ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Graduate Education Scale, Training Output, and Regional Innovation: An Analysis Based on Structural Effects and Market Environment

Yao Pan[1, a]

[1]School of Finance and Public Administration, Anhui University of Finance and Economics, Bengbu 233030, China

[a]2765831952@qq.com

Abstract

Against the background of building China into a leading country in education and pursuing innovation-driven development, the role of graduate education in regional innovation has become increasingly prominent. Based on provincial panel data for 31 Chinese provinces from 2005 to 2022, this paper uses a two-way fixed-effects model to examine the empirical relationship between graduate education scale and regional innovation, and further analyzes training output, educational structure, and differences in market environment. The results show that the direct effect of graduate education scale on regional innovation is not stable, and scale expansion alone cannot fully explain improvements in regional innovation. The number of graduate degree recipients and training efficiency have significant positive effects on basic research, indicating that training output is an important dimension for understanding how graduate education serves knowledge production. Structural variables such as the doctoral share and the doctoral-master ratio have positive effects on regional innovation, especially basic research, but scale expansion and structural optimization do not simply reinforce each other. Market heterogeneity and interaction tests show that the innovation effect of graduate education scale is more evident in low-marketization regions, with particularly significant intergroup differences in basic research. Supplementary analysis also shows that university R&D expenditure and university R&D projects mainly promote basic research output. The findings suggest that graduate education should serve regional innovation by shifting from mere scale expansion toward structural optimization, quality improvement, and stronger regional adaptation.

Keywords

Graduate education; regional innovation; training output; educational structure; market heterogeneity.

1. Introduction

Innovation is an important driver of high-quality regional economic development and a key indicator of regional development quality and competitiveness. Under the deepening implementation of the innovation-driven development strategy, the improvement of regional innovation capacity depends not only on R&D input, industrial foundation, and market environment, but also on high-level talent and knowledge-production systems. Graduate education, as a key link in cultivating high-level talent and producing knowledge, connects the higher education system with the regional innovation system [1]. With the continuous expansion of graduate education in China, its role in serving the national innovation system and regional innovation has become increasingly important. Existing studies emphasize that

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

graduate education in the new era should focus not only on scale expansion but also on quality improvement [2], structural optimization [3], and classified development [4].

In practice, the expansion of graduate education can provide a talent base and knowledge resources for regional innovation, but a larger scale does not necessarily lead to a simultaneous improvement in regional innovation capacity. Graduate education can affect innovation through high-level talent supply, research training, and knowledge-production activities; however, whether education resources are transformed into innovation outcomes is also constrained by training output, hierarchical structure, resource allocation, and external environment. Previous research has shown that the role of higher education and graduate education in innovation development does not depend solely on scale expansion; structural optimization, quality improvement [8], and resource-allocation efficiency [15] are becoming increasingly important.

Accordingly, this paper uses provincial panel data from 2005 to 2022 and a two-way fixed-effects model to examine the empirical relationship between graduate education scale and regional innovation. On the basis of baseline regressions, the paper further analyzes the roles of graduate output, training efficiency, doctoral share, and doctoral-master ratio, and investigates the heterogeneity in the transformation of graduate education resources from the perspective of marketization. It also tests coefficient differences between high- and low-marketization regions through interaction models, conducts robustness checks by replacing dependent variables and core explanatory variables, introducing lagged terms, testing nonlinearity, and excluding municipalities, and adds university R&D expenditure and R&D projects for supplementary analysis.

The marginal contributions of this paper are as follows. First, it distinguishes graduate education scale, training output, and hierarchical structure, avoiding a simplified understanding of graduate education as a pure scale effect. Second, it examines heterogeneity in the innovation transformation of graduate education resources from the perspective of market environment and further tests differences between high- and low-marketization regions through grouped regressions and interaction models. Third, by combining robustness checks and supplementary analysis, it shows that the relationship between graduate education resources and regional innovation is more likely to be reflected in training output, structural optimization, and effective innovation accumulation.

2. Literature Review and Research Hypotheses

2.1. Graduate Education and Regional Innovation

Existing research mainly examines the relationship between graduate education and regional innovation from the perspectives of direct effects, spatial spillovers, and coupling coordination. Du and Li analyze provincial panel data and argue that both the training scale and cumulative scale of graduate education can affect regional innovation [5]. Li and Du point out from a spatial-spillover perspective that graduate education may influence not only local innovation but also neighboring regions through talent mobility and knowledge diffusion [6]. Ma analyzes the spatiotemporal relationship between graduate education and regional innovation from the perspective of coupling coordination [7].

In terms of mechanism, graduate education can influence regional innovation by increasing high-level talent supply, improving knowledge-production capacity, and strengthening research training. Li and Wang argue that graduate education serves innovation-driven development by enhancing innovation capacity [9]. Yet the effect of graduate education on innovation is not necessarily limited to scale expansion. Cui and Tian suggest that the influence of graduate education on high-tech innovation may be reflected either in talent increment or in stock resource advantages [8]. Therefore, graduate education scale may be related to regional

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

innovation, but its direct effect still requires further testing. Existing studies still leave room for explaining why scale effects are unstable and whether they are constrained by training output and structural conditions.

Based on the above analysis, this paper proposes Hypothesis H1: Graduate education scale is associated with regional innovation, but its direct effect may be affected by control variables and regional conditions and may not necessarily appear as a stable and significant positive effect.

2.2. Graduate Training Output and Regional Innovation

The impact of graduate education on regional innovation depends not only on enrollment scale but also on training output and training quality. Scale expansion can increase the total amount of graduate education resources, but the actors who actually enter the regional innovation system and play a role are often high-level talents formed through research training. Long and Cui emphasize the importance of high-quality doctoral education for cultivating high-level innovative talent [10]. Yang et al. show that independent research ability, problem analysis and problem solving, supervisor guidance, and research-resource platforms are important factors influencing doctoral training quality [11].

From the perspective of regional innovation, graduates entering universities, research institutes, and firms can participate in innovation through knowledge application, technological R&D, and research collaboration. Compared with enrollment scale alone, the number of graduate degree recipients and training efficiency may better reflect the transformation of graduate education resources into regional innovation capacity. Existing research highlights the importance of graduate training and innovation-capacity improvement [2,9]. Therefore, this paper regards training output as an important dimension of graduate education's innovation effect, while also noting that existing studies have paid relatively insufficient attention to whether training-output variables differ between technological innovation and basic research.

Hypothesis H2 is therefore proposed: Graduate training output and training efficiency help improve regional innovation.

2.3. Graduate Education Structure and Regional Innovation

Beyond scale and training output, the structure of graduate education is also an important factor affecting regional innovation. Graduate education structure mainly reflects the allocation relationship among different levels and types of graduate education resources. Doctoral education places greater emphasis on original innovation, independent research ability, and high-level knowledge production, and therefore plays an important role in basic research and high-level innovation. Tian and Cui argue that the hierarchical structure of graduate education has an important effect on scientific and technological innovation, and that structural upgrading can promote high-tech R&D and achievement transformation under certain conditions [12]. Wang et al. also note that graduate education in China still faces imbalances in level, type, and regional structure, and that structural optimization is essential for improving quality [14].

However, the structure of graduate education is not necessarily better simply because it is higher. It should match regional development stages, resource-carrying capacity, and innovation demand. Sun et al. suggest that graduate education may have an optimal degree-type structure [13]. Tian and Li argue that as the stage of innovation development changes, the importance of scale, structure, and quality in higher education also changes, with structural optimization and quality improvement becoming more important [15]. This implies that structural optimization may improve regional innovation, but structural upgrading and scale expansion may not have a simple linear additive relationship.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Hypothesis H3a: Optimizing the structure of graduate education helps improve regional innovation.

Hypothesis H3b: Graduate education scale expansion and structural optimization do not simply reinforce each other; in regions with a high structural level, further scale expansion may face resource-carrying pressure or diminishing marginal returns.

2.4. Realization Conditions for the Innovation Effect of Graduate Education

Whether graduate education resources can be transformed into regional innovation outcomes also depends on internal education-system conditions and the external market environment. Internally, graduate education resources are unevenly distributed, and spatial layout, platform conditions, and resource-allocation efficiency all affect regional innovation. Wang et al. point out that the spatial layout of graduate education resources has an important influence on regional innovation [16]. Studies by Yao and Feng and by Li and Guo show that the efficiency of graduate education resource allocation is affected by platform construction, faculty conditions, and the regional development environment [17,18]. Supervisor guidance and training capacity are also important conditions for graduate students' innovation ability [19].

Externally, the market environment affects the allocation efficiency of innovation factors such as talent, capital, technology, and knowledge. Existing studies show that higher education resource agglomeration, marketization, and human capital all influence regional innovation efficiency or innovation-system resilience [20-22]. Thus, the effect of graduate education resources on regional innovation is constrained by the external environment. In regions with different levels of marketization, the supply of high-level talent, allocation of innovation resources, and efficiency of knowledge transformation may differ, leading to different marginal innovation effects of graduate education resources.

Hypothesis H4 is proposed: The impact of graduate education resources on regional innovation differs across market environments.

3. Model Design, Variables and Data Sources

3.1. Model Design

To examine the empirical relationship between graduate education scale and regional innovation, this paper constructs a two-way fixed-effects model using provincial panel data. Considering differences in resource endowment, educational foundation, industrial structure, and innovation environment across provinces, as well as common shocks across years such as macro policies, economic cycles, and technological changes, the model controls for both province fixed effects and year fixed effects. The baseline model is specified as follows:

$$\mathrm{Innovation}_{it} = \alpha_0 + \alpha_1 \mathrm{Grad}_{it} + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where $\mathrm{Innovation}_{it}$ denotes regional innovation in province i and year t, measured by technological innovation and basic research; Grad_{it} denotes graduate education scale; X_{it} is a set of control variables including economic development, industrial structure, openness, and urbanization; μ_i denotes province fixed effects, λ_t denotes year fixed effects, and ε_{it} is the random error term. Standard errors are clustered at the provincial level to address heteroskedasticity and within-province serial correlation.

On this basis, the paper further analyzes training output and educational structure. First, to examine the effect of graduate training output on regional innovation, the following model is constructed:

$$\mathrm{Innovation}_{it} = \alpha_0 + \alpha_1 \mathrm{Output}_{it} + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

where $Output_{it}$ includes the number of graduate degree recipients and graduate training efficiency. Second, to examine graduate education structure and its relationship with scale expansion, the following structural-effect model is constructed:

$$Innovation_{it} = \alpha_0 + \alpha_1 Grad_{it} + \alpha_2 Structure_{it} + \alpha_3 Grad_{it} \times Structure_{it} + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where $Structure_{it}$ includes the doctoral share and doctoral-master ratio. The interaction term $Grad_{it} \times Structure_{it}$ is used to test whether scale expansion and structural optimization have a conditional relationship.

To examine differences in the transformation of graduate education resources under different external environments, the sample is divided into high- and low-marketization regions, and grouped regressions are estimated based on the baseline model. To further test coefficient differences between the two groups, the following marketization interaction model is constructed:

$$Innovation_{it} = \alpha_0 + \alpha_1 Grad_{it} + \alpha_2 (Grad_{it} \times HighMarket_i) + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$HighMarket_i$ is a dummy variable equal to 1 for high-marketization regions and 0 for low-marketization regions. Because it is time-invariant at the provincial level, its main effect is absorbed by province fixed effects; therefore, the focus is on the coefficient of $Grad_{it} \times HighMarket_i$. If the interaction term is significant, the relationship between graduate education scale and regional innovation differs significantly across marketization groups.

The paper also constructs extended interaction models that allow control-variable coefficients to differ between high- and low-marketization regions. Additional robustness checks include alternative dependent variables, alternative core explanatory variables, lagged variables, squared terms, and exclusion of municipalities. The results should be interpreted as empirical associations rather than strict causal effects, because graduate education resource allocation and regional innovation may be mutually reinforcing and some regional policy and research-platform factors are difficult to observe.

3.2. Variables

The dependent variable is regional innovation. Because regional innovation includes both application-oriented technological innovation and basic knowledge production, this paper uses two indicators: technological innovation, measured by the logarithm of patent grants (ln_patent), and basic research, measured by the logarithm of SCI publications (ln_sci). The core explanatory variable is graduate education scale, measured by the share of graduate students among students in regular higher education and denoted grad_ratio.

Further variables include training-output variables and educational-structure variables. Training output is measured by the logarithm of graduate degree recipients (ln_grad_out) and graduate training efficiency (grad_eff), where training efficiency is the ratio of graduate degree recipients to enrolled graduate students. Educational structure is measured by doctoral share (phd_share) and doctoral-master ratio (phd_master_ratio). The heterogeneity variable is marketization level, with provinces divided into high- and low-marketization groups according to the median of the provincial mean marketization index during the sample period. Control variables include economic development, industrial structure, openness, and urbanization.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Table 1. Variable Definitions

Variable type	Chinese name	Variable	Measurement	Data source
Dependent variable	Technological innovation	ln_patent	Log of patent grants	EPS database; China Statistical Yearbook on Science and Technology, etc.
Dependent variable	Basic research	ln_sci	Log of SCI publications	EPS database; China Statistical Yearbook on Science and Technology, etc.
Core explanatory variable	Graduate education scale ratio	grad_ratio	Enrolled graduate students / regular higher-education students	China Educational Statistics Yearbook; EPS database
Training output variable	Graduate output	ln_grad_out	Log of graduate degree recipients	China Educational Statistics Yearbook; EPS database
Training output variable	Training efficiency	grad_eff	Graduate degree recipients / enrolled graduate students	China Educational Statistics Yearbook; EPS database
Structural variable	Doctoral share	phd_share	Doctoral students / graduate students	China Educational Statistics Yearbook; EPS database
Structural variable	Doctoral-master ratio	phd_master_ratio	Doctoral students / master's students	China Educational Statistics Yearbook; EPS database
Controls	Economic development	ln_pgdp	Log of GDP per capita	China Statistical Yearbook; provincial statistical yearbooks
Controls	Industrial structure	industry3	Tertiary-industry value added / GDP	China Statistical Yearbook; provincial statistical yearbooks
Controls	Openness	trade	Total imports and exports / GDP	China Statistical Yearbook; provincial statistical yearbooks
Controls	Urbanization	urban	Urban population / total population (0-1)	China Statistical Yearbook; provincial statistical yearbooks
Supplementary variable	University R&D expenditure	ln_univ_rdfund	Log of university R&D expenditure	China Statistical Yearbook on Science and Technology; EPS database
Supplementary variable	University R&D projects	ln_univ_rdproject	Log of university R&D projects	China Statistical Yearbook on Science and Technology; EPS database

Note: Data sources are compiled according to the statistical caliber of each variable; some variables are calculated from raw data.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

3.3. Data Sources and Descriptive Statistics

This paper uses provincial panel data for 31 provinces, autonomous regions, and municipalities in China's mainland from 2005 to 2022. The data mainly come from the EPS database, China Statistical Yearbook, China Educational Statistics Yearbook, China Statistical Yearbook on Science and Technology, and provincial statistical yearbooks. To reduce heteroskedasticity and facilitate coefficient interpretation, continuous variables such as patent grants, SCI publications, graduate output, and GDP per capita are logarithmically transformed. Observations with missing data due to statistical-caliber or availability issues are handled according to the available samples in each regression.

Table 2. Descriptive Statistics of Main Variables

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Log domestic patent grants	558	9.537	1.840	3.807	13.679
Log SCI publications	556	8.040	1.812	1.099	11.426
Graduate education scale ratio	558	0.078	0.077	0.012	0.561
Log graduate output	558	9.131	1.369	2.890	12.065
Training efficiency	558	0.228	0.042	0.047	0.358
Doctoral share	558	0.116	0.065	0.002	0.300
Doctoral-master ratio	558	0.138	0.088	0.002	0.429
Log GDP per capita	558	10.571	0.677	8.528	12.156
Tertiary-industry share	558	0.453	0.099	0.286	0.839
Openness	558	0.139	0.221	0.000	1.095
Urbanization	558	0.554	0.147	0.209	0.896

Note: Technological innovation, basic research, graduate output, and GDP per capita are logarithmic values; graduate education scale ratio, training efficiency, doctoral share, doctoral-master ratio, industrial structure, openness, and urbanization are ratio variables.

Table 2 shows that both technological innovation and basic research differ substantially across provinces, indicating strong regional heterogeneity in innovation. The mean graduate education scale ratio is 0.0776, with a minimum of 0.0120 and a maximum of 0.5610, showing large regional differences in graduate education scale. Graduate output, training efficiency, doctoral share, and doctoral-master ratio also vary notably, providing a basis for further analysis.

4. Empirical Analysis

4.1. Baseline Regression Results

In the baseline regressions, control variables are added step by step to test changes in the core coefficient. All models control for province and year fixed effects, with standard errors clustered at the provincial level. Columns (1)-(4) use technological innovation as the dependent variable, and columns (5)-(8) use basic research.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Table 3. Baseline Regression Results

Variable	Tech. innovation (1)	Tech. innovation (2)	Tech. innovation (3)	Tech. innovation (4)	Basic research (5)	Basic research (6)	Basic research (7)	Basic research (8)
Graduate education scale ratio	-2.4598* (1.2535)	-1.5159 (0.9962)	-1.5524 (0.9418)	1.8021 (1.1956)	-3.3872*** (0.8918)	-2.6289** (0.9584)	-2.4310** (0.9069)	-1.1444 (1.9282)
Economic development		0.6330*** (0.1852)	0.5924** (0.2270)	0.1912 (0.2314)		0.5078** (0.2202)	0.3229 (0.2131)	0.1713 (0.3202)
Industrial structure			-0.3804 (0.9608)	-0.4586 (0.8914)			-1.2003 (1.4627)	-1.2021 (1.4999)
Openness			0.0119 (0.2241)	-0.3501 (0.2483)			0.3671 (0.2604)	0.2254 (0.3551)
Urbanization				0.0582*** (0.0152)				0.0224 (0.0292)
Constant	9.7274*** (0.0972)	2.9627 (1.9640)	3.5655 (2.6659)	4.4092* (2.4165)	8.3034*** (0.0694)	2.8744 (2.3714)	5.3067** (2.5751)	5.5862** (2.6591)
Year effects	YES	YES	YES	YES	YES	YES	YES	YES
Province effects	YES	YES	YES	YES	YES	YES	YES	YES
Adj. R2	0.9796	0.9814	0.9814	0.9831	0.9809	0.9821	0.9826	0.9828
N	558	558	558	558	556	556	556	556

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

In the technological innovation models, the graduate education scale ratio is marginally negative when controls are not included, but its significance disappears and the coefficient direction changes after controls are added. In the basic research models, the scale ratio is significantly negative in the first several specifications but becomes insignificant after urbanization is included. This indicates that the direct effect of graduate education scale is sensitive to model specification.

4.2. Further Analysis: Training Output and Structural Effects

The baseline results suggest that the direct effect of graduate education scale is unstable. This may be because enrollment scale mainly reflects the stock allocation of education resources and does not fully capture the process through which graduate education resources are transformed into innovation capacity. Therefore, this paper further examines training output and educational structure.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

4.2.1. Training Output

Table 4. Training Output Analysis

Variable	Tech. innovation-output	Basic research-output	Tech. innovation-efficiency	Basic research-efficiency
Graduate education scale ratio	1.8767 (1.1280)	-1.1788 (1.0439)	1.7966 (1.1841)	-0.8605 (1.8369)
Graduate output	0.1895 (0.1541)	1.0197*** (0.1731)		
Training efficiency			-0.0445 (0.7683)	2.7140** (0.9799)
Controls	YES	YES	YES	YES
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Obs.	558	556	558	556
Adj. R2	0.9834	0.9902	0.9831	0.9834

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels.

Table 4 shows that graduate output and training efficiency both have significant positive effects on basic research, while their effects on technological innovation are not evident. This suggests that training output mainly affects knowledge production and basic research. H2 is therefore mainly supported in the basic research dimension, but not fully verified for technological innovation measured by patent grants.

4.2.2. Structural Effects

Table 5. Structural Effect Analysis

Variable	Tech. innovation-doctoral share	Basic research-doctoral share	Tech. innovation-doctoral/master	Basic research-doctoral/master
Graduate education scale ratio	2.2157* (1.1930)	2.9636 (1.9678)	2.3605* (1.1921)	3.0664 (2.0182)
Doctoral share	0.3063*** (0.1055)	0.8177*** (0.1102)		
Scale × doctoral share	-0.2679 (0.3978)	-2.3567*** (0.6255)		
Doctoral-master ratio			0.2924** (0.1089)	0.7947*** (0.1371)
Scale × doctoral/master			-0.2870 (0.3248)	-2.0876*** (0.5667)
Controls	YES	YES	YES	YES
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Obs.	558	556	558	556

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Table 5 shows that doctoral share and doctoral-master ratio, which reflect the hierarchical structure of graduate education resources, have positive effects on regional innovation, especially basic research. Meanwhile, the interaction terms between scale and structural variables are significantly negative in the basic research models, indicating that structural optimization and scale expansion do not simply add to each other. In regions with a higher structural level, further scale expansion may face resource-carrying constraints and diminishing marginal returns.

4.3. Heterogeneity Analysis: Market Environment

Whether graduate education resources can be transformed into regional innovation outcomes is affected not only by internal educational conditions but also by the external market environment. To examine differences across market environments, the sample is divided into low- and high-marketization regions, and grouped regressions are estimated.

Table 6. Market Heterogeneity Analysis

Variable	Low marketization-tech.	Low marketization-basic	High marketization-tech.	High marketization-basic
Graduate education scale ratio	7.4348*** (2.0206)	14.4155*** (4.6972)	0.9209 (1.6591)	-1.9439* (1.1089)
Economic development	0.5809* (0.2877)	0.8468* (0.4770)	0.3217* (0.1721)	0.2671 (0.1818)
Industrial structure	1.1110 (0.8640)	-0.0416 (1.5840)	0.2413 (1.1858)	-0.0703 (0.6752)
Openness	-0.2078 (0.5233)	1.3309 (0.7729)	-0.6676*** (0.1951)	-0.1925 (0.2569)
Urbanization	0.0542** (0.0194)	-0.0110 (0.0492)	0.0306 (0.0184)	0.0124 (0.0113)
Year effects	YES	YES	YES	YES
Province effects	YES	YES	YES	YES
N	279	277	277	277
Adj. R2	0.9779	0.9779	0.9728	0.9895

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels.

Table 6 shows that in low-marketization regions, the graduate education scale ratio has significant positive effects on both technological innovation and basic research. In high-marketization regions, its effect on technological innovation is insignificant, and its effect on basic research is marginally negative. Overall, the innovation effect of graduate education scale is not consistent across market environments and is more evident in low-marketization regions.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Table 6B. Interaction Test for Marketization and Intergroup Coefficient Differences

Variable	Basic interaction-tech.	Basic interaction-basic	Extended interaction-tech.	Extended interaction-basic
Graduate education scale ratio	6.5993** (2.7940)	9.5805** (4.3511)	5.3850** (2.6181)	8.2007* (4.4920)
Scale ratio × high-marketization region	-5.1697* (2.8861)	-11.6268** (4.3125)	-4.8753* (2.7931)	-9.7490** (4.3500)
Marginal effect in low-marketization regions	6.5993** (2.7940)	9.5805** (4.3511)	5.3850** (2.6181)	8.2007* (4.4920)
Marginal effect in high-marketization regions	1.4296 (1.3717)	-2.0464 (1.8897)	0.5096 (1.4044)	-1.5483 (1.3150)
P value for group difference	0.0834	0.0114	0.0911	0.0326
Controls	YES	YES	YES	YES
Controls × high-marketization region	NO	NO	YES	YES
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	558	556	558	556
Adj. R2	0.9836	0.9854	0.9845	0.9857

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels. The main effect of the high-marketization dummy is absorbed by province fixed effects and is not reported. The basic interaction model allows only the core explanatory-variable coefficient to differ across groups; the extended interaction model also allows control-variable coefficients to differ across groups.

Table 6B shows that in the basic interaction model, the marginal effects of the graduate education scale ratio in low-marketization regions are 6.5993 for technological innovation and 9.5805 for basic research, both significant at the 5% level. The interaction terms with the high-marketization dummy are -5.1697 and -11.6268, significant at the 10% and 5% levels, respectively. This indicates that the marginal effect of graduate education scale is significantly weaker in high-marketization regions, especially for basic research. In the extended interaction model, the signs remain consistent and the intergroup difference is still evident, supporting H4.

4.4. Robustness Checks

To test the reliability of the above results, this paper conducts robustness checks by replacing dependent variables, replacing core explanatory variables, and using other treatments. The results are shown in Table 7.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

Table 7. Robustness Checks

Test type	Model	Dependent variable / treatment	Core variable	Core coefficient	Additional term	N	Adj. R2
Alternative dependent variable	(1)	Patent applications	Graduate education scale ratio	0.8783 (1.3263)	-	558	0.9793
	(2)	Valid patents	Graduate education scale ratio	2.5573** (0.9678)	-	527	0.9913
	(3)	Enterprise innovation density	Graduate education scale ratio	4.4263*** (1.4159)	-	558	0.9436
	(4)	Technology-market transactions	Graduate education scale ratio	-1.0892 (3.5869)	-	546	0.9192
Alternative core variable	(5)	Technological innovation	Graduate students per 10,000 persons	0.4277* (0.2393)	-	558	0.9836
	(6)	Basic research	Graduate students per 10,000 persons	1.3021*** (0.2519)	-	556	0.9888
	(7)	Technological innovation	Graduate output per 10,000 persons	0.1681 (0.1651)	-	558	0.9831
	(8)	Basic research	Graduate output per 10,000 persons	0.9441*** (0.2094)	-	556	0.9884
Other tests	(9)	One-period lag-tech.	L. graduate education scale ratio	0.7701 (1.3143)	-	527	0.9822
	(10)	One-period lag-basic	L. graduate education scale ratio	-1.5051 (1.8588)	-	526	0.9843
	(11)	Nonlinear-tech.	Graduate education scale ratio	1.5418 (2.8632)	Squared scale ratio: 0.3555 (3.1089)	558	0.9831
	(12)	Nonlinear-basic	Graduate education scale ratio	4.0620 (4.8115)	Squared scale ratio: -7.1432 (5.7542)	556	0.9833
	(13)	Excluding municipalities-tech.	Graduate education scale ratio	0.5439 (2.9345)	-	486	0.9834
	(14)	Excluding municipalities-basic	Graduate education scale ratio	2.2641 (4.4486)	-	484	0.9808

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels. All models control for economic development, industrial structure, openness, urbanization, province fixed effects, and year fixed effects.

When alternative dependent variables are used, the graduate education scale ratio is significantly positive for valid patents and enterprise innovation density, but insignificant for patent applications and technology-market transactions. When alternative core explanatory variables are used, graduate students per 10,000 persons have a marginally significant positive effect on technological innovation and a significant positive effect on basic research; graduate output per 10,000 persons is significant for basic research but insignificant for technological innovation. After introducing lagged terms, nonlinear tests, and excluding municipalities, the original scale ratio and its squared term do not show stable significance. These results support the basic judgment that simple scale expansion cannot fully explain improvements in regional innovation.

4.5. Supplementary Analysis of Traditional Research Input

Because university research input may be an important input for regional innovation and may also be highly related to graduate training, this paper includes it as supplementary analysis

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

rather than directly adding it to the baseline model. Specifically, university R&D expenditure and university R&D projects are included for estimation.

Table 8. Supplementary Analysis of Traditional Research Input

Variable	Technological innovation	Basic research	Technological innovation	Basic research
Graduate education scale ratio	1.9472* (1.0757)	-0.5364 (1.7326)	1.8403 (1.1175)	-0.3411 (1.6402)
University R&D expenditure	0.0747 (0.0747)	0.3101** (0.1327)		
University R&D projects			0.0229 (0.1236)	0.5672*** (0.1674)
Economic development	0.1422 (0.2212)	-0.0324 (0.2791)	0.1833 (0.2168)	-0.0260 (0.2410)
Industrial structure	-0.4801 (0.8788)	-1.2830 (1.5592)	-0.4214 (0.9691)	-0.4960 (1.2546)
Openness	-0.2899 (0.2622)	0.4739 (0.3519)	-0.3510 (0.2482)	0.2390 (0.3045)
Urbanization	0.0578*** (0.0145)	0.0209 (0.0260)	0.0585*** (0.0143)	0.0265 (0.0255)
Year effects	YES	YES	YES	YES
Province effects	YES	YES	YES	YES
Adj. R2	0.9832	0.9847	0.9831	0.9848
N	558	556	558	556

Note: Robust standard errors clustered at the provincial level are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels.

The results show that university R&D expenditure and university R&D projects have significant positive effects on basic research output but insignificant effects on technological innovation. This indicates that traditional university research input mainly contributes to basic research and knowledge production, but does not necessarily translate directly into patent-based technological innovation. Overall, the direct effect of the graduate education scale ratio remains model-sensitive.

5. Conclusions and Policy Implications

5.1. Conclusions

Using provincial panel data and two-way fixed-effects models, this paper examines the relationship between graduate education scale and regional innovation. It further analyzes training output and structural effects, investigates market heterogeneity, conducts interaction tests for high- and low-marketization regions, performs robustness checks, and adds university R&D expenditure and R&D projects for supplementary analysis.

The study finds that the direct impact of graduate education scale on regional innovation is unstable. After controls are added, the graduate education scale ratio does not show stable significance for either technological innovation or basic research. Graduate training output and training efficiency are important for understanding the innovation effect of graduate education, especially in basic research. Structural variables such as doctoral share and doctoral-master ratio have positive effects on regional innovation, particularly basic research, but the interaction terms suggest that scale expansion and structural optimization do not simply add together. Market heterogeneity analysis shows that the innovation effect of graduate education scale is mainly reflected in low-marketization regions. The interaction tests further show that intergroup differences are marginally significant for technological innovation and significant for basic research. Supplementary analysis indicates that traditional university research input mainly supports basic research.

5.2. Policy Implications

First, graduate education development should shift from scale expansion to quality improvement. Graduate education scale can provide a talent base for regional innovation, but scale itself does not necessarily translate into innovation outcomes. Future development should place greater emphasis on training quality, training efficiency, and the quality of talent output.

Second, the hierarchical structure of graduate education should be optimized to strengthen high-level talent cultivation. The empirical results show that doctoral share and doctoral-master ratio have positive effects on regional innovation, especially basic research. Doctoral education should be developed according to regional innovation needs and institutional foundations, while avoiding blind expansion beyond faculty, platform, and research-resource capacity.

Third, graduate education resources should be allocated according to local conditions to improve regional innovation transformation. Low-marketization regions depend more strongly on high-level talent supply and graduate education resources in improving their innovation systems. For high-marketization regions, policy should move beyond scale expansion toward disciplinary optimization, quality improvement, industry-university-research collaboration, and platform capacity.

Fourth, the synergy between university research input and graduate training should be strengthened. University R&D expenditure and R&D projects mainly promote basic research, suggesting that research platforms, projects, and graduate training should be better integrated so that graduate students can improve innovation ability through project participation, supervisor guidance, and research training.

Overall, the role of graduate education in regional innovation is not a simple scale effect. It is shaped by training output, educational structure, research input, and the regional market environment. Policies should focus on doctoral-level talent cultivation, research-platform support, training-efficiency improvement, and differentiated regional layouts.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

[1] Hong, D. Y. (2023). Implementing the spirit of the 20th CPC National Congress and accelerating the construction of a strong graduate education system. *Academic Degrees & Graduate Education*, (9), 1–7. (In Chinese)

[2] Wang, Z. J. (2024). The trend of graduate education in China from the perspective of strategic development. *Education Development Research*, 44(3), 3. (In Chinese)

[3] Li, L. G., Liu, S. C., & Du, F. (2026). Structural optimization of graduate education for building a leading country in education. *Journal of Graduate Education*, (1), 1–11. (In Chinese)

[4] Lin, M. Q., Liao, J. L., Wang, P., et al. (2026). Classified evaluation of graduate education under the background of building a leading country in education: Underlying logic, theoretical framework and practical path. *China Higher Education Research*, (2), 10–19. (In Chinese)

[5] Du, F., & Li, L. G. (2023). Graduate education and regional innovation: An empirical study based on provincial panel data of China and state panel data of the United States, 2000–2019. *Fudan Education Forum*, 21(2), 39–46. (In Chinese)

[6] Li, L. G., & Du, F. (2021). The spillover effect of graduate education on regional innovation in China. *Tsinghua Journal of Education*, 42(4), 40–49, 90. (In Chinese)

[7] Ma, J. F. (2023). Spatiotemporal pattern and spatial convergence of the coupling coordination between graduate education and regional innovation. *China Higher Education Research*, (5), 79–86. (In Chinese)

[8] Cui, S., & Tian, H. R. (2022). Talent increment expansion or stock resource advantage: An empirical study on the impact of graduate education scale on high-tech innovation. *Journal of Graduate Education*, (6), 22–30, 76. (In Chinese)

[9] Li, F. L., & Wang, Y. Q. (2021). The role of graduate education in innovation-driven economic growth. *Educational Research*, 42(5), 23–29. (In Chinese)

[10] Long, B. X., & Cui, Y. W. (2025). High-quality development of doctoral education: Value, mechanism and path. *Journal of Graduate Education*, (4), 19–25, 84. (In Chinese)

[11] Yang, Y., Zhang, L., & Zhang, L. Q. (2025). Where should doctoral training focus? An analysis based on survey data from graduated doctoral students. *Academic Degrees & Graduate Education*, (7), 74–84. (In Chinese)

[12] Tian, H. R., & Cui, S. (2023). The impact of graduate education hierarchical structure on scientific and technological innovation: Expanding the top or consolidating the foundation? *Education & Economy Review*, 8(3), 59–79. (In Chinese)

[13] Sun, Z. S., Zhang, H. Y., & Xu, X. L. (2025). Estimating the optimal degree-type structure of graduate education: An empirical study based on provincial panel data. *Journal of Graduate Education*, (6), 1–11. (In Chinese)

[14] Wang, D. M., Yang, J. L., & Huang, Y. (2019). The current situation, problems and optimization strategies of graduate education structure in China. *Journal of Graduate Education*, (2), 1–5. (In Chinese)

[15] Tian, H. R., & Li, L. G. (2025). From world factory to global R&D laboratory: The importance and sequence change of higher education scale, structure and quality in innovation development. *Journal of East China Normal University (Educational Sciences)*, 43(12), 1–15. (In Chinese)

[16] Wang, Z. J., Wang, J., & Yu, Y. (2024). Spatial layout of graduate education resources and its spillover effect on regional innovation. *Education Development Research*, 44(19), 1–9. (In Chinese)

[17] Yao, H., & Feng, X. X. (2023). Resource allocation efficiency and influencing factors of graduate education in double first-class universities: An empirical analysis based on 63 universities directly under the Ministry of Education. *Education Academic Monthly*, (11), 29–36. (In Chinese)

[18] Li, K. B., & Guo, J. (2023). Analysis of factors influencing the input-output efficiency of graduate education in China. *Heilongjiang Researches on Higher Education*, 41(11), 95–101. (In Chinese)

[19] Pan, B. R., & Gu, J. M. (2022). The influence of supervisor guidance factors on graduate students' innovation ability: A difference analysis based on disciplinary categories. *Academic Degrees & Graduate Education*, (4), 52–60. (In Chinese)

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0012

[20] He, N., & Yao, C. L. (2025). Testing the effect of higher education resource agglomeration on regional innovation efficiency. *Statistics & Decision*, 41(9), 99–104. (In Chinese)

[21] Zhao, Y. D. L., & Ren, J. (2023). The impact of marketization on regional innovation capacity: A mechanism test based on capital factor allocation. *Commercial Economy Research*, (15), 183–188. (In Chinese)

[22] Li, J. S., & Li, G. P. (2025). Digital economy, talent capital and the resilience of regional innovation ecosystems. *China Soft Science*, Suppl. 1, 176–187. (In Chinese)