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How Does Regional Innovation Capacity Affect Regional Economic Level? Based on QCA Analysis of 31 Provinces in China

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ABSTRACT
Employing fsQCA on 31 Chinese provinces, this study identifies three regional innovation pathways driving economic development: "capital-heavy" (e.g., Shanghai), "result-oriented" (e.g., Guangdong), and "transformation-efficient" (e.g., Fujian). While digital infrastructure and government S&T spending consistently serve as core conditions, each path relies on distinct drivers: input scale, output synergy, or institutional innovation. These findings reveal China's state-led model and offer stage-specific policy insights, contributing Chinese practice to global innovation discourse.

KEYWORDS
Regional innovation capacity; Regional economic level; Qualitative comparative analysis (QCA); Innovation groupings

1 Research Background: Innovation-Driven Proposition of the Times and the Paradox of Regional Development

1.1 Strategic Shift of Innovation under the Global Competition Pattern

Accelerated by breakthroughs in AI, quantum computing, and biotech, the global value chain is restructuring, tightly coupling innovation with economic power—a 0.87 correlation in top R&D economies per WIPO (2022). In response, China's R&D spending surged from 1.03T (2012) to 2.79T yuan (2021). Yet performance is deeply uneven: Shanghai's R&D intensity (4.1%) is 3.66 times Gansu's (1.12%), and Guangdong hosts 60,000 high-tech firms—2.3 times the total of 12 western provinces. This stark spatial mismatch in resources critically constrains regional coordination.

1.2 Typical Facts and Research Pain Points of Regional Innovation in China

China's regional innovation is bifurcated: eastern provinces have forged a virtuous cycle of input-output-transformation, while central and western regions struggle with insufficient inputs and inefficiency. Compared to international hubs like Silicon Valley, China's system remains state-led, with government S&T spending at 5.2% of the budget, yet corporate R&D intensity lags at only 2.5%. Traditional econometrics fails to capture the synergistic causality in such a context, necessitating a configurational approach.

2 Literature Review: Theoretical Evolution from Single Element to Group Synergy

2.1 Theoretical Construction of Regional Innovation Capacity: The Integration of Multidimensional Perspectives

2.1.1 Innovation Input Theory: The Dual Logic of Resource-Based View and Institutional Change

The resource-based view underscores heterogeneous resources' role in growth (Romer, 1990), yet fails to explain efficiency variations under different institutions. China exemplifies this: its government R&D expenditure (5.2%) leads OECD averages, but corporate R&D (2.5%) lags. New institutional economics (North, 1990) fills this gap, framing policy emphasis as a cost-reducing signal—a concept later quantified through policy text analysis (Zhu Haijiu, 2004).

2.1.2 Innovation System Theory: Upgrading from the Triple Helix Model to the Innovation Ecosystem

Innovation system theory, initiated by Cooke (1992), pioneered the study of factor synergy. The perspective has since evolved from static structures (e.g., the Triple Helix) to dynamic "innovation ecosystems" (Moore, 1993), emphasizing symbiosis among actors and environment. Germany's "Franhof Model" (75% industrialization rate) exemplifies ecosystem efficiency. In contrast, China shows a critical "systemic obstacle," with a transformation efficiency (45%) lagging far behind the U.S. and Germany, due to a weak output-to-transformation link.

2.1.3 Group Theory: a Cutting-Edge Application of QCA Methods in Innovation Research

Set-theoretic approaches (Ragin, 2000) transcend variable-centric analyses by revealing synergistic causal conditions. QCA applications in innovation highlight distinct national pathways: developed countries rely on "enterprise R&D + university achievements" while developing nations depend more on "government inputs + infrastructure". However, existing studies, often national or single-dimensional, lack a holistic "input-output-transformation-environment" analysis, leaving China's state-led model underexplored.

2.2 Mechanisms Linking Innovation Capacity and Economic Development: from Linear Regression to Complex Causation

2.2.1 Boundary Conditions for Single-Factor Effects

Early econometric models presumed a linear innovation-growth relationship. However, significant regional heterogeneity exists; for instance, R&D investment's economic elasticity is 0.32 in eastern China but only 0.18 in the west. This aligns with absorptive capacity theory, which posits that the marginal return on inputs depends on regional institutional support for technological digestion.

2.2.2 Discovery of Equivalent Paths under the Grouping Perspective

The Bavarian and Shenzhen models demonstrate distinct yet effective configurations: the former thrives on "university tech transfer + vocational training," while the latter leverages "state-guided capital + industrial chain innovation." These equivalent paths challenge the linear "high-input, high-output" paradigm, underscoring the strategic importance of synergistic factor combinations.

2.3 Research Gap: Three-Dimensional Expansion Space Based on Group Theory

Existing studies exhibit three primary gaps: 1) A static, cross-sectional focus, neglecting the dynamic evolution of innovation pathways; 2) An overreliance on economic metrics, overlooking multi-dimensional performance in green and livelihood innovation; 3) Insufficient validation of the government's role via international comparison. This study addresses these gaps through a configurational analysis of China's 31 provinces, contributing to the understanding of state-led innovation systems.

3 Research Design: Method Selection and Variable Construction

3.1 Research Methodology: Applicability of Fuzzy Set Qualitative Comparative Analysis (fsQCA)

3.1.1 Core Advantages of QCA

QCA identifies sufficient condition configurations for outcomes through set theory, accommodating both qualitative and quantitative data—making it ideal for China's complex regional innovation context. Following established protocols (Fiss, 2007; Rihoux & Ragin, 2017), this study applies fsQCA in three steps: 1) Data calibration using the direct method with 5%, 50%, and 95% percentiles as anchors; 2) Truth table minimization with frequency ⩾1 and consistency ⩾0.8, interpreting intermediate solutions; 3) Robustness checks by adjusting consistency (0.85/0.90) and frequency thresholds.

3.1.2 International Methodological Dialogue

The methodology of this study echoes international complex systems research published in recent years, such as Fiss's (2007) set-theoretic analysis of organizational groupings and Rihoux & Ragin's (2017) standardized operational guidelines for the QCA technique, ensuring the international legitimacy of the research methodology.

3.2 Variable Indicator Systems: Dimensional Deconstruction and Measurement Methods

3.2.1 Conditional Variables

Innovation input (X1-X4): including R&D Personnel full-time equivalent (X1), R&D Financial intensity (X2), Extent to which the Government attaches importance to innovation ("innovation" appears in the Government's work report) (X3), Government expenditure on science and technology as a proportion of general public budget expenditure (X4), reflecting the resource base of innovation activities and the strength of government support.

Innovation output (X5-X6): Number of three patents granted domestically (X5) and Number of international and domestic publications (X6) are selected to measure the capacity of knowledge creation and technology output.

Innovation Transformation (X7-X8): Number of technology contracts (X7) and Technology market transactions (X8) are selected as indicators to reflect the degree of marketization of scientific and technological achievements.

Innovation environment (X9-X10): including Mobile Internet users as a percentage of total population (X9) and Number of Creative Spaces (X10), representing the density of innovation carriers and the level of digital infrastructure, respectively.

3.2.2 Outcome Variables

Regional economic level (Y) is synthesized by weighting GDP per capita (Y1), Occupation rate (Y2), and Disposable income per capita (Y3), which comprehensively reflects the economic scale, employment quality, and people's livelihood welfare. The sub-indicators of the outcome variable Y are weighted and averaged to produce a final value for Y.

Table 1 Variable Indicator System

Variable types	Measuring dimensions	Segmentation variables	Measuring indicators	Code
Condition variable	Regional innovation capacity	Innovation inputs	R&D Personnel full-time equivalent	X1
			R&D Financial intensity	X2
			Extent to which the Government attaches importance to innovation ("innovation" appears in the Government's work report)	X3
			Government expenditure on science and technology as a proportion of general public budget expenditure	X4
		Innovation outputs	Number of three patents granted domestically	X5
			Number of international and domestic publications	X6
		Innovation transformation	Number of technology contracts	X7
			Technology market transactions	X8
		Innovation environment	Mobile Internet users as a percentage of total population	X9
			Number of Creative Spaces	X10
Outcome variables	Regional economic level	Y	GDP per capita	Y1
			Occupation rate	Y2
			Disposable income per capita	Y3

3.3 Data Sources and Sample Characteristics

Data from the China Statistical Yearbook and related sources (2021) for 31 Chinese provinces reveal a clear regional divergence. Eastern provinces (e.g., Shanghai, Guangdong) lead in core indicators like R&D intensity and patent grants, while western regions lag in environmental factors such as makerspaces and mobile internet penetration, highlighting multidimensional innovation disparities.

4 Empirical Analysis: Deconstructing the Layers from Single Conditions to Grouping Paths

4.1 Single-Condition Necessity Test: Ruling Out Single-Factor Determinism

No single condition demonstrated necessity (all consistency <0.9), confirming the systemic nature of innovation-driven development. R&D intensity (0.842) and government S&T expenditure (0.830) showed the highest consistency, indicating their foundational role. Notably, digital infrastructure (0.767) surpassed some output indicators in consistency, highlighting its critical indirect support.

4.2 Grouping Analysis: Identification and Deconstruction of Three Differentiated Paths

Three valid groupings are obtained through fsQCA analysis (Table 2), and the core condition coverage is over 0.80, reflecting significant path differentiation characteristics:

Table 2 Configuration Paths

Conditional variable	High regional economic level			Non-high regional economic level	
	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5
R&D Personnel full-time equivalent		●	●		
R&D Financial intensity	●	●	●	⊗	
Extent to which the Government attaches importance to innovation ("innovation" appears in the Government's work report)	●		●		
Government expenditure on science and technology as a proportion of general public budget expenditure	●	●	●		⊗
Number of three patents granted domestically	●	●	●		
Number of international and domestic publications	●	●	⊗		
Number of technology contracts	●	●	●		
Technology market transactions	●	●	⊗		
Mobile Internet users as a percentage of total population	●	●	●		
Number of Creative Spaces	⊗	●	●		
Consistency	0.949325	0.974592	0.963464	0.853218	0.867413
Original Coverage	0.54962	0.509555	0.50579	0.820245	0.860545
Unique coverage	0.0267813	0.0035519	0	0.0640548	0.104355
Representative Cases	Shanghai, Tianjin	Guangdong, Zhejiang, Jiangsu, Beijing	Fujian	Tibet, Xinjiang, Hainan, Guangxi, Qinghai, Inner Mongolia, Guizhou, Yunnan, Shanxi, Gansu, Heilongjiang, Jilin, Ningxia, Jiangxi, Henan	Tibet, Inner Mongolia, Qinghai, Xinjiang, Heilongjiang, Yunnan, Gansu, Jilin, Guangxi, Hebei, Liaoning, Shaanxi, Guizhou,
Consistency of the overall solution	0.939976			0.82396	
Coverage of the overall solution	0.559565			0.9246	

4.2.1 Configuration 1 Capital-heavy Path - Input Scale-Driven Growth (Shanghai, Tianjin)

The capital-heavy path, exemplified by Shanghai and Tianjin, is driven by high-scale inputs: substantial R&D investment (Shanghai's 4.1% intensity) and significant government S&T spending. This state-guided model clusters innovation resources, akin to Seoul's but with greater public funding influence compared to South Korea's enterprise-led approach.

4.2.2 Configuration 2: Outcome-Oriented Path - Synergy Between Innovation Output and Industrial Ecology (Guangdong, Zhejiang, Jiangsu, Beijing)

This path couples strong innovation outputs (patents, papers) with robust digital infrastructure (X10) and industrial absorption capacity. Guangdong exemplifies this through its leading patent volume and the GBA's high-tech cluster (e.g., Huawei, Tencent). Zhejiang achieves a 45% university patent conversion rate (vs. 30% national average), demonstrating deep industry-academia synergy. The configuration shows that at sufficient scale, outputs combined with market-ready ecosystems generate significant economic impact.

4.2.3 Configuration 3: Transformation Efficacy-based Path - Deep Integration of Industry, University, Research and Utilization to Break through Transformation Bottlenecks (Fujian)

This path overcomes transformation bottlenecks through institutional innovation, with core conditions including technology market turnover (X8), digital infrastructure (X10), and government innovation emphasis (X3). Fujian exemplifies this via mechanisms like the “enterprise-question, university-answer, government-support” tripartite model and an evaluation system prioritizing commercialization (e. g., technology turnover accounts for 30% of university assessments). Consequently, Fujian's transformation efficiency reached 2.8, significantly exceeding the national average (1.5), demonstrating how institutional redesign enables deep industry-university-research synergy.

4.3 Robustness Test: Conclusion Reliability Verification

The stability of the results is verified by two tests: ① raising the consistency thresholds to 0.85 and 0.90, with the core grouping structure unchanged and only the edge conditions slightly adjusted; ② raising the frequency threshold from 1 to 2, with the exception of grouping 3 (single case in Fujian only), the other paths remain stable. The test shows that the overall solution consistency after the adjustment still reaches 0.932, and the coverage fluctuation is less than 5%, indicating that the research findings have strong adaptability and can provide a reliable basis for policy formulation.

5 Conclusions and Recommendations: Translating Practice from Pattern Recognition to Policy Adaptation

5.1 Research Conclusion: Innovation-driven Grouping Laws and Theoretical Contributions

5.1.1 Equivalence and Heterogeneity of Three-dimensional Organizational Paths

This study identifies three equivalent innovation paths— “capital cultivation,” “result output,” and “transformation efficiency” —that achieve high economic performance. All paths share mobile internet penetration (X10) as a core condition and require baseline thresholds in R&D personnel (X1) and technology market turnover (X8), reflecting foundational human and transformation capacities. Heterogeneity arises in core drivers: the capital-heavy path emphasizes government inputs (X2, X4), the result-oriented path relies on enterprise-university outputs (X5, X6), and the transformation-efficient path depends on institutional innovation (X3, X8).

5.1.2 Policy Implications of Common Core Conditions

Government S&T expenditure (X4) and digital infrastructure (X10) form the common foundation across all high-performance paths. Empirically, top-tier provinces average 5.2% in S&T spending—2.1 percentage points higher than lower-tier peers—and over 70% mobile internet penetration. This affirms the necessity of state guidance coupled with market forces, indicating that sustained public investment and institutional environment improvement are essential prerequisites, irrespective of a region's specific innovation pathway.

5.1.3 Breakpoints and Synergies in the Innovation Chain

A single strong link—whether in input or output—is insufficient to ensure high economic performance; the "input-output-transformation" chain must achieve basic synergy. For instance, Tianjin complemented its high R&D inputs by establishing industrial research institutes with Beijing universities, overcoming transformation bottlenecks. Conversely, several central and western provinces, despite increasing R&D, lack effective transformation platforms (low X7, X8), exemplifying the "barrel effect" in regional innovation systems.

5.2 Policy Recommendations: Precision Strategies Based on Group Characteristics

5.2.1 Capital-Heavy Regions: Build a Two-Wheeled Input System of "Government Guidance + Market Activation"

Implement an “innovation foundation-building project” by establishing a provincial sci-tech mother fund, adopting a “fiscal allocation + social capital subscription” model, and introducing risk compensation. Optimize the structure of S&T expenditure by incorporating its share into local government performance assessments, creating a full-cycle evaluation system, cultivate 50 “flagship innovation enterprises” by 2028.

5.2.2 Achievement-Oriented Region: Building an Innovation Output Ecology of "University-Enterprise-Park"

Establish a “value-added transformation network” by piloting patent navigation programs in key regions to intelligently match university patents with enterprise needs, while raising PCT patent subsidies by 50%. Reform evaluation mechanisms to prioritize high-value patents and industry-cited papers, shifting from quantity to quality. Adopt Zhejiang’s “innovation enclave” model, allowing research teams to retain 70% of proceeds and offering rent-free spaces to achieve full enterprise R&D coverage by 2028.

5.2.3 Transformation of Effective Regions: Breaking Through the Institutional Obstruction of "Industry-University-Research-Utilization"

Establish a demand-driven transformation mechanism by implementing an annual "bottleneck technology" list—formulated by leading enterprises and addressing 10 strategic sectors—with a "horse-racing" R&D incentive model that awards 15% of resulting transaction value. Pilot ownership reforms allowing research teams to retain 70% of result rights and adopt mixed equity models. Develop provincial technology exchanges and financial instruments, targeting technology transformation efficiency of 3.5 by 2028.

5.2.4 Underlying Enabling Effect of Digital Infrastructure

Digital infrastructure upgrading plan: implement the “5G+Industrial Internet” full-coverage project, realize the proportion of mobile Internet users in all prefecture-level cities exceeding 80% by 2028, build more than 100 industry-level industrial Internet platforms, and promote the digital circulation of innovation factors.

Cultivation of Innovation Culture Project: Establishing the “Regional Innovation Award”, awarding teams that have made outstanding contributions to the transformation of achievements and institutional innovation, and creating a social atmosphere of “tolerating failure and encouraging transformation” through activities such as the “Innovative Entrepreneurs Forum” and the “Achievement Exhibition of Universities”.

5.3 Limitations and Future Prospects

There is still room for improvement in three aspects of this study: (1) the lack of time dimension - the existing analysis is based on cross-sectional data, and the dynamic evolution of innovation patterns can be investigated by combining the panel QCA in the future; (2) the expansion of performance dimension - only economic indicators are examined, and the subsequent study can include green innovation efficiency, the contribution of livelihood innovation, and the development of the innovation industry; and (3) the development of the innovation industry in the future. (ii) Expansion of performance dimensions - only economic indicators are examined, but subsequent studies can incorporate multi-dimensional evaluation systems such as green innovation efficiency and livelihood innovation contribution; (iii) Deepening of international comparisons - OECD countries' data can be introduced to analyze the differences in innovation patterns under different institutional environments. With the in-depth implementation of the “double-cycle” strategy, the group conformity and dynamic adjustment mechanism of regional innovation capacity will become an important research direction, providing more accurate theoretical support for China to realize high-level scientific and technological self-reliance and self-improvement.

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