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Transforming Higher Education Resources into Innovation and Development: Evidence from Grey Relational Analysis in Hubei

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Abstract: *This study investigates the key factors influencing the transformation of higher education resources into regional innovation and development outcomes in Hubei Province. Drawing on grey system theory, a three-stage indicator framework is constructed—encompassing research output, intermediary mechanisms, and application performance. Grey Relational Analysis (GRA) is applied to assess the relative impact of each indicator. Results reveal that intermediary capacity plays a dominant role, with service personnel ranking highest in correlation. Foundational research inputs, such as patents and applied R&D projects, also show strong associations. However, technology transfer contracts rank lowest, indicating persistent gaps in formalized commercialization. These findings highlight the importance of strengthening intermediary structures and optimizing resource allocation to improve transformation efficiency. The study provides empirical evidence and theoretical insight for enhancing the role of universities in regional innovation ecosystems.*

Keywords: *Higher education; Technology transfer; Grey relational analysis; Innovation transformation; Regional development*

1. Introduction

Technological innovation has become a central pillar of regional competitiveness under China's high-quality development strategy. Universities, as key institutions of knowledge production and technological advancement, are shifting roles from traditional research centers to active drivers of innovation. Hubei Province, a higher education hub in central China, is home to 132 universities, including seven “Double First-Class” institutions. With significant investments, a growing R&D workforce, and steady output in patents and research platforms, Hubei has established a strong foundation for scientific development.

Despite these advantages, the conversion of research output into tangible economic and societal outcomes remains limited. Although research input and academic achievements have increased, the commercialization rate of scientific results continues to lag behind [1-2]. For instance, technology transfer contracts account for less than 13% of patent authorizations—well below the national average—highlighting persistent inefficiencies in the transformation process. Structural issues such as the misalignment between research and industrial demand, underdeveloped intermediary mechanisms, and inadequate allocation of funding for transformation stages have been widely reported .

In addition, recent empirical research tends to focus on transformation efficiency using models like DEA-BCC [3]or eXplores factor influences via Ordered Logit models[4]. While these approaches are insightful, they often emphasize macro performance or linear causality and may overlook structural heterogeneity and multi-stage dynamics in the transformation process.

To address these challenges, this study aims to identify the key factors influencing the transformation of higher education resources into innovation and development outcomes. Drawing on a three-stage evaluation framework—Research Output, Transformation Intermediaries, and Application Performance—and applying Grey Relational Analysis (GRA), this research provides empirical insights into the structural dynamics shaping the effectiveness of university-driven knowledge transfer in Hubei Province.

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2. Data and Methods

This study draws on panel data from the Compilation of Science and Technology Statistics of Higher Education Institutions (2018–2023) and the Statistical Yearbook of Hubei Province, covering the period from 2017 to 2022. The datasets feature standardized formats and consistent definitions across years, making them suitable for small-sample, multi-indicator empirical analysis.

To enhance the quality and reliability of the indicator system, a two-step screening process was employed. First, the Coefficient of Variation (CV) was used to eliminate indicators with limited variability ($CV < 0.10$), as such variables offer little discriminatory power over time. Second, Spearman's rank correlation was applied to detect and exclude highly collinear indicators (> 0.90) that share overlapping trends, thus improving the structural independence of the final set.

Following indicator refinement, this study adopted the Grey Relational Analysis (GRA) method to assess the relative impact of each factor on university technology transfer performance. Developed by Deng Julong, GRA is particularly suitable for small samples and high-dimensional data. It does not require strict assumptions about data distribution and enables effective variable ranking by measuring the degree of association between each indicator and the reference outcome.

3. Framework and Indicators

3.1. Conceptual Framework: Translating Educational Strengths into Innovation and Development Outcomes

In the context of China's high-quality development agenda, universities are increasingly positioned not only as centers of education and research but also as engines of regional innovation and economic advancement. This study proposes a three-tier conceptual framework—educational strengths, innovation potential, and development outcomes—to structure the transformation path from academic input to practical output.

Educational strengths encompass foundational inputs such as R&D funding, academic personnel, research infrastructure, and intellectual property assets. Innovation potential refers to the originality, maturity, and transferability of scientific outputs, which determine their readiness for commercialization. Development outcomes capture the realized economic and social impacts of these innovations, including technology transfer income, industrial performance, and international collaboration.

While innovation and development phases may overlap in practice, this study adopts a sequential lens—generation, intermediation, and realization—to analytically distinguish the stages of the transformation chain. This structure enables a clearer identification of bottlenecks and key drivers along the pathway from knowledge production to real-world application.

3.2. Theoretical Foundations and Literature Review

A substantial body of research has examined the mechanisms underlying university-based technology transfer. Internationally, Bozeman[5]emphasize that institutional pathways and supportive policy environments are central to successful commercialization. Siegel et al.[6] highlighted how the internal efficiency and practices of transfer offices influence outcomes. Grimaldi et al.[7]and Markman et al.[8] further identified entrepreneurial incentives, access to research platforms, and organizational support structures as essential enablers of innovation diffusion.

In the Chinese context, Xu and Xie proposed an indicator system encompassing R&D funding, human capital, contracts, and patents, emphasizing the alignment between inputs and outputs [9]. Sun and Wei, using fuzzy-set QCA, found that intermediary support and human resources play a decisive role in technology transformation [10]. Luo et al. employed a DEA-Malmquist model to validate the impact of incentive mechanisms and transfer personnel [11]. Tan and Li demonstrated that coordinated investments in platforms and contract facilitation are closely tied to regional industrial development [12].

Collectively, these studies underscore that effective technology transfer depends on three core dimensions: resource input (e.g., funding, personnel), intermediary mechanisms (e.g., service capacity, platforms), and performance outcomes (e.g., contract volume, income generation). These theoretical insights directly inform the indicator framework adopted in this study.

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3.3. Indicator System and classification

Building on the conceptual framework and supporting literature, this study develops a three-stage indicator system aligned with the transformation process: Output Generation, Intermediary Mechanisms, and Outcome Realization. As summarized in Table 1, fifteen indicators are categorized accordingly.

Table1 Definition and coding of indicators

Primary Category	Secondary Indicator Name	Code	Indicator Definition
Output Generation	Research Input Intensity (person-years)	X_1	Reflects the intensity of human resource input by faculty and research staff
Output Generation	Number of Authorized Patents (items)	X_2	Measures the level of intellectual property realization and the quality of research output
Output Generation	Number of Applied Basic and Experimental Projects(items)	X_3	Indicates the activity level of research tasks and foundational output capacity
Output Generation	Research Expenditure (thousand RMB)	X_4	Refers to the financial resources allocated to research activities
Output Generation	Total Research and Teaching Personnel (persons)	X_5	Represents the overall scale of the university's research workforce
Output Generation	Number of Awarded Scientific Achievements (items)	X_6	Counts the number of national or local awards received for scientific achievements
Intermediary Mechanisms	R&D Application and Tech Service Personnel(persons)	X_7	Denotes the number of staff engaged in achievement transformation and related services
Intermediary Mechanisms	Number of Technology Transfer Contracts (items)	X_8	Represents the number of contracts signed for transferring results into the market
Intermediary Mechanisms	Number of R&D Institutions (units)	X_9	Refers to the number of university-affiliated incubation and research service platforms
Intermediary Mechanisms	Number of Research Projects (items)	X_{10}	Indicates the number of research projects undertaken during the reporting period
Intermediary Mechanisms	Proportion of Research Funding for Transformation (%)	X_{11}	Measures the share of research expenditure allocated to transformation activities
Outcome Realization	International Conference Participation (person-times)	X_{12}	Assesses the external communication and dissemination capacity of scientific achievements
Outcome Realization	Value Added of "Four High" High-Tech Industries (billion RMB)	X_{13}	Reflects the economic output level and transformation capacity of regional high-tech industries
Outcome Realization	Annual Enterprise-Funded R&D Application Income (thousand RMB)	X_{14}	Indicates actual income received from enterprises for R&D result application in the current year
Reference Indicator	Technology Transfer Income (thousand RMB)	X_0	Serves as the ultimate measure of economic benefit from university research achievements

The Output Generation category includes inputs that reflect the research capacity of universities, such as the number of research personnel, research intensity, funding levels, and patent authorizations. These indicators capture the foundational R&D capabilities.

The Intermediary Mechanisms category focuses on the institutional and organizational elements that facilitate the transition from research to application. This includes service personnel engaged in transformation activities, the number of technology transfer contracts, the scale of R&D platforms, and the proportion of funding allocated to transformation efforts.

The Outcome Realization category evaluates the practical results of research output in both economic and social dimensions. Key indicators include value-added from high-tech industries, international collaboration, and enterprise-funded R&D application income—representing the extent to which research outcomes are successfully translated into real-world impact.

This classification enables a structured examination of the transformation process across its full

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lifecycle, supporting the identification of critical drivers at each stage.

4. Results and Analysis

4.1. Indicator Screening and Classification

To ensure the robustness and distinctiveness of the selected indicators, a two-step screening process was conducted using panel data from 2017 to 2022. First, the Coefficient of Variation (CV) was employed to assess temporal variability. Indicators with CV values below 0.10 were deemed to lack sufficient annual fluctuation and were excluded accordingly. For instance, X_5 was removed due to its minimal variation, while X_6—despite being near the threshold—was retained for its structural significance within the indicator framework.

Second, Spearman's rank correlation was applied to evaluate potential multicollinearity. Indicators with strong monotonic relationships ($\rho \geq 0.90$) were considered highly redundant. For example, X_3 showed high correlation with both X_4 and X_5, suggesting overlapping trends. However, indicators such as X_{14} and X_8, and X_{14} and X_2, while also correlated, were retained based on their distinct functional roles in the transformation pathway—representing value realization, intermediary services, and research output, respectively.

As a result, a refined set of 10 indicators exhibiting both adequate variability and structural independence was finalized for subsequent analysis (see Table 2).

Table 2 Classification of Core Indicators for University Technology Transfer (After Screening)

Primary Category	Secondary Indicator Name	Code	Indicator Definition
Output Generation	Number of Authorized Patents (items)	X_2	Measures the level of intellectual property realization and the quality of research output
Output Generation	Number of Applied Basic and Experimental Projects(items)	X_3	Indicates the activity level of research tasks and foundational output capacity
Output Generation	Number of Awarded Scientific Achievements (items)	X_6	Counts the number of national or local awards received for scientific achievements
Intermediary Mechanisms	R&D Application and Tech Service Personnel(persons)	X_7	Denotes the number of staff engaged in achievement transformation and related services
Intermediary Mechanisms	Number of Technology Transfer Contracts (items)	X_8	Represents the number of contracts signed for transferring results into the market
Intermediary Mechanisms	Number of R&D Institutions (units)	X_9	Refers to the number of university-affiliated incubation and research service platforms
Intermediary Mechanisms	Proportion of Research Funding for Transformation (%)	X_{11}	Measures the share of research expenditure allocated to transformation activities
Outcome Realization	International Conference Participation (person-times)	X_{12}	Assesses the external communication and dissemination capacity of scientific achievements
Outcome Realization	Value Added of "Four High" High-Tech Industries (billion RMB)	X_{13}	Reflects the economic output level and transformation capacity of regional high-tech industries
Outcome Realization	Annual Enterprise-Funded R&D Application Income (thousand RMB)	X_{14}	Indicates actual income received from enterprises for R&D result application in the current year

4.2. Justification of Indicator Selection

The screening process was guided by both statistical rigor and structural logic. The CV method ensured sufficient temporal variation, while the Spearman correlation analysis addressed redundancy by identifying trend convergence. Rather than applying rigid exclusion rules, indicators were assessed based on both empirical behavior and their role in the conversion chain.

The final set of indicators captures critical dimensions across the "input–intermediary–outcome"

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stages, offering a structurally independent and functionally representative system for the subsequent grey relational analysis.

4.3. Grey Relational Analysis Results

Using the screened indicators, the study applied the Grey Relational Analysis (GRA) model to evaluate the relationship between each factor and the core performance metric—technology transfer income. The results are presented in Table 3.

The top-ranked indicators in terms of grey relational degree include X_7 (R&D Application and Tech Service Personnel), X_2 (Number of Authorized Patents), and X_3 (Number of Applied Basic and Experimental Projects). These findings highlight that intermediary human capital and the capacity for original research output play a central role in driving technology transfer effectiveness.

Meanwhile, X_{13} (Value Added of "Four High" High-Tech Industries) and X_{12}(Number of International Conference Participations) also exhibit strong relational degrees, suggesting that the external absorptive capacity and recognition of research quality are integral to outcome realization.

Indicators such as X_{14} (Annual Enterprise-Funded R&D Application Income), X_9 (Number of R&D Institutions), and X_{11} (Proportion of Research Funding for Transformation) reinforce the importance of sustained funding and organizational infrastructure.

Notably, X_8 (Number of Technology Transfer Contracts) ranks the lowest among the selected indicators, implying that while formal agreements reflect outcomes, they may not independently capture the underlying institutional capacity or transformation mechanisms required for broader impact.

Table3 Ranking of Indicators by Average Grey Relational Coefficient

Ranking	Indicator Name	Average GRC
1	X_7	0.771
2	X_2	0.708
3	X_3	0.698
4	X_{13}	0.695
5	X_6	0.683
6	X_{12}	0.682
7	X_{14}	0.679
8	X_9	0.677
9	X_{11}	0.672
10	X_8	0.587

5. Discussions

This study provides empirical evidence on the structural factors influencing the transformation of higher education resources into regional innovation and development outcomes in Hubei Province. By applying Grey Relational Analysis (GRA), the findings highlight the central role of intermediary mechanisms—particularly R&D Application and Tech Service Personnel—in shaping transformation performance. These results reinforce key propositions in knowledge transfer theory, which emphasize that effective transformation depends not only on the volume of research output, but also on the presence of organizational support systems that bridge universities and markets. In this regard, the study contributes to the literature by offering a structured, multi-stage perspective on university-based technology transfer under a small-sample, regional context.

At the same time, several limitations of this study should be acknowledged. The analysis is based on provincial-level panel data, which ensures temporal consistency but may mask heterogeneity among individual universities. Differences in institutional strategy, disciplinary focus, and local industry engagement are therefore not fully captured. Future research could employ university-level or multi-level datasets to provide a more granular understanding of transformation dynamics.

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6. Conclusion

6.1. Intermediary mechanisms are key drivers of transformation effectiveness

Based on the results of Grey Relational Analysis (GRA), intermediary mechanisms play a dominant role in the transformation of higher education resources into regional innovation outcomes. Among all variables, R&D Application and Tech Service Personnel (X_7) ranked highest, highlighting the critical role of human capital and institutional support in linking universities with industries. This suggests that organizational infrastructure and intermediary engagement are central to improving the practical impact of research.

6.2. Research capacity remains foundational but insufficient alone

Indicators related to research capacity, such as number of Authorized Patents (X_2) and number of Applied Basic and experimental Projects (X_3), also showed strong associations with transformation performance. These findings confirm that high-quality and application-oriented research is essential. However, such capacity must be complemented by effective downstream mechanisms to fully realize development outcomes.

6.3. Weak transactional mechanisms hinder technology commercialization

The relatively low ranking of technology transfer contracts (X_8) indicates persistent structural bottlenecks in formalizing the transition from research to market. Despite a steady supply of research outputs, universities in Hubei continue to face coordination challenges between supply and demand. This reflects the “available but untransferred”dilemma, signaling the need for improved matchmaking platforms and policy support.

6.4. Systemic alignment is essential for regional impact

Taken together, these findings support key propositions of knowledge transfer theory: successful transformation relies not only on research excellence but also on aligned institutional services and enabling policies. For regions like Hubei with strong academic resources, enhancing intermediary mechanisms and optimizing structural support are essential for maximizing the contribution of higher education to regional innovation and economic development.

7. Policy Implications

7.1. Strengthening Intermediary Support Systems

To strengthen the foundational quality of research outputs, universities should adopt an industry-oriented selection mechanism for R&D projects and build a comprehensive pipeline from basic research to pilot testing. Leveraging external influence indicators such as “awarded scientific achievements”institutions are encouraged to promote joint research initiatives with enterprises and research institutes to accelerate scenario-based technology transformation. In response to the lower ranking of "technology transfer contracts," efforts should focus on improving contract efficiency through a unified provincial results transaction platform, regularized achievement announcements, and a dynamic supply－demand list system.

7.2. Enhancing Knowledge Supply and Coordination

To reinforce the foundation of technology transfer, it is essential to improve the quality of research supply and the level of institutional coordination. Universities should adopt industry-oriented project selection mechanisms and establish complete pipelines from basic research to pilot validation. Indicators such as international conference participation reflect external influence and can serve as leverage to promote collaborative research and applied transformation with enterprises and research institutes.

7.3. Restructuring Resource Allocation for Process Continuity

To sustain the transformation chain, universities should incorporate transformation-related spending

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into overall research budgeting and create dedicated funding pools to support intermediate stages such as pilot testing and market entry. Mechanisms such as joint projects, enterprise co-investment, and benefit-sharing can help attract downstream investment and establish a positive cycle from research to transformation to application. Furthermore, scientific research institutions should evolve into functional entities—such as pilot-scale platforms and shared technology centers—to enhance organizational support across the entire transformation process.

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