies that encourage deep cooperation between universities and enterprises, thereby establishing long-term and stable partnerships. Meanwhile, universities should actively respond to enterprise demands and promote the industrial application of their research outcomes. Enterprises, in turn, are expected to participate proactively in university research projects by providing practical support, financial resources, and exploring new cooperation models. Ultimately, these collaborative efforts aim to create a mutually beneficial and win-win situation.

Moreover, the uneven development of regional economy in China has led to disparities in innovation levels among provinces. The government should increase policy support for economically and technologically underdeveloped areas, for example, by using fiscal transfer payments, tax incentives, and other means to guide innovation resources to tilt towards underdeveloped areas and narrow the innovation gap between provinces. Underdeveloped regions still need to leverage their own advantages, strengthen infrastructure construction, optimize the business and education environment, attract more innovative talents and enterprises to settle in, and enhance the overall level of innovation in the province.

In summary, by strengthening the construction of innovation capabilities in universities, promoting industry university research cooperation, and optimizing the provincial innovation environment, it is possible to effectively enhance provincial innovation capabilities, promote coordinated economic development, and offer robust impetus for high - caliber development.

6.3 Reflection

Despite achieving certain outcomes in theoretical analysis and empirical investigation, this study inevitably has some limitations. First, the study solely employs the number of patent applications as an indicator of innovation output. While the number of patent applications can partially reflect the level of innovation activity, it is challenging to fully capture the broader implications of innovation output. Future research could consider integrating more diverse indicators of innovation, such as the quantity of published papers and monographs, the rate of transformation of scientific and technological achievements, and the economic benefits generated by innovation outcomes, to provide a more comprehensive and precise evaluation of the impact of university innovation output on provincial innovation output. Second, the data sources and time frame of this study are restricted, focusing only on specific years and regions. Subsequent studies could further expand data collection channels, incorporate additional samples from various years and regions, explore the long-term mechanisms of university innovation on provincial innovation, and analyze the dynamic interactions between university innovation and provincial innovation under different developmental stages and regional contexts.

In summary, university innovation output plays a crucial role in provincial innovation output. In the future development of provincial innovation systems, it is essential to fully leverage the innovation leadership efficiency of universities, strengthen collaborative partnerships among universities, enterprises, and governments, optimize the provincial innovation ecosystem, and promote the overall enhancement of China's provincial innovation capabilities, thereby providing robust momentum for the high-quality advancement of the economy and society.

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