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The Mechanism of Influence of Higher Education Scale on Regional Economic Development in China: The Perspective of the Industry–University–Research Collaboration

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Abstract

To clarify the internal mechanism through which the scale of higher education influences regional economic development, this work constructed an operational framework of education, talents, science and technology, and industry. Based on the 2023 data of 31 provincial administrative regions in China, covering 178 national high-tech industrial development zones, an empirical analysis was conducted using descriptive statistics and the Bootstrap mediating-effect test. The findings indicate that the expansion of higher education scale can enhance the level of talent supply, promote the agglomeration of scientific and technological innovation resources, drive the development of industrial scale, and thereby significantly boost economic growth. Among these pathways, the scale of the undergraduate and postgraduate student population exerts a complete mediating effect, while research and development investment and the number of enterprises in high-tech zones demonstrate a partial mediating effect. Notably, a striking contrast emerges between regular undergraduate institutions and double-first-class universities. The former exhibit significant positive mediating effects, whereas the latter's economic driving effect remains largely unrealized. Furthermore, the uneven distribution of high-quality educational resources, particularly the spatial polarization of double-first-class universities, coupled with a mismatch between talent cultivation and industrial demands, and the "spatial isolation" of achievements, all restricted the radiating effect of higher education on regional economies. Therefore, it is necessary to implement a regionally differentiated layout of higher education, optimize the allocation mechanism of scientific and technological innovation resources, strengthen industry–university–research collaboration, and give full play to the effect of industrial agglomeration.

Keywords: industry–university–research collaboration; higher education; economic development; talent supply; scientific and technological innovation; talent supply

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1. Introduction

Globally, higher education has long been recognized as a core driver of innovation and economic development, serving as the key hub for integrating education, science and technology, and talent elements in the process of national modernization. Previous studies have consistently confirmed its pivotal role; theories such as Schultz's human capital theory and Romer's endogenous growth theory have laid the theoretical foundation for

understanding how higher education promotes economic growth by enhancing labor quality and accelerating knowledge accumulation. Cross-national empirical studies further validated this positive linkage. Higher education expansion significantly boosts labor productivity, technological innovation, and long-term economic growth across both developed and developing economies (Q. Zhou & Qi, 2023).

Against this global backdrop, China, as the world's largest developing country with the largest higher education system, presents unique characteristics and typicality that deserve in-depth exploration. However, a series of practical obstacles have prevented the full release of the economic value of higher education. On the one hand, high-quality higher education resources represented by double-first-class universities continue to expand with increasing national investment. On the other hand, a large number of outstanding graduates from limited top universities flow to the eastern coastal regions, and high-level scientific and technological achievements have not been effectively transformed into practical drivers for local industrial upgrading (Borsi et al., 2022; Cai & Liu, 2015). Practices in central and western regions such as Gansu and Guizhou show that the agglomeration of educational resources does not necessarily bring about the coordinated development of regional economies, which is consistent with the findings of regional heterogeneity in education's economic effects worldwide (Valinurova et al., 2022). Moreover, higher education has a certain lagging effect on local economic development (Fahim et al., 2023).

Existing studies have laid an important foundation for understanding the above issues. Human capital theory reveals the internal logic of education promoting economic growth by improving labor quality (Schultz, 1961), and endogenous growth theory further clarifies the driving role of knowledge accumulation and technological innovation in economic development (Romer, 2010). Scholars have conducted extensive research from the perspectives of higher education agglomeration and regional innovation (Orlando et al., 2019; Tian & Li, 2024), higher education and industrial structure (Lv et al., 2023; Durazzi, 2023), scientific and technological innovation and economic growth (Vázquez et al., 2021; Ji et al., 2023), and the coupling and coordination of education, science and technology, and talent (Gao & Hai, 2024; Y. L. Liu & Yao, 2025). Nevertheless, most studies focus on single or bivariate relationships, paying insufficient attention to the dynamically intertwined and complex relationships among education, talent, science and technology, and industry. Although some studies have confirmed the positive effect of higher education on economic growth, there is a lack of systematic research on the mechanisms, such as how this effect is transmitted and what obstacles exist. Research methods are mostly dominated by qualitative induction or single-factor panel data analysis, which can hardly systematically explain the internal mechanism through which the scale of higher education affects regional economic development via multiple paths.

Therefore, from the integrated perspective of education, science and technology, and talent, this study constructs an operational framework of "education, talent, science and technology, and industry". Using relevant data from 31 provincial-level administrative regions in China in 2023 (covering 178 national high-tech industrial development zones, hereinafter referred to as "national high-tech zones"), the multi-path mechanism of influence of higher education scale on regional economic development from the perspective of industry–university–research collaboration is discussed. Specifically, the study adopted descriptive statistics, regression analysis, and Bootstrap mediating-effect tests to carry out the following objectives.

Firstly, to examine whether and how the scale of higher education influences regional economic development through the mediating paths of talent supply, technological innovation, and industrial upgrading. Secondly, to identify the major constraints that hinder the radiation effect of higher education on regional economic development and conduct an in-depth analysis of the reasons. Thirdly, on this basis, to propose targeted policy

measures to optimize the allocation of higher education and scientific and technological innovation resources and further deepen industry–university–research integration.

The innovative value of this study is threefold. Theoretically, it breaks through the single or bivariate analytical paradigm, constructs an integrated framework linking the four core factors, and deepens the understanding of the connotation of the “trinity” strategy. Methodologically, it adopts the Bootstrap method to simultaneously test multiple mediating paths, expanding the research paradigm of the economic effects of higher education. Practically, it proposes tiered policy recommendations based on path differences, providing a decision-making basis for the allocation of higher education layout and advanced regional high-quality economic development.

2. Theoretical Foundation and Research Status

2.1. Higher Education’s Impact on Economic Development

At the theoretical level, the mechanism by which higher education drives regional economic development unfolds primarily through two core pathways: talent supply and technological innovation. These two pillars interact synergistically and together form the critical driving force for economic growth (Bertoletti et al., 2022).

In terms of talent supply, higher education boosts population agglomeration and attracts population inflow through expanded enrollment and improved educational quality, exerting a positive effect on the upgrading of industrial structures (Xiao et al., 2023). Human capital theory posits that higher education cultivates high-caliber talents, enhances the knowledge and skill levels of the labor force, and thereby drives productivity growth and economic expansion. Existing studies have confirmed a positive correlation between the development of higher education institutions and the level of regional human capital (Schultz, 1961; Orlando et al., 2019). Regional economic growth theory further emphasizes that, as an integral component of the regional innovation system, higher education fuels technological progress and industrial upgrading, driving regional economic development. J. L. Yang (2023) used cross-country data to verify that the relative scale of higher education plays a significant role in promoting the construction of major global talent hubs and innovation highlands. Wu (2022) pointed out that the quality of higher education must be based on a certain quantity. The continuous expansion of higher education in China has consolidated the foundation for building a strong country concerning human resources. This theoretical logic can be summarized as “the expansion of higher education scale→increase in talent supply→improvement of labor productivity→economic growth”.

In the realm of technological innovation, higher education institutions, as the cradle of original innovation, elevate the level of regional human capital through research and development (R&D) activities (Abel & Deitz, 2012) and drive technological transformation and industrial evolution. Schumpeter’s innovation theory stresses that technological innovation is a pivotal driver propelling a country’s economic development to a higher stage, with higher education serving as the core engine of technological innovation. Neo-classical growth theory identifies capital and labor as the fundamental factors of economic development, a theory further advanced by Romer, who emphasized that knowledge accumulation and technological innovation are the core elements of economic development (Romer, 2010), while human capital is the key to enabling technological innovation. Technological innovation not only directly boosts productivity and raises the potential economic growth rate, but also fosters new economic growth poles, which gradually evolve into strategic pillar industries (Yi, 2018) and expand the space for economic growth. From the perspective of policy evolution, China has consistently emphasized the “coordination between the innovation chain and the industrial chain”. Evolving from “organic connec-

tion” and “precision docking” to “seamless integration”; this reflects the deepening integration mechanisms of education, science and technology, and industry. The theoretical logic can be summarized as “expansion of higher education scale→agglomeration of scientific and technological innovation resources→technological transformation and industrial upgrading→economic growth”.

The rapid development of the new round of scientific and technological revolution and industrial transformation has created unprecedented opportunities for education, strengthening the key role of higher education in gathering innovation factors and leading industrial transformation.

2.2. Relationship Between Higher Education and Economic Development

Existing studies have generally recognized that higher education, as a core carrier of knowledge creation, talent cultivation, and scientific and technological R&D, exerts a multi-path radiating effect on economic development. Based on different research perspectives, the relevant research results can be categorized into the following three types.

The first type focuses on how higher education influences economic development through scientific and technological innovation. For example, Zhao (L. Zhao et al., 2025) highlighted that enhancing higher education institutions is key for knowledge innovation and achievement transformation, which can help improve the overall innovation level of the country. Tian and Li (Tian & Li, 2024) revealed through a comparative study of higher education between China and the United States that the agglomeration of higher education has a significant promoting effect on regional innovation and is coordinated with the socioeconomic development of regions. Zhou et al. (G. L. Zhou et al., 2023) confirmed that raising the agglomeration level of high-quality educational resources in central cities can enhance innovation capacity and construct a regional innovation system. From the perspective of the digital economy, Sun and Wan (J. H. Sun & Wan, 2024) demonstrated the mediating role of scientific and technological innovation in the process of higher education affecting regional economic development.

The second type centers on the impact of higher education on economic development through the industrial structure. Education acts as a booster for industrial upgrading; the expansion of educational scale and the improvement of educational quality will exert a stronger radiating and driving effect on the quality improvement and efficiency enhancement of regional economies (Xu et al., 2025). Q. Yang and Omar (2026) have found that educational quality and structural investment are important drivers of the talent chain performance. The service industry and knowledge-intensive activities play a significant role in absorbing highly skilled labor and supporting regional industries. Better synchronization of educational reform and industrial upgrading is conducive to achieving sustainable development goals. Lv et al. (2023) compared the development of higher education and industry between China and Germany and found that China’s industrial development level lags behind its higher education system, suggesting that the leading function of higher education in industrial structure upgrading should be strengthened. Studies have shown a mismatch between the scale of higher education and the industrial and economic structures in China, indicating that higher education should not only adapt to economic development but also take a leading role in it.

The third type emphasizes the coupling and coordinated development of education, science and technology, talent, and the economy. Gao and Hai (Gao & Hai, 2024) argued that the coupling and coordination of higher education, talent, scientific and technological innovation, and the regional economy help unleash the advantages of human capital and form a pattern where talent innovation drives economic development. Liu and Yao (Y. L. Liu & Yao, 2025) confirmed that optimizing the structure of general and vocational edu-

cation and improving the degree of coupling and coordination with high-quality economic development can narrow the gap in regional economic development. Based on the observational data from Denmark, Akcigit et al. (Akcigit et al., 2023) profoundly revealed the coupling logic among education, technology and talent, emphasizing that only through the innovative combination of education and technology policies can sustainable economic growth be achieved.

Overall, existing studies have revealed the impact of higher education on economic development from different dimensions, providing a solid theoretical and empirical basis for understanding the relationship between the two. However, most research results are limited to the analysis of a single perspective (e.g., scientific and technological innovation, industrial structure, talent cultivation) or coupling and coordination, lacking in-depth analysis of all factors and exploration of the influence mechanisms among them. Methodologically, most studies rely on theoretical deduction or partial empirical analysis, and there is a lack of simultaneous verification of the multi-path mediating mechanisms.

2.3. Operational Framework: From the Knowledge Triangle to the Integration of Four Chains

The Knowledge Triangle model proposed in the EU's Lisbon Strategy provides a classic framework for understanding the socioeconomic functions of higher education. In the knowledge ecosystem featuring the coordinated development of education, research, and innovation, higher education undertakes the functions of cultivating innovative talents and conducting cutting-edge scientific research, and is closely related to national innovation (Maasen & Stensakerb, 2011). The three elements do not follow a linear progressive relationship, but form an organic whole of mutual empowerment and circular reinforcement. Education provides talent reserves for research and industrial development, research supplies the sources and momentum for innovation, and innovation transforms knowledge into practical products, services, and business models to enhance economic and social value. However, this model implicitly embeds talent within the function of education and fails to highlight the value-added effect of talent as an independent factor. Meanwhile, it does not incorporate industry as an independent component into the analytical framework, making it difficult to reveal the whole process of transforming innovative achievements into actual productive forces.

The report to the 20th National Congress of the Communist Party of China systematically planned the work of education, science and technology, and talent development for the first time (Chang et al., 2025). The integrated promotion of educational development, scientific and technological innovation, and talent cultivation holds a crucial strategic position in the construction of a new development pattern. By integrating educational, scientific, and technological resources and innovating the talent training system (Du et al., 2024), human capital can be promoted to accumulate and transform efficiently and provide impetus for economic growth. Based on the above theoretical context and the national trinity strategy, an operational framework of "education, talent, science and technology, and industry" (Figure 1) was constructed. Inheriting the core idea of the co-evolution of the Knowledge Triangle, this framework expands along two dimensions. It elevates talent from a function implicit in education to an independent analytical dimension, emphasizing its flow and value-added role among education, science, technology, and industry. It upgrades industry from a terminal recipient of innovation to a closed-loop feedback, revealing the mechanism through which industry feeds back resources to education and science and technology. The core operational logic of the framework is depicted as follows.

The framework uses the talent chain as the engine to build a human capital support system for the industry: relying on discipline construction, higher education cultivates general talents to consolidate the industrial foundation. Through the integration of science

and education, as well as industry and education, it trains skilled talents to meet industrial demands. By implementing bachelor–master–doctoral integrated programs and customized high-level talent projects, it fosters top innovative talents to lead industrial upgrading. Industry then transforms from labor-intensive to knowledge-intensive, driving economic growth.

The framework uses the innovation chain as the driving force to lead industrial technological transformation: universities provide theoretical support for technological innovation in basic research. Through joint laboratories, engineering research centers, and other platforms, they transform research results into feasible technical solutions. With the support of national university science parks, technology transfer offices, and other institutions, they accelerate the transformation of achievements into real productive forces. Scientific and technological innovation can enhance industrial total-factor productivity through knowledge and technology spillover effects, support the construction of a modern industrial system, and ultimately achieve economic growth.

The framework uses the industrial chain as the carrier to form a closed loop of coordinated development: tax revenue growth and market demand generated by industrial development feed back into investment in education, science, and technology. On the one hand, industry provides educational technology products and practical venues for universities, promoting the precise alignment of talent cultivation with industrial needs. On the other hand, it offers market-oriented channels for scientific and technological achievements and guides the direction of scientific and technological research. Innovative achievements diffuse through the industrial chain, continuously strengthening industrial competitiveness.

This framework regards education, talent, science and technology, and industry as an organic whole, reveals the mechanism by which higher education, as a key hub, drives regional economic development through multi-chain integration, and provides a theoretical basis for empirical analysis.

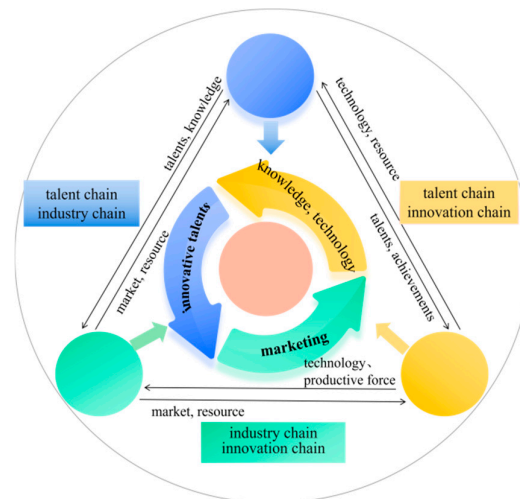


Figure 1. The operation framework of education, talent, science and technology, and industry.

2.4. Research Hypotheses

Based on the above theories and operational framework, three sets of core hypotheses are proposed.

Hypothesis H1 (talent supply path). *Controlling for other factors, the expansion of higher education scale improves the level of talent supply, thereby promoting regional economic growth.*

Hypothesis H2 (scientific and technological innovation path). *Controlling for other factors, the expansion of higher education scale drives regional economic growth by promoting the agglomeration of scientific and technological resources.*

Hypothesis H3 (industrial development path). *Controlling for other factors, the expansion of higher education scale boosts economic growth by promoting the expansion of industrial scale.*

Economic growth depends not only on external factors but also on internal knowledge accumulation and human capital within the economic system (Ding et al., 2024), which are eventually transformed into GDP growth through technological innovation and improved production efficiency. On the one hand, the expansion of higher education scale directly affects the structure of talent supply and increases the proportion of highly skilled labor in a region; meanwhile, high-quality talent can facilitate the transformation of scientific and technological achievements (Q. L. Liu et al., 2025). On the other hand, knowledge creation and scientific and technological R&D achievements help enterprises break through traditional production boundaries, accelerate technological iteration, and achieve cross-field and cross-industry integrated innovation. University clusters can also attract the agglomeration of upstream and downstream supporting enterprises, reshaping productive forces and production relations (Song & Zhang, 2024).

In addition, during the preparation of this manuscript, generative artificial intelligence was used solely to assist with English language translation and polishing to improve linguistic accuracy and readability. All research content, data analysis, interpretations, and arguments in this paper are original and independently completed by the authors themselves.

3. Methodology

3.1. Data and Samples

National high-tech zones are science and industrial parks officially launched under China's National Torch Program, with formal approval from the State Council of China. Rooted in major cities with concentrated intellectual resources and technological strengths across the country, these zones serve as the core carriers for implementing China's innovation-driven development strategy, advancing high-level technological self-reliance, facilitating the commercialization of research achievements, and fostering emerging high-tech industries. Distinct from conventional industrial parks, national high-tech zones feature intensive clustering of universities, research institutions, and high-tech enterprises, and form a mature ecosystem integrating talent training, R&D, and industrial development. Serving as a vital hub connecting education, talent, science and technology, and industry, national high-tech zones occupy an irreplaceable position in China's economic and innovation system. In 2024, the gross domestic product (GDP) of high-tech zones reached 19.3 trillion yuan, accounting for 14.3% of China's total GDP. By the end of 2024, high-tech zones had gathered 33% of the country's high-tech enterprises, 46% of the specialized, sophisticated, distinctive, and innovative "little giant" enterprises, 67% of unicorn enterprises, and 80% of the national joint laboratories nationwide. Their enterprise R&D expenditure and number of invention patents held each accounted for approximately half of the national total, highlighting the core position of high-tech zones in the in-depth integration of science and technology and industry (Y. Y. Wang, 2025).

To respond to the practical demands of the integrated strategy for education, science and technology, and talent, as well as the industry–university–research collaborative development, this study takes 178 high-tech zones across China and the 31 provincial-level administrative regions where they are located as the samples. High-tech zones have been established in batches; the total number stood at 169 by the end of 2020 and 8 new zones

were added in 2022, covering all 31 provinces, municipalities directly under the Central Government, and autonomous regions in China, and one more was added in 2023. Notably, the Xizang Autonomous Region had no high-tech zones before 2022. Therefore, to ensure the completeness, authority, and consistency of the data, this study conducts an empirical analysis based on the cross-sectional data of 2023, with the original data sourced from the National Bureau of Statistics, the official websites of the Ministry of Education, and various national high-tech zones, respectively.

3.2. Methods and Model

3.2.1. General Thought

This study adopts a combination of descriptive statistics and mediating-effect analysis to explore the mechanism through which the scale of higher education affects economic development. The Bootstrap sampling method is used for mediating-effect testing (Efron, 1979), which involves repeated sampling from the original data to generate a large number of simulated samples, so as to estimate the statistics of the dataset and make inferences about population parameters. This method avoids reliance on normality and is effective for mediating-effect testing regardless of sample size, distribution, or scenario complexity. Before conducting the Bootstrap test, the data are standardized. Then, nonparametric sampling is adopted with 5000 resamples, and effect decomposition is performed. Finally, the regression parameters are estimated to determine the significance of the mediating effects.

All analyses are conducted using online SPSS (SPSSAU.COM). This study constructs three core regression models. Equation (1) is the total effect model, aiming to obtain the total effect value, wherein the dependent variable, the independent variable, the control variables, and the regression residual are defined accordingly. Equation (2) is the direct and mediating-effect model, designed to obtain the direct effect value and intermediate effect process values after controlling for mediating variables. Equation (3) is the mediating variable regression model, used to estimate the intermediate effect process values. Mediation is considered significant if the 95% confidence interval of the regression coefficient for the mediating effect does not contain 0. Otherwise, no mediating effect exists.

3.2.2. Mediating-Effect Model

To improve the comparability of the results, the data were standardized before the Bootstrap test. Subsequently, nonparametric sampling was adopted, with the number of sampling iterations set to 5000, followed by effect decomposition. Finally, the regression parameters were estimated to judge the significance of the mediating effect.

$$Y = cX + \beta Z + e_1 \quad (1)$$

$$Y = c'X + bM + \beta Z + e_2 \quad (2)$$

$$M = aX + \beta Z + e_3 \quad (3)$$

3.3. Indicator Selection and Descriptive Statistics

Based on the operation framework in Figure 1, a comprehensive index system covering four core variables, including regional economic development, higher education scale, scientific and technological innovation investment, and industrial agglomeration, was constructed (see Table 1).

Table 1. Indicator system.

First-Level Indicator	Second-Level Indicator
Economic development level	Regional gross domestic product (GDP)
Higher education scale	Number of regular undergraduate universities (NRUU)
	Number of double-first-class universities (NDFU)
	Number of enrolled undergraduate students (NEUS)
	Number of enrolled postgraduate students (NEPS, including masters and doctoral students)
Scientific and technological innovation resources	R&D expenditure
	Number of high-tech zones in the region (NHTZ)
Industrial development scale	Number of enterprises in high-tech zones (NE)
	Number of employees in enterprises (NEE)
Policy support intensity	Provincial fiscal expenditure on science and technology (PFEST)
Industrial development structure	Proportion of secondary and tertiary industries in GDP (PSTI)

3.3.1. Explained Variables and Explanatory Variables

The level of economic development is measured by the gross domestic product (GDP) of a region. As the aggregate value of all final products generated by all resident units in a region over a specific period, GDP serves as a key basis for reflecting the scale, overall strength, and growth rate of regional economic development. It also embodies the ultimate outcome of higher education, driving economic development through talent cultivation, scientific and technological innovation, and industrial upgrading.

The scale of higher education serves as the core explanatory variable. Drawing on existing research findings (Lv et al., 2023; S. Y. Wang & Yang, 2022; G. L. Zhou & Geng, 2023; Q. N. Zhao & Liu, 2025), the number of colleges and universities and the number of enrolled students are selected to characterize the spatial allocation structure of regional higher education resources and the hierarchical structure of talent reserves. In line with the strategic demand of the “trinity” initiative, it is further refined into the number of regular undergraduate institutions, the number of double-first-class universities, and the number of undergraduate and postgraduate students (masters and doctoral students) enrolled. Among them, the scale of regular undergraduate education directly reflects the allocation of basic resources in regional higher education. As a core component of national strategic scientific and technological strength, the number of double-first-class universities indicates the density of high-quality regional educational resources and the capacity to support original innovation. The scale of postgraduate education characterizes the reserve of high-level talents and the potential for scientific and technological research and development. Existing studies have confirmed that advanced human capital can improve total-factor productivity through technological innovation and boost economic growth (Li et al., 2025).

3.3.2. Mediating Variables

Mediating variables fall into two categories: scientific and technological innovation resources and industrial development scale. For scientific and technological innovation resources, the number of national high-tech zones and regional investment in research and experimental development (R&D) funds are selected as measurement indicators. Among them, R&D funds constitute the core resource guarantee for scientific and technological innovation; a larger funding scale exerts a greater impact on the output of scientific and technological innovation (Liang & Chen, 2025), determining the advancement of the whole chain of basic research, applied development, and achievement transformation. National high-tech zones boast a strong ability to gather scientific and technological elements and industrial technological elements (W. L. Sun & Guo, 2022), and their number

reflects the density of regional scientific and technological innovation carriers and the degree of policy agglomeration, serving as an important manifestation of the spatial allocation of scientific and technological resources. For industrial development scale, the number of enterprises and the scale of employees in regional high-tech zones are chosen as proxy variables. The number of enterprises represents the degree of regional industrial agglomeration and the vitality of the innovation ecosystem; the number of employees reflects the capacity of regional high-tech industries to absorb innovation elements and talents, as well as the level of human capital accumulation, acting as a carrier to undertake the spillover effects of higher education.

3.3.3. Control Variables

In addition to the variables mentioned above, regional economic development is affected by multiple factors. From the perspective of innovation actors, the main influencing factors include government investment in science and technology (an important support for scientific and technological innovation and economic development), industrial development structure (a key factor affecting the quality of economic growth), and labor supply (closely related to the distribution of higher education resources and total economic output). To improve the accuracy and explanatory power of the model, regional policy support is included as a control variable, measured by the proportion of provincial fiscal expenditure on science and technology (fiscal expenditure on science and technology divided by local general public budget expenditure). Regional industrial structure is measured by the proportion of added value of the secondary and tertiary industries in GDP. Labor supply is usually measured by the year-end population; however, the variance inflation factor (VIF) test reveals severe multicollinearity between this indicator, the number of enterprise employees, and the number of students enrolled, so it is excluded.

3.3.4. Descriptive Statistical Analysis of Variables

The descriptive statistics of the core variables are presented in Table 2. The results show that there are significant regional differences in higher education resources, science and technology investment, and industrial development across regions. The number of regular undergraduate institutions ranges from 4 to 77, R&D expenditure spans from 115 million yuan to 342.664 billion yuan, and the number of enterprises in high-tech zones varies from 45 to 31,270. The sample exhibits good variability, which provides a solid foundation for further analysis.

Table 2. Descriptive statistics of variables.

Variable Name	Mean	Standard Deviation	Minimum Value	Maximum Value
NRUU	40.06	20.73	4	77
NDFU	4.74	6.66	1	34
NEUS	656,352.70	383,862.50	30,574	1,428,713
NEPS	125,256.10	103,192.20	6194	494,566
R&D expenditure	676.45	861.55	1.15	3426.64
NHTZ	5.74	4.37	1	18
NE	7212.07	8117.59	45	31,270
NEE	864,886.30	993,287.70	4641	3,778,835
GDP	40,352.64	32,815.65	2392.70	135,673.20
PSEST	2.63%	0.019	0.31%	6.55%
PETI	90.89%	0.052	77.85%	99.80%

4. Empirical Analysis

4.1. Mediating-Effect Analysis of the Talent Supply Path

Talent supply is a fundamental path through which higher education influences regional economic development. To test this path, taking the NRUU and NDFU as core independent variables, and the NEUS, NEPS, and NE as mediating variables, the Bootstrap method (with 5000 resamples) was adopted to conduct the mediating-effect test.

In the model with the number of undergraduate institutions as the core independent variable (see Table 3), two talent supply paths show significant mediating effects. First, the two parallel mediating paths, “NRUU→NEUS→GDP” and “NRUU→NEPS→GDP”, have 95% confidence intervals that do not contain 0, indicating the existence of the mediating-effect paths.

Table 3. The mediating-effect test with NRUU as the independent variable.

Acting Path	$a * b$	Standard Deviation	95%LCL	95% UCL	z	p
NRUU→NEUS→GDP	0.305	0.234	0.014	0.906	1.307	0.191
NRUU→NEPS→GDP	−0.787	0.490	−1.929	−0.030	−1.604	0.109
NRUU→NEE→GDP	−0.499	0.322	−1.151	0.145	−1.547	0.122
NRUU→NEUS→NEPS→GDP	0.455	0.344	−0.008	1.265	1.325	0.185
NRUU→NEUS→NEE→GDP	0.516	0.272	−0.027	1.043	1.898	0.058
NRUU→NEPS→NEE→GDP	0.922	0.430	0.295	1.949	2.145	0.032
NRUU→NEUS→NEPS→NEE→GDP	−0.534	0.334	−1.313	−0.006	−1.599	0.110

Note: The parts in blue are the chain mediating-effect test, while the rest denote parallel mediation. The following table is similar.

The expansion of the scale of the undergraduate student population has a positive promoting effect on economic growth, while the expansion of the postgraduate student population shows a negative effect in the parallel mediating paths. This may be attributed to the “time-lag effect” and “outflow effect” of postgraduate education: postgraduate training has a longer cycle, and postgraduates are more inclined to flow to developed regions, making it difficult to capture immediate positive contributions in provincial cross-sectional data. Second, the two chain mediating-effect paths, “NRUU→NEPS→NEE→GDP” and “NRUU→NEUS→NEPS→NEE→GDP”, also have 95% confidence intervals that do not contain 0, with significant mediating effects. A common feature of these two paths is that they both pass through the industrial carrier link of NE, indicating that the impact of talent supply on the economy can realize value transformation through industrial absorption. The mediating effects of other paths are not significant.

In sharp contrast to regular undergraduate institutions, none of the paths with the number of double-first-class universities as the core independent variable show mediating effects (see Table 4). This result profoundly reveals the structural dilemma of China’s double-first-class universities in serving regional economic development. This might be due to the significant regional polarization of the distribution of these double-first-class universities. For instance, Beijing has 34 double-first-class universities, while Hebei, Guizhou, Yunnan, Qinghai and other regions have only 1, leading to a high geographical concentration of high-level talents; second, the industrial structure is mismatched with talent supply: economically underdeveloped regions are usually dominated by traditional or resource-based industries, which are difficult to accurately connect with the disciplinary advantages of double-first-class universities.

Table 4. Mediating effect with NDFU as the independent variable.

Acting Path	$a*b$	Standard Deviation	95%LCL	95% UCL	z	p
NDFU→NEUS→GDP	−0.031	0.120	−0.256	0.233	−0.260	0.795
NDFU→NEPS→GDP	−0.082	0.246	−0.736	0.262	−0.335	0.738
NDFU→NEE→GDP	0.256	0.279	−0.268	0.889	0.919	0.358
NDFU→NEUS→NEPS→GDP	0.002	0.034	−0.072	0.074	0.074	0.941
NDFU→NEUS→NEE→GDP	−0.024	0.084	−0.197	0.157	−0.286	0.775
NDFU→NEPS→NEE→GDP	0.185	0.380	−0.401	1.116	0.488	0.626
NDFU→NEUS→NEPS→NEE→GDP	−0.006	0.044	−0.116	0.071	−0.125	0.900

Note: The parts in blue are the chain mediating-effect test, while the rest denote parallel mediation. The following table is similar.

In conclusion, the main path of hypothesis H1 is confirmed. Higher education provides human capital support for economic development through large-scale talent cultivation, but the economic driving effect of double-first-class universities has not been fully realized due to the imbalance in spatial distribution and insufficient integration of industry and education.

4.2. Mediating-Effect Analysis of Scientific and Technological Innovation Paths

This study takes the number of high-tech zones and R&D investment as mediating variables to examine the mediating role of scientific and technological innovation between higher education and economic development. The test results (see Table 5) show that in the path of “NRUU→R&D expenditure→GDP”, both paths are significant at the 0.01 significance level and the direct effect is also significant, indicating that R&D expenditure plays a partial mediating role in the mechanism through which the scale of higher education affects economic development, with a mediating-effect ratio as high as 61.89%. This result verifies the internal logic that the expansion of the scale of higher education can attract the agglomeration of more R&D resources, thereby driving economic growth through technological innovation.

Table 5. Mediating-effect test results for H2.

Acting Path	a	b	$a*b$	z	p	95% Confidence Interval	c'
NRUU→R&D expenditure→GDP	0.474 **	0.802 **	0.380	3.986	0.000	0.205~0.581	0.220 **
NDFU→NHTZ→GDP	—	—	−0.047	−0.487	0.626	−0.211~0.171	—
NDFU→R&D expenditure→GDP	—	—	−0.006	−0.043	0.966	−0.300~0.231	—
NDFU→NHTZ→R&D expenditure→GDP	—	—	−0.121	−0.584	0.559	−0.475~0.277	—

Note: ** expresses $p < 0.01$.

However, for the three paths with the NDFU as the independent variable, all 95% confidence intervals include 0, meaning the mediating-effect paths are not significant. This may stem from the fact that the allocation of scientific and technological resources in double-first-class universities is mostly dominated by national macro-strategies, resulting in an insufficiently close connection between research directions and regional industrial demands. Meanwhile, regions concentrated with double-first-class universities often witness an “enclave transformation” of scientific and technological achievements, leading to the omission of their direct contributions to the local regional economy in statistics.

In summary, hypothesis H2 is partially verified. The expansion of ordinary undergraduate institutions attracts more R&D resource input, forming an important mechanism for boosting economic growth. Nevertheless, the scientific and technological innovation-

driven effect of double-first-class universities has not yet been effectively transmitted to the regional economic level.

4.3. Mediating-Effect Test of the Industrial Development Path

Industrial development serves as the carrier for the ultimate realization of the effects of the previous two paths. Tests are conducted using the number of enterprises in national high-tech zones and the number of enterprise employees as mediating variables. The results (see Table 6) show that in the path of “NRUU→NHTZ→GDP”, both paths are significant at the 0.01 significance level, and the direct effect is also significant with a consistent sign. Therefore, the NE plays a partial mediating role in the impact of higher education scale on economic development, accounting for 44.463% of the total effect. This confirms that the expansion of the higher education scale can promote economic growth through industrial agglomeration effects by attracting and fostering more high-tech enterprises.

Table 6. Mediating-effect test results for H3.

Acting Path	<i>a</i>	<i>b</i>	<i>a*b</i>	<i>z</i>	<i>p</i>	95% Confidence Interval	<i>c'</i>
NRUU→NE→GDP	0.474 **	0.577 **	0.273	1.680	0.093	−0.185~0.484	0.340 *
NDFU→NE→GDP	0.459 **	1.316 **	0.605	2.386	0.017	0.243~1.267	−0.689 **

Note: * expresses $p < 0.05$, ** expresses $p < 0.01$.

Notably, the path of “NDFU→NE→GDP” shows a significant suppression effect, accounting for 87.801% of the total effect. This indicates that the impact of double-first-class universities on local economic development may be overshadowed by other stronger external factors. One possible explanation is that regions with a high concentration of double-first-class universities often implement strict industrial relocation policies and face high operating costs, which restrict the expansion of manufacturing enterprises. Meanwhile, these regions have entered a development stage dominated by high-end service industries, and traditional industrial agglomeration indicators measured by the number of enterprises can hardly accurately reflect their real economic contributions.

In summary, hypothesis H3 is partially supported. The expansion of the scale of higher education helps form industrial economies of scale. However, the relationship between double-first-class universities and industrial development is more complex, and their economic contributions may be realized through more advanced forms such as knowledge-intensive service industries, which require further investigation with more appropriate indicators.

5. Discussion

5.1. Main Findings

Firstly, the coexistence of positive and negative effects and dependence on industrial absorption in the talent supply path are discussed. The scale of undergraduate education has a direct positive mediating effect on economic growth, while the scale of postgraduate education shows a negative effect in the parallel path. However, both can achieve positive transmission through the industrial carrier of enterprise employees. This finding deepens the understanding of human capital theory. Talents cultivated by higher education are not directly transformed into economic output, but require the intermediate link of industrial absorption. The negative effect of postgraduate education may stem from the time-lag effect caused by long training cycles and the spillover effect from cross-regional mobility of high-level talent.

Secondly, there are partial mediation and transformation blockages in the scientific and technological innovation path. R&D investment exerts a partial mediating effect of 61.889% between undergraduate universities and GDP, indicating that the agglomeration of R&D resources is indeed an important mechanism for higher education to drive the economy. Nevertheless, the scientific and technological innovation paths of double-first-class universities are fully blocked, revealing structural contradictions in the current innovation system. A large number of high-level scientific research achievements accumulate in universities in the form of papers and patents, failing to be effectively transformed into actual productive forces, with limited direct contributions to the local regional economy. This finding echoes the argument by Yi (Yi, 2018) that “scientific and technological innovation needs to coordinate with the industrial chain”, and also highlights the importance of bridging the final gap between the laboratory and the production line.

Thirdly, there is a partial mediation and suppression effect in the industrial development path. The path whereby ordinary undergraduate institutions promote economic growth by attracting enterprise agglomeration is verified, whereas the path of double-first-class universities presents a suppression effect. In regions densely populated with double-first-class universities, the industrial form may have shifted from the quantitative expansion of enterprises to quality improvement, making traditional indicators inadequate to capture their real contributions. Meanwhile, strict industrial relocation policies may cause the economic effects of universities to spill over to surrounding areas rather than manifest within the local administrative region. Therefore, regional development stages and differences in industrial forms should be fully considered when selecting measurement indicators.

5.2. In-Depth Mechanism of the “Double-First-Class” Blockage

The insufficient manifestation of the economic driving effect of double-first-class universities can be understood from the following three dimensions.

From the spatial dimension, the polarized distribution and siphonic effect of high-quality higher education resources is impactful. Double-first-class universities are highly concentrated in eastern coastal areas and central cities, with only a sparse distribution in central and western provinces. Under such a spatially polarized pattern, outstanding talent cultivated by the limited number of double-first-class universities naturally flows to eastern regions with more opportunities and higher platforms, faced with scarce local employment opportunities and development space. Gansu Province has only one double-first-class university, Lanzhou University, and less than 20% of its graduates are employed in the northwest region, which serves as a typical example of this mechanism.

From the industrial dimension, structural mismatch between talent cultivation and regional demand has an impact. The disciplinary advantages and research directions of double-first-class universities mostly focus on basic research and cutting-edge technologies, which are misaligned with the demand structure dominated by traditional and resource-based industries in less-developed regions. Provinces such as Gansu, Guizhou, and Yunnan are in urgent need of application-oriented talent serving local characteristic industries (e.g., new energy, modern agriculture, cultural tourism), rather than basic research-oriented doctors. Such a supply–demand mismatch results in it being difficult for high-level talent to settle down and be retained, further exacerbating brain drain.

From the transformation dimension, the enclave transformation of scientific and technological achievements and statistical leakage has an effect. The scientific research achievements of double-first-class universities are highly mobile: a patented technology developed by a university in the central and western regions may well be industrialized in the eastern coastal areas. The current statistical caliber bounded by administrative divisions fails to capture such cross-regional contributions, featuring “R&D locally but

transformation elsewhere” and thus underestimating the real economic effects of high-quality higher education resources.

6. Policy Recommendations

6.1. Optimizing the Differential Layout of Higher Education

This section discusses implementing the national strategy of optimizing the layout of higher education and tilting newly added higher education resources toward the central and western regions. During the 15th Five-Year-Plan period, this involves coordinating the development of universities under central ministries and local universities. In provinces with scarce double-first-class universities, building some application-oriented undergraduate universities and specialty colleges through ministry–province co-construction and paired assistance, strengthening the collaborative education mechanism with local pillar industries, optimizing discipline settings with the “one university, one policy” framework, and improving the regional adaptability of talent cultivation. In eastern regions and other areas rich in science and education resources, it is crucial to support universities to target world-class scientific and technological frontiers, develop cutting-edge interdisciplinary disciplines such as artificial intelligence and quantum information, and strengthen the national strategic-talent pool, as well as high-level basic research and original innovation capabilities.

Launching the Regional-Stickiness Enhancement Program for High-Level Talent: To address the issue that the expansion of postgraduate education fails to serve the local economy, the Ministry of Finance, the Ministry of Education, and other departments shall jointly establish a Special Fund for Retention Rewards for graduates from universities in central and western regions. Postgraduates employed by enterprises in national high-tech zones in central and western provinces shall be granted individual income tax rebates or resettlement subsidies; local enterprises recruiting masters and doctoral graduates shall receive social insurance subsidies per head. Meanwhile, it is necessary to promote the reform experience of “dual appointment by universities and enterprises”, and encourage teachers and graduates of double-first-class universities in eastern China to take temporary posts in high-tech zones in central and western regions to realize “flexible mobility” of talents.

Optimizing the pyramid-shaped talent training structure: In industrially developed and innovation-clustered regions such as Zhejiang, Jiangsu, and Guangdong, strengthening postgraduate education and basic research and targeting strategic urgent fields including integrated circuits and artificial intelligence to cultivate “industrial scientists” and “outstanding engineers” in a targeted manner are necessary. In regions with weak talent support, the priorities should be consolidating the skill training of undergraduate students, accelerating the application-oriented transformation of local universities, promoting the co-construction of modern industrial colleges by provincial undergraduate universities and national high-tech zones, and carrying out order-based training by implementing the *Talent Support Plan for the Revitalization of Higher Education in Central and Western Regions*, encouraging the expansion of university enrollment to tilt toward provinces with low net-talent inflow, such as Gansu and Ningxia, and guiding the effective allocation of human resources.

6.2. Improving Investment in Scientific and Technological Innovation Resources

Establishing a zone–university linkage community for achievement transformation: The Ministry of Science and Technology, the Ministry of Education, and other departments should jointly promote regular docking mechanisms between national high-tech

zones and local universities, jointly formulate a list of key industrial technological breakthroughs, and implement a collaborative research model featuring “enterprise-proposed topics, government support, university problem-solving, and market verification”. For scientific and technological achievement transformation projects launched by university research teams in high-tech zones, provincial, municipal, and county governments shall provide appropriate subsidies, and rolling support shall be given to projects with outstanding performance.

Implementing the construction project of concept verification and pilot maturation platforms: To tackle the inefficient transformation of university scientific research achievements from laboratories to production lines, follow the deployment of the Ministry of Industry and Information Technology to “give full play to the roles of national manufacturing innovation centers and pilot platforms”, and build some concept verification centers and pilot platforms in national high-tech zones. Support universities in central and western regions to jointly establish “reverse enclaves” with eastern high-tech zones, set up R&D centers in central and western universities and transformation bases in eastern high-tech zones, and retain R&D talents while realizing the value of achievements through industrial supporting facilities in eastern China.

Improving the benefit-sharing mechanism for scientific and technological achievement transformation: To address the “enclave transformation” of scientific and technological achievements, the National Bureau of Statistics, the Ministry of Science and Technology, and other departments shall jointly establish a system for cross-regional contribution accounting of scientific and technological achievement transformation. For scientific and technological achievements established in other regions, the place of achievement origin and the place of transformation shall be allowed to share the statistical weight of GDP and tax revenue in a certain proportion, so as to institutionally incentivize long-term cooperation between universities in central and western regions and industrial supporting zones in eastern China. Meanwhile, focus on promoting the experience of “progressive distribution of technology income”, and distributing the income from scientific and technological achievement transformation in the form of basic guarantee, performance rewards, and long-term dividends to stimulate endogenous motivation for achievement transformation.

6.3. Deepening the Industry–University–Research–Application Integration Mechanism

Launching the new track cultivation initiative for national high-tech zones: Follow the deployment of the Ministry of Industry and Information Technology to “implement the new track cultivation initiative for national high-tech zones and strengthen the construction of innovative industrial clusters”. National high-tech zones shall cultivate some future industrial new tracks (such as intelligent agents, quantum information, and biomanufacturing) based on the disciplinary advantages of local universities. Industrial clusters included in the national new track cultivation list shall be entitled to special financial support and other preferential policies. Support the co-construction of future industrial science parks by high-tech zones and universities, and provide financial support for eligible scenario projects with reference to Zhejiang Province’s “Artificial Intelligence+” benchmark scenario support policies.

Establishing a national digital cloud platform for high-tech-zone talent: Integrate data on university discipline settings, talent training, enterprise positions, and talent mobility nationwide, using artificial intelligence, big data, and other technologies to generate a talent cloud map and realize intelligent matching of supply and demand. Set up a scarce-talent early-warning module to dynamically adjust discipline construction and talent training programs, and set up an enterprise special talent reservation module to promote

industry–university–research collaborative education and order-based training and improve the pertinence and practicality of talent. Realizing cross-regional sharing of talent through the cloud platform to solve problems such as insufficient supply of high-tech talents and difficulties in resource allocation.

Constructing a monitoring and evaluation system for the linkage between higher education and industry: In response to the indicator adaptability reflected by the suppression effect of double-first-class universities, focus on monitoring data such as university scale, talent training, scientific research level, funding input, and the number of specialized, sophisticated, distinctive, and new enterprises, so as to realize the full-chain tracking of innovation factors. Issue early warnings quarterly and annually, and implement precise regulations. Visualize the trajectory of talent mobility, and launch special supervision and policy interventions for phenomena such as excessively high talent-outflow rate and persistently low R&D investment.

Through systematically optimizing the layout of higher education, strengthening investment in innovation resources and institutional advantages, and deepening industry–university–research collaboration, a virtuous circular channel of education, talent, science and technology, and industry can be opened up, which can then provide momentum for high-quality economic development.

7. Conclusions

This study theoretically and empirically explores the mechanism of the impact of higher education scale on regional economic growth, revealing that higher education affects regional economic development mainly through three paths. Large-scale talent training can consolidate the foundation of human capital. Strengthening basic research and original innovation sources can gather scientific and technological innovation resources. Serving industrial upgrading can lead to the improvement of economic structure. Especially in terms of talent supply, the number of undergraduate and postgraduate students both exerts complete mediating effects on economic growth. However, the economic driving effect of double-first-class universities has not been fully realized. Accordingly, this study proposes to promote the differential layout of high-quality higher education resources, optimize the hierarchical talent training system through region-specific policies, the integration of science and education, and the integration of industry and education, stimulate the original innovation momentum of higher education and promote the transformation of scientific and technological achievements, deepen the in-depth integration of industry, university, research and application, and facilitate the circular flow of innovation factors such as talent, technology and capital.

This study still has several limitations that need to be further improved in the future. First, there are complex two-way causal relationships among education, science and technology, industry, and economic development. Analysis based only on cross-sectional data in 2023 can hardly eliminate endogeneity bias. Future research may adopt more precise identification of causal effects by introducing instrumental variables and using panel data models. Second, vocational education is a key component of industry–education integration, and subsequent research needs to explore the relationship between higher education and the regional economy by category.

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Abbreviations

The following abbreviations are used in this manuscript:

R&D	Research and development
GDP	Regional gross domestic product
NRUU	Number of regular undergraduate universities
NDFU	Number of double-first-class universities
NEUS	Number of enrolled undergraduate students
NEPS	Number of enrolled postgraduate students
NHTZ	Number of high-tech zones in the region
NE	Number of enterprises in high-tech zones
NEE	Number of employees in enterprises
PFEST	Provincial fiscal expenditure on science and technology
PSTI	Proportion of secondary and tertiary industries in GDP
UCL	Upper confidence limit
LCL	Lower confidence limit

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