Analysis of the Impact of High-Level Human Capital on Regional Innovation Capability - Based on Panel Data of 31 Provinces in China

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Abstract. Enhancing regional innovation potential and promoting innovation development require top-tier people. This study examines the relationship between high-level human capital and regional innovation capability using balanced panel data from 31 Chinese provinces. It comes to the conclusion that a region's capacity for innovation is greatly enhanced by high-level human capital. More specifically, the regional capacity for innovation rises by 0.0840% for every 1% increase in the proportion of high-level human capital.

Keywords : High-level human capital, Regional innovation capability

1 Introduction

Innovation is the primary driving Force behind national and regional development, and a country's ability to innovate is one of the most important variables in determining its overall strength. The endogenous economic growth theory posits that factors such as human capital and market structure promote sustained economic growth by influencing production efficiency, technical advancement, and knowledge accumulation. Empirical analysis has shown that the proportion of the workforce with a higher education background significantly impacts the innovation activities of various provinces. Within the higher education system, the graduate education phase is the main field for the generation of innovative knowledge. The core of graduate education lies in tracking the cutting-edge of scientific and technological development, emphasizing the development of inventive thinking, and focusing on the output of original research. This not only provides a solid foundation for the country's technological innovation and economic competitiveness but also has profound significance for promoting social progress and economic development. Graduate education is the most advanced level of academic education, and the workforce with graduate education typically possesses strong innovation capabilities. Graduate education produces human capital that is considered to be at the highest level. Many countries are committed to advancing graduate education, viewing it as a key strategy for cultivating talent with innovative capabilities and enhancing the country's innovative strength. In May 2021, the UK Council for Graduate Education conducted the UK Research Supervision

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Survey (UKRSS) to deeply understand and evaluate the role of research supervisors, challenges, support needs, and the experience and satisfaction of graduate students in the UK's graduate education system, providing data support for policymakers and higher education institutions to further improve graduate education and research supervision practices. In June 2021, eleven independent graduate schools in the United States jointly established the National Association of Independent Graduate Schools (NASGS), dedicated to improving the quality and impact of graduate education, supporting research, teaching, and innovative activities to strengthen the competitiveness of independent graduate schools domestically and internationally, encouraging and supporting academic research and innovative activities, and helping member institutions to achieve breakthroughs and accomplishments in their respective research fields.

China has issued a series of policy documents to encourage the growth of graduate education, seeking to increase the quality of graduate education through elements such as the training method and structure of graduate students, and emphasizing the role of graduate education in serving the country's key strategies, focal areas, and important socioeconomic needs. Holding the steady popularization of higher education, the scope of graduate study has expanded, as has the proportion of the Chinese workforce holding graduate degrees. In 2007, the labor force with graduate degrees in China's employment market amade up only 0.2% of the overall employed population. By 2022, this fraction had risen dramatically to 1.3%, which means that there is more than one individual with a graduate degree among every hundred employed persons. Therefore, based on the innovation-driven economic development and the emphasis on graduate education by various countries, this paper employs empirical research methods to examine the impact of high-level human capital with graduate degrees on regional innovation capabilities.[1-2]

2 Literature Review

Innovation has been widely confirmed as the core force driving economic development in numerous theoretical studies and practical applications. Since Schumpeter innovatively introduced the "theory of innovation" in 1912, highlighting the close connection between innovation and economic development, scholars worldwide have focused on the factors influencing innovation capabilities and have conducted extensive research on this topic. Early international studies were mostly based on the industrial cluster theory proposed by Michael E. Porter in 1990 and the national innovation system theory put forward by Richard R. Nelson in 1993, and the endogenous growth theory represented by Paul M. Romer, which primarily aimed to improve national innovation skills. Given the identical makeup of national and regional innovation systems, research on the influencing factors of regional innovation capabilities has also come into the view of researchers. Regional innovation and national innovation are innovations carried out in different subjects or categories; these two concepts are interconnected but distinct, with different boundaries, main elements, network structures, ways of resource flow, and industrial structures . Regional innovation, an essen-

tial part of the national innovation system, directly and significantly affects the general effectiveness and caliber of national invention. When Chinese scholars discuss the elements impacting innovation capacity, they mostly focus on analysis from a regional viewpoint, which is closely related to China's national scale and geographical diversity.[3-4]

The economic development levels of China's eastern, central, and western regions differ significantly, and the regional innovation capacity gap is even more acute, and this gap seems to be widening gradually. Differences in human capital have a substantial impact on the enhancement of innovative capacities across different areas. and this impact is particularly evident in the spatial correlation of regional innovation [5]. Zhang Kuan and Huang Lingyun (2022)[6] investigated changes in regional innovation capabilities in the context of structural differences in human capital and discovered that improving the structure of human capital can significantly improve regional innovation capabilities, with the effectiveness of this impact influenced by institutional environmental factors. Zhang Chunhong (2019)[7] stated that human capital and R&D investment are critical components in improving regional innovation skills, and they have a major beneficial impact on encouraging regional innovation activities.

Education, particularly higher and graduate education, is an important approach to developing human capital, which play a significant role in cultivating high-level talents. When studying the factors that influence regional innovation capability, scholars have increasingly focused on education's unique role in improving regional innovation capacities. There have been numerous international studies that have empirically analyzed the impact of education on regional innovation[8-9], using methods such as quantitative testing and case studies to analyze the effects of various educational measures on innovation capabilities, confirming a positive relationship between education and innovative development. Many domestic scholars have begun to focus on the role of education in regional innovation . Pu Xiaosong et al. (2019)[10] employed the quantile regression model to examine the relationship between education and innovation through four lenses: educational safeguards, educational opportunities, educational excellence, and educational benefits. Zhu Tiantian and Ai Hongshan (2016)[11] believe that education, especially higher education, is critical to innovation-led development. However, existing research has mainly focused on the overall level of education or higher education[12], neglecting the unique impact that graduate education may have on regional innovation. Only a few scholars have taken the scale of graduate education as a sub-indicator of human capital[13]. The fundamental task of graduate education is to cultivate high-level, high-quality talents for society. The continuous accumulation of high-level human capital can affect regional innovation capabilities[14-19]. As a result, this article presents Hypothesis 1: High-level human capital has a considerable impact on regional innovation capacities.

3 Model Setting

Four critical elements encourage the development of regional innovation capability:

Economic Level: The level of development in the area's economy has a significant positive impact on innovative capacity. The economic prosperity of a region provides the financial resources and market demand required for innovation to flourish.

Investment in Human Capital Formation: Significant investment in education provides a firm material foundation for innovation. Talents developed via high-quality education are the primary drivers of scientific and technical progress.

Investment in Innovation Activities: Investment in research and development (R&D) is the key component that drives technological innovation and scientific advancement. R&D funding is critical for driving advances in technology and research.

Regional Characteristics: The completeness of infrastructure, such as the level of informatization and the convenience of transportation, together constitute the intrinsic motivation for innovation. These variables considerably lower the cost of knowledge and information sharing.

In summary, the measurement model for a region's innovation level can be expressed as:

$$\mathrm{Inno}_{it} = \alpha \cdot \mathrm{Econ}_{it} + \rho \cdot \mathrm{H}_{it} + \beta \cdot \mathrm{Grawork}_{it} + \gamma \cdot \mathrm{Edufund}_{it} + \delta \cdot \mathrm{RDfund}_{it} + \mu \cdot \mathrm{Infrustruc}_{it} + \varepsilon_{it} \quad (1)$$

Among them, Inno_{it} represents regional innovation capability; Econ_{it} represents the level of regional economic development; H_{it} represents the scale of regional labor force; $\mathrm{Grawork}_{it}$ represents the scale of labor force with postgraduate education, representing high-level human capital; $\mathrm{Edufund}_{it}$ represents regional education funding; RDfund_{it} represents regional research and development funding; $\mathrm{Infrustruc}_{it}$ represents regional factors, indicating the level of regional infrastructure construction.

4 Summary Statistics

4.1 Variable Definitions

Patents, as legal means of protecting the fruits of innovation, not only demonstrate the scale of invention and creation but also highlight their quality. The number of granted patents can to some extent serve as an indicator of a region's capabilities in technological innovation and research and development. In today's globalized economy, the quantity of patent authorizations has become one of the key indicators to measure a region's competitiveness within the global innovation system. Based on this, this study uses the number of patent authorizations as the primary indication of regional innovation capability.

Graduate education, being the pinnacle of higher education, develops skills who comprise high-level human capital, and these talents frequently display great geographical mobility. Since the data on graduate enrollments, the amounts of students studying, and the conferment of degrees are all completed before their employment, these data cannot reflect the impact of the post-employment mobility of graduates on regional distribution. Therefore, this study chooses the proportion of the employed

population with graduate degrees as the indicator to measure high-level human capital.

When investigating regional innovation potential, in addition to the key element of graduate education scale, other impacting factors must be addressed. In this study, we used regional gross domestic product (GDP) as the primary metric to assess regional economic progress. Simultaneously, the share of tertiary industry value contributed to GDP is utilized to reflect the industrial structure's features. In addition, the number of people in the labor force is used to assess the scale of the population engaged in production activities within the region. These indicators together form a comprehensive analytical framework for the influencing factors of regional innovation capabilities. R&D funds refer to the funds invested in research and development activities, educational funds refer to the total funds invested in education at all levels, and the total volume of regional telecommunications services and railway passenger volume represent the level of regional infrastructure construction. The specific variables are shown in Table 1.

Table 1. Variable Definitions.

Category	Variable Name	Explanation	Unit
Dependent Variable	Regional Innovation Capability	Patent authorization numbers	Items
Economic Factors	Regional Gross Product	The final outcome of production activities	Billion Yuan
	Industrial Structure	Proportion of Tertiary Industry Value Added	%
	Labor Force Scale	Number of Employed People	Ten Thousand People
Investment in Human Capital Formation	High-Level Human Capital	Proportion of graduate students in the workforce	%
	Education Expenditure	Funds Provided for Education	Billion Yuan
Investment in Innovation Activities	R&D Expenditure	Funds for sponsoring scientific research and technological innovation projects	Billion Yuan
Regional Characteristics	Level of Transportation Infrastructure	Railway passenger volume	Ten Thousand People
	Level of Informatization	Total Telecommunications Services	Billion Yuan

4.2 Data Sources

This analysis uses balanced panel data from 31 provinces (municipalities, autonomous areas) in China (excluding Hong Kong, Macao, and Taiwan) between 2008 and 2022. The data sources include the "China Statistical Yearbook," "China Education Statistics Yearbook," "China Science and Technology Statistics Yearbook," "China Labor Statistics Yearbook," and the National Bureau of Statistics of China.

4.3 Basic Summary Statistics

Table 2 presents the basic statistical information of variables that may affect regional innovation capabilities. From 2008 to 2022, the average number of patent authorizations across 31 provinces was 8,554 items, the proportion of the employed population with graduate degrees was 0.882%, the regional GDP totaled 2,340.9 billion yuan, educational funding was 107.6 billion yuan, R&D funding was 50.27 billion yuan, tertiary industry value added accounted for 48.6% of total GDP, railway passenger volume was 74.92 million people, and telecommunications services totaled 117.4 billion yuan.

Table 2. Regional Key Variable Statistics.

	Sample Size	Standard Deviation	Standard Deviation	Minimum	Maximum	Unit
High-Level Human Capital	465	0.882	1.539	0.0160	12	%
Patent Authorizations	465	8,554	14,861	7	115,080	Items
Regional GDP	465	23,409	21,898	398.2	129,514	Billions
Industrial Structure	465	48.60	9.255	29.79	83.76	%
Labor Force Scale	465	2,508	1,690	163.5	7,072	Ten Thousand People
Transportation Level	465	7,492	5,454	65	38,699	Ten Thousand People
Informatization Level	465	1,174	1,644	23.86	15,025	Billions
Education Expenditure	465	1,076	869.8	49.41	6,725	Billions
R&D Expenditure	465	502.7	673.1	1.153	4,412	Billions

4.4 Correlation

Using the proportion of the employed population with graduate degrees in each province in 2022 as the horizontal coordinate and the number of patents authorized in each province in 2022 as the vertical coordinate, a scatter plot of the relationship between the scale of graduate students and the number of patent authorizations is obtained, as shown in Figure 1. There is a positive association between the level of graduate education and the number of inventive patent authorizations. In most provinces, graduate degrees account for less than 2% of the workforce. However, the proportion of graduate students in Tianjin, Shanghai, and Beijing is relatively high, at 4.1%, 7.4%, and 11.6%, respectively.

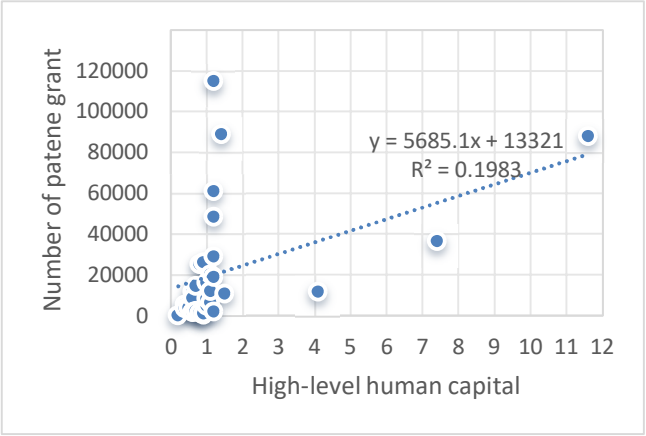

Fig. 1. The Relationship Between High-Level Human Capital and the Number of Patent Grants.

Table 3 reports the correlation matrix among all variables. The correlation coefficient between regional innovation capability and high-level human capital is 0.5255, indicating a significant positive link at the 1% level. This shows that high-level human capital plays an important role in improving regional innovation capability. By attracting and fostering top personnel, regions may boost their innovation potential and support high-quality economic development.

Table 3. Correlation Matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Regional Innovation Capability	1.00								
(2) High-Level Human Capital	0.53* (0.00)	1.00							
(3) GDP	0.82* (0.00)	0.17* (0.01)	1.00						
(4) Education Funding	0.79* (0.00)	0.1301 (0.16)	0.96* (0.00)	1.00					
(5) R&D Funding	0.95* (0.00)	0.47* (0.00)	0.92* (0.00)	0.86* (0.00)	1.00				
(6) Industrial Structure	0.46* (0.00)	0.79* (0.00)	0.17 (0.01)	0.18* (0.00)	0.41* (0.00)	1.00			
(7) Labor Force Scale	0.40* (0.00)	-0.17* (0.01)	0.74* (0.00)	0.72* (0.00)	0.53* (0.00)	-0.29* (0.00)	1.00		
(8) Transportation Level	0.62* (0.00)	0.16 (0.02)	0.81* (0.00)	0.78* (0.00)	0.72* (0.00)	0.11 (0.37)	0.70* (0.00)	1.00	
(9) Informatization Level	0.41* (0.00)	0.05 (1.00)	0.59* (0.00)	0.62* (0.00)	0.51* (0.00)	0.15 (0.05)	0.45* (0.00)	0.59* (0.00)	1.00

Note: 1.*** p<0.01, ** p<0.05, * p<0.1;2.Numbers in parentheses are standard errors.

The correlation coefficient between regional innovation capability and GDP is 0.8199 (significant at the 1% level), indicating a strong positive relationship between the two. This means that when GDP grows, regional innovation capability increases,

suggesting that the improvement in economic development levels helps to drive regional innovation activities. At the 1% significance level, the correlation coefficient between R&D investment and regional innovation capability is 0.9533, indicating a strong positive relationship between the two. Increasing investment in R&D funds can significantly improve regional innovation capability.

The correlation coefficients between regional innovation capability and funding for education, industrial structure, labor force size, transportation level, and informatization level, at the 1% significance level, are 0.7943, 0.4609, 0.4002, 0.6213, and 0.4144, respectively.

From the perspective of the strength of the correlation between regional innovation capability and the four aspects of economic factors, investments in innovation activities, human capital formation, and regional traits, the strongest correlation with regional innovation capability is R&D funding investment, followed by regional GDP, and the weakest is the labor force scale. This suggests that R&D financing is the cornerstone of regional innovation activities for the growth of regional innovation, providing the necessary financial support for R&D activities and is relatively the most important influencing factor. The next step is raising the degree of regional economic development, and the last step is increasing the size of the labor force.

5 Regression Results

5.1 The Impact of High-Level Human Capital on Regional Innovation Capability

Table 4 shows the regression analysis results for the impact of high-level human capital on regional innovation capabilities. In this table, columns (1) to (8) are all based on panel data and estimated using a two-way fixed effects model. Specifically:

-Column (1) investigates the impact of top-tier human capital on regional innovation capabilities.

- Column (2) includes GDP.
- Column (3) adds education funding and research and development (R&D) funding.
- Column (4) incorporates industrial structure.
- Column (5) includes labor force scale.
- Column (6) adds transportation and informatization factors.
- Columns (7) and (8) present combinations of the various variables.

According to the regression results, increasing the scale of high-level human capital by 1% improves regional innovation capability by 0.0840%. This implies that the higher the share of the labor force with postgraduate education, the larger the pool of high-level innovative talent, and thus the greater the regional innovation capability. This finding supports Hypothesis 1, which states that high-level human capital has a considerable beneficial impact on regional innovation capabilities. This could be because postgraduate education prioritizes the development of students' self-directed learning, research skills, inventive thinking, and independent thinking and innovation

talents. As a result, human capital developed through postgraduate study is more capable of improving regional innovation capacity.

Table 4. The Impact of High-Level Human Capital on Regional Innovation Capability.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
High-Level Human Capital	1.107***	0.194***	0.182***	0.822***	1.106***	1.004***	0.113***	0.084*
	(0.070)	(0.045)	(0.048)	(0.062)	(0.070)	(0.064)	(0.040)	(0.044)
GDP		1.689***					0.736***	0.896***
		(0.086)					(0.203)	(0.216)
Education Funding			0.872***				0.463**	0.408*
			(0.215)				(0.213)	(0.202)
R&D Funding			0.577***				0.367**	0.323**
			(0.153)				(0.150)	(0.157)
Industrial Structure				2.411***			0.528**	0.942***
				(0.485)			(0.223)	(0.242)
Labor Force Scale					0.428		-0.617**	-0.561*
					(0.427)		(0.247)	(0.293)
Transportation Level						0.425***		-0.014
						(0.065)		(0.060)
Informatization Level						-0.023		-0.115***
						(0.019)		(0.016)
Constant	8.711***	-8.214***	-0.877	-0.829	5.491*	5.154***	-1.553	-3.666
	(0.052)	(0.848)	(0.786)	(1.895)	(3.218)	(0.611)	(2.366)	(2.636)
Sample Size	465	465	465	465	465	465	465	465
N	31	31	31	31	31	31	31	31
R^2	0.736	0.921	0.924	0.778	0.737	0.772	0.933	0.941

Note: 1.*** p<0.01, ** p<0.05, * p<0.1;2.Numbers in parentheses are standard errors.

From an economic standpoint, the bigger the regional GDP, the greater the regional innovation capability, implying that a developed economy is a solid guarantee of technological advancement. In terms of educational investment, education financing and research and development (R&D) funding have a considerable positive impact on regional innovation capabilities. In terms of industrial structure, the larger the proportion of tertiary sector added value to total GDP, the greater the regional innovation capacity. This suggests that a higher level of service industry development can provide richer markets and application scenarios for innovation activities, promoting the circulation and integration of knowledge and technology.

From the standpoint of labor force size, human capital alone does not greatly improve innovation capabilities. When considering regional infrastructure construction,

advances in transportation facilities and informatization levels have had no substantial impact on regional innovation capabilities.

6 Conclusions and Recommendations

High-level talent is critical for driving innovation development and improving regional innovation potential. The study concludes that high-level human capital significantly improves regional innovation capability. Specifically, a 1% increase in the share of high-level human capital results in a 0.0840% rise in regional innovation capability.

Policy Recommendations:

(1) Expand Postgraduate Education to Meet Regional Innovation Needs: In the context of rapid social and technical growth, extending postgraduate education has become a critical strategy for meeting the demands of regional innovation and technological advancement. With the change and upgrading of the economic structure, as well as the emergence of the knowledge economy, there is an increased demand for high-level talent, particularly in disciplines such as information technology, biotechnology, and novel materials. Postgraduate education, as a key gateway for developing high-level experts, can supply more specialized expertise to satisfy the needs of diverse businesses that require highly trained labor. It can also encourage in-depth scientific research, resulting in technical innovation and industrial advancement. By increasing postgraduate enrollment, optimizing training programs, and improving the quality of education, more high-quality talents with innovative abilities and practical skills can be cultivated, providing a solid talent base and intellectual assistance for the long-term growth of regions and countries.

(2) Increase Funding for Education and R&D to Drive Regional Innovation: The study discovered that investing in education and research and development (R&D) greatly improves regional innovation capabilities. The government should adopt long-term education investment plans to ensure consistent increase in education financing that corresponds to the degree of regional economic development. Education money should be given fairly, with a focus on STEM education, vocational education, and continuing education in order to increase educational quality. Measures such as tax incentives and financial subsidies should be used to encourage investment in education by enterprises, social organizations, and individuals, promoting industry-academia-research collaboration. The government should also establish special R&D funds to support research in key technologies and frontier fields. Investing in the development of innovation platforms, such as science parks, incubators, and accelerators, can give physical space and support for innovation activities.

(3) Optimize Industrial Structure and Strengthen Regional Innovation Systems: Empirical evidence suggests that industrial structure has a significant positive impact on regional innovation capacity. A region with an efficient industrial structure that channels resources (such as capital, labor, and technology) into high-value-added and high-growth-potential industries will promote innovation activities and enhance regional innovation capability. Typically, the process of optimizing and upgrading the industrial structure is accompanied by an increased demand for highly skilled talent. This will attract and cultivate more professionals, creating a talent agglomeration effect that provides intellectual support for regional innovation. In order to drive the

optimization and upgrading of the industrial structure, it is necessary to support the fast growth of modern services, increase their share in the economy, build industrial clusters, facilitate coordination across the industrial chain, and achieve cross-regional resource and market sharing and expansion.

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