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Examining Innovation Performance Enhancement in an Underdeveloped Chinese Region Using fsQCA

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Abstract. This research aims to advance regional innovation performance and stimulate economic development in Gansu Province, a less developed region in western China. Applying Regional Innovation System (RIS) theory, we employ fuzzy-set Qualitative Comparative Analysis (fsQCA) to scrutinize influencing factors. The study delineates four distinct pathways for enhancing regional innovation performance: the knowledge-driven, urbanization-led, industrial structure optimization, and comprehensive development pathways. Pioneering in its approach to unraveling complex causal relationships within RIS, this research significantly enriches pertinent studies and RIS theories tailored for relatively backward regions like Gansu. Emphasizing its contribution to academic discourse, the study provides a policy analysis framework and theoretical reference, illuminating strategies for promoting RIS construction and bolstering regional innovation capacity in underdeveloped areas such as Gansu.

Keywords: regional innovation system; RIS; regional innovation performance; promotion path; fsQCA; an underdeveloped region

1. Introduction

After the COVID-19 pandemic, an increasing number of countries and regions have come to recognize the crucial role of innovation in regional development(Ab Aziz et al., 2023; Kwon & Lee, 2023; Retkutė & Davidavičienė, 2021). There is a growing desire across the world among competing nations to establish innovative regions and cities within their country. As early as 2006, the Chinese government's vision was to construct an innovative country where functional economic spaces can co-exist (and if necessary, extend this infrastructure across borders). Hence, it made great efforts to achieve this lofty goal. Nevertheless, China's economic development has shifted from the stage of rapid growth to the stage of high-quality development, with economic growth gradually shifting from factor-driven to innovation-driven(Gao & Jin, 2021). That said, a high-level regional innovation system (RIS) was also integrated into the plan and can be defined as the guarantee of high-quality economic development nationwide. Furthermore, since RIS is an important part of the national innovation system, which can effectively improve total factor productivity and promote high-quality economic development, it should key into the existing ecosystem of innovation processes of firms, research, technology, and education establishments, as well as public institutions. As an input-output system, RIS performance refers to the ability and efficiency of the innovation system to allocate resources within the system. Besides, the performance of RIS is mainly reflected in two aspects: innovation ability and innovation performance (Zhu, 2010).

According to the Research Group on China's Science and Technology Development Strategy, regional innovation capability is the ability of a region to transform knowledge into new products, processes, and services. Moreover, it is a comprehensive evaluation based on knowledge creation, knowledge acquisition, enterprise technology innovation, innovation environment, and management, as well as innovation economic benefits. Taken together, innovation performance refers to the innovation achievements made by economic entities through the effective development and allocation of various resources — based on their innovation ability (Zhu, 2010). In recent years, the relationship between regional innovation systems and regional innovation performance, as well as relevant influencing factors and improvement paths have increasingly become the focus of contemporary research. Quite recently, the report of the 19th National Congress of the Communist Party of China pointed out that China's economy has shifted from a stage of rapid growth to a stage of high-quality development. In this context, exploring the improvement path of regional innovation performance in RIS has become the key to promoting high-quality economic development. In addition, the obvious regional diversity in China makes the ensuing RIS rich and diverse, despite Chinese regional innovation performance being significantly unbalanced (Zhang, 2019). According to the China Regional Innovation Capacity Assessment Report 2020, which analyzed the innovation capacity of 31 provinces in 2018 (i.e., comprising autonomous regions and municipalities directly under the central government), it was observed that Gansu Province has dropped to 27th in the innovation ranking across China.

Contemporaneously, Wang and Tang (2020) conducted a dynamic evaluation of China's RIS based on panel data that were obtained from 31 provinces between the periods 2009 to 2017 using a two-dimensional analysis framework of "structure-function". He found that the structural performance of the RIS in the western region was high, however, its growth trend was slow and gradual. In contrast, Du and Li (2021) argue that Gansu Province exhibited certain strengths in science and technology innovation development in the comprehensive level index of science and technology innovation evaluation from 2015 to 2018, where it ranked 18th in China. Interestingly, this indicates that Gansu Province has greater potential in science and technology innovation capacity. On top of that, the Outline of the 14th Five-Year Plan and the 2035 Vision for National Economic and Social Development of Gansu Province reveals the region's plan to adhere to innovation as the first driving force not just leading development, but also accelerating the construction of an innovative province. Consequently, it is expected that Gansu Province can be transformed into a new highland of innovation-driven development in the western region of China.

Although there are shortcomings in the regional innovation performance of Gansu Province, it offers tremendous potential for improvement. Nevertheless, improving regional innovation performance has not attracted extensive attention from scholars. This informs an investigation in this field of study, as exemplified in this research. As an important province in western China, Gansu Province has a strategic impact on the national economic development pattern, which has not been well-studied. This research, therefore, attempts to explore how to effectively improve the level of regional innovation performance in Gansu Province, as well as enhance the rate of economic development in the province. However, to the best of the researcher's knowledge, there exists a gap in the current literature stream to analyze the improvement path of regional innovation performance in Gansu Province. To this end, this study relies on regional innovation system theory to develop a framework for RIS, as well as applies fuzzy-set Qualitative Comparative Analysis (fsQCA) to explore the configuration of multiple influencing factors, and to distinguish between core and peripheral conditions — using a histotypic perspective i.e. multi-dimensional paths. Likewise, fsQCA was used to summarize multiple effective paths to enhance regional innovation performance, and then, provide policy recommendations to enhance the level of regional innovation performance in Gansu Province.

2. Literature Review

Innovation performance is concerned with the innovation achievements made by various economic entities through the effective development and allocation of resources — based on their innovation ability (Zhu, 2010). Hence, the improvement of regional innovation performance is an important research area in the field of RIS. After conducting a thorough literature review on RIS both locally and internationally in the specialized area of regional innovation capability improvement, the extant literature streams which were enumerated by various scholars can be categorized into four main dimensions. This is outlined in the following section.

2.1. Influencing Factors in terms of the Innovation Foundation

The contemporary international literature highlights entrepreneurial resources and innovation capability as key elements of value creation, competitiveness and sustainability in knowledge-based economies and the digital era (Taleb et al., 2023). Innovation base input is an important factor influencing regional innovation. Unsurprisingly, Su and Li (2021) observed that the intensity of cooperation among subjects in regional innovation systems is beneficial to regional innovation performance, and can strengthen the knowledge absorption capacity among subjects. Similarly, knowledge absorption capacity contributes to the improvement of regional innovation performance. This is because knowledge absorption capacity plays a mediating and bridging role, while energy structure plays a positive moderating role, and conversely, technology dependency plays a negative moderating role towards the improvement of regional innovation performance. That is why Zhao (2021), carried out an in-depth analysis of the factors influencing collaborative innovation in Beijing, Tianjin and Hebei, and found that investment in research personnel and funding had a significant positive impact on the collaborative innovation performance of neighboring cities.

2.2. Influencing Factors in the Innovation Environment

The European Innovation Research Group (EIRG) considers the regional innovation environment as an informal and complex social relationship that exists between key actors in the region, which is accentuated through collaboration and joint learning (Breschi, 2000). While Zhao et al. (2020), argue that the innovation environment also includes infrastructure, institutional environment, international environment, as well as other factors. Whereas industrial restructuring had a significant effect on innovation performance, this effect was heterogeneous across regions with ingrained spatial spillover effects (Han & Kong, 2021). Intriguingly, Li et al. (2021) also pointed out that the rapid development of the global digital economy can contribute significantly to regional innovation performance levels in China. Timely interventions in the digital economy can also lead to an indirect improvement in regional

innovation performance, as well as accelerate the accumulation of human capital and investment in R&D capital.

2.3. Influencing Factors in Government-Industry-University-Research Linkages

Regional innovation relies on the synergy between government, business and universities. In his seminal paper, Leydesdorff (2003) constructed a triple helix innovation system of universities, firms, and government. Based on observed literature gaps, Xue (2021) studied the factors and mechanisms influencing the regional innovation system in Guangdong Province. Expectedly, it was observed that investments in education, and, science and technology can directly improve the innovation capacity of universities, as well as other research institutions. This improves the innovation environment and ultimately fosters more innovative talents and innovation units too. According to Zhou and Duan (2013), the macroeconomic and industrial structure have a highly positive impact on regional innovation performance, as well as a highly positive correlation with the regional innovation environment in China.

2.4. International Technology Spillovers

Communication and technology development plays an important role in RIS since it does not operate in isolation like other closed systems. According to Zhang (2015), the contribution of international trade development to regional innovation performance is indirect and time-lagged, with the ensuing effect taking some time to emerge. Likewise, Wang (2018) studied the impact of regional innovation performance on export trade volume using regional panel data of 30 provinces and cities in mainland China (excluding Tibet) from 2010 to 2016, and found that there was indeed a significant positive correlation between regional innovation performance and export trade volume. In fact, a 0.549% increase in the log value of export trade volumes accounted for every 1% increase in the log value of innovation performance in China. Simultaneously, to mitigate high risks, Burinskienė and Leonavičienė (2022) suggests that international enterprises can opt for different market entry strategies or increase the concentration of departments in foreign markets where the company is already operating.

Given that the abovementioned studies focused on different aspects of the mechanisms of regional innovation performance, laying a solid foundation for new theoretical insights and empirical research on regional innovation performance. Some studies have also analyzed the impact of multiple factors, such as, Tang and Zhang (2019) who noted that transport infrastructure needs to work in conjunction with foreign direct investment, human capital, innovation inputs, R&D activities, and institutional innovation to facilitate regional innovation performance. Correspondingly, Liu and Wang (2020) focused on the role of infrastructure development, market-based positive incentives for innovation factors, household registration systems and government subsidies on regional innovation capacity. While, Peng and Hou (2020) innovatively used the QCA method to explore the condition grouping and paths that affect the improvement of regional innovation capacity. In the same vein, Wang and Wang (2017) studied the spatial spillover effects of fiscal expenditures on regional innovation. However, significantly Zhu et al. (2021) applied the QCA method to study the grouping of high (and non-high) regional innovation levels, the temporal evolution of grouping solutions and spatial contextual differences and analyzed the development patterns and paths of regional innovation. Moreover, based on this technique, their study was able to analyze the development patterns and paths of regional innovation.

The current research has achieved important research results. It has underscored the foundational nature of innovation bases, elucidated the complexity of innovation environments from institutional and international perspectives, emphasized the pivotal role of collaboration among government, industry, and university, and highlighted the substantial impact of international technology spillovers on innovation performance. Nevertheless, these studies exhibit certain limitations. Firstly, there is a lack of comprehensive research on key factors and enhancing innovation performance under different conditions. Only through cross-regional comparative research can we fully comprehend its complexity.

Lastly, At present, research on regional innovation systems in China mainly focuses on developed regions(Liu et al., 2023; Wang et al., 2022; Wu & Tu, 2022; Xiong & Song, 2021), Despite the significant attention of international scholars on innovation research in developing countries(Taleb & Pheniqi, 2023), studies specifically targeting the underdeveloped regions of China remain insufficient.

Zhao and Zhang (2020) conducted a strategic comparative analysis of innovation capabilities between developed and underdeveloped regions based on four dimensions: entrepreneurial capability, knowledge learning capability, innovation environment, and network capability. They proposed a strategy of precise support to enhance regional innovation capabilities by highlighting distinctive features and simultaneous advancement. Jiao et al. (2020) evaluated rural innovation capabilities in underdeveloped areas using Gansu Province's 86 county-level administrative units as an example but overlooked crucial cities like Lanzhou. Therefore, this study builds upon existing research outcomes, focusing on Gansu Province as a case study, concentrating on underdeveloped areas, and employing the fsQCA method to conduct a more in-depth and comprehensive analysis of the pathways to enhance innovation performance in these regions. Through the fsQCA method, we can comprehensively and dynamically analyze key factors of the innovation system, providing a more profound perspective for understanding the pathways to improve regional innovation performance, especially through empirical research in different regional contexts.

Based on the abovementioned literature review findings and methodology, it was observed that the following limitations exist in the current research:

(1) In the analysis of the pathways to enhance innovation performance, we acknowledge the profound complexity encountered in previous literature. In reality, a prevailing inclination exists towards interpreting regional innovation performance through the lens of a solitary influencing factor. However, this inclination oversimplifies the intricate nature of the factors influencing regional innovation performance. It is implausible to propose an optimal approach to enhance regional innovation performance solely from the perspective of a single factor. The intricacy arises from the acknowledgment that innovation is not constrained solely by a singular factor but is a result of the mutual influence and interaction of multiple factors.

(2) Regional inequality persists in innovation capacity across China. However, research on performance enhancement paths tailored to less-developed regions is lacking. Simultaneously, we have identified a research gap in this domain, signifying not only a sidestepping of complexity but also a neglect of innovation performance issues in underdeveloped regions. Current research tends to concentrate its focus on areas with relatively high levels of innovation, with a limited understanding of regions characterized by lower innovation levels, particularly in the Northwestern part of China. This inclination in research may partially stem from a heightened interest in regions with high innovation levels, but it also exposes the risks associated with neglecting potential innovation opportunities.

In the Northwestern region of China, especially in Gansu Province, we observe an area that remains largely unexplored in the realm of research. The economic, social, and geographical characteristics of this region have given rise to a distinctive innovation ecosystem, deserving in-depth exploration due to its complexity and diversity. Prior studies primarily utilized population samples from larger provinces, further constraining our understanding of the specific circumstances in Gansu Province. Therefore, there is an urgent need for targeted research in this region, as it could reveal innovative pathways that were previously overlooked in regions with high innovation levels.

Consequently, we recognize unique opportunities within this research gap, which can be seized by delving into the study of Gansu Province as a typical representation of an underdeveloped region. Such in-depth exploration will enhance our comprehension of the pathways to improve innovation performance. This endeavor not only addresses prior research shortcomings but also contributes a more comprehensive and enriched perspective to innovation theory and practice.

To address the above limitations, this paper endeavors to introduce the fsQCA method, aiming to

explore the path of improving regional innovation performance in less developed regions across China. It takes the Regional Innovation System (RIS) as the research framework and combines it with the provincial situation of Gansu Province, holding crucial theoretical and practical implications for constructing RIS and implementing an optimized regional innovation policy. These critical points are elucidated in the rational, targeted, and specific research framework shown in Figure 1. This conceptual framework will revolve around innovation base, innovation environment, government-industry-university-research linkages, and international technology spillovers. Specifically, our focus will be on the interplay of these factors within the innovation system of underdeveloped regions, placing particular emphasis on the dynamic equilibrium of innovation bases and the connections between government, industry, academia, and research in environments characterized by relative resource scarcity and technological lag. This conceptual framework not only deepens our understanding of the operational mechanisms of innovation systems but also establishes a theoretical and empirical foundation for referencing the innovation trajectories in underdeveloped regions.

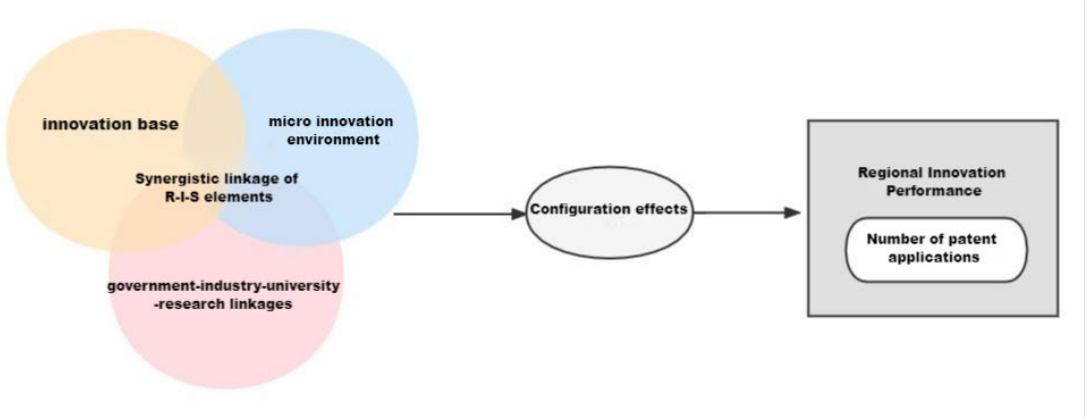

Fig. 1: Conceptual Framework

3. Research Methodology

3.1. Research Methodology

In recent years, QCA methods have been adopted by numerous scholars, and are now being applied across disciplines such as management, economics, and sociology. It is based on the ideas of set theory and the application of Boolean algebra to achieve comparative analysis between multiple cases, fully integrating the advantages of case-oriented qualitative methods, and variable-oriented quantitative methods (Rihoux & Ragin, 2008). In addition, the QCA method is mainly divided into the fuzzy set qualitative comparative analysis (i.e., fsQCA), clear set qualitative comparative analysis (i.e., csQCA), and multi-valued set qualitative comparative analysis (i.e., mvQCA). The fsQCA method is applied during the analysis procedure because it is an effective method for exploring 'joint effects' and 'interactions'. Comparatively, the QCA method considers a series of combinations of antecedent and outcome variables. By studying the effect of different combinations of antecedent variables on the outcome variables, the joint effect of the combination of antecedent and outcome variables can be accurately measured, thus explaining the improvement path of regional innovation performance.

3.2. Variable Design

Sun (2015) analyzed the influence of innovation systems on different stages of innovation activities — based on the extended Furman (2002) framework, from the following four aspects: (1) innovation base, (2) micro-innovation environment, (3) government-industry-university-research linkage, and (4) international technology spillover. Consequently, in this study, the dependent variables were selected to explore the path of regional innovation performance improvement from a histological perspective, as shown in Table 1.

Table 1. Variable Design for Regional Innovation Performance Improvement.

Type	Name	Measure	Proxy
Outcome variable	Regional innovation performance	Regional patent applications	Patent
Anteceden t variables	Knowledge stock	GDP per capita	Knowledge
	R&D funding intensity	R&D expenditure	Money
	R&D human investment intensity	Full-time Equivalent of R&D Personnel	Human
	Regional industrial structure	Industrial value added as a share of regional GDP	Industry
	Level of infrastructure development	Road mileage as a proportion of land area	Facilities
	Urbanization rate	Share of the urban population in total population	City
	Government's emphasis on education	Government investment in education as a proportion of general public budget expenditure	Education
	Government's emphasis on science and technology	Government investment in science and technology as a proportion of general public budget expenditure	Science

3.2.1. Outcome Variables

Regional innovation performance: Regional innovation performance has been measured from the perspective of innovation output, which is divided into intermediate output and final output. Furthermore, intermediate output includes the number of patent applications and patents granted, while final output includes the output value of new products, new product sales revenue, and technology contract turnover (Chen et al., 2010). Prior studies have selected patent data such as the number of patents granted, the number of patents received and the number of patent applications in each region as indicators to measure regional innovation performance. However, for the sake of data availability and accuracy, this paper uses the number of patent applications in each region as the main indicator to measure regional innovation performance, as well as reflect the level of regional innovation in China.

3.2.2. Antecedent Variables

(1) Innovation foundation: When measuring regional innovation performance, it has been observed that it cannot be separated from the necessary basic inputs, such as R&D personnel input, R&D capital input and regional knowledge stock. Besides, economic growth theory considers that the two key variables affecting innovation output are R&D personnel input and R&D capital input. In terms of R&D personnel input, scholars often use two indicators: the number of R&D personnel and the full-time equivalent of R&D personnel. Nevertheless, the full-time equivalent of R&D personnel can better reflect the actual labor input of R&D personnel (Liu et al., 2015). In accordance with R&D expenditure literature, this paper selects R&D expenditure to characterize the R&D expenditure in the province. At the same time, this paper draws on Furman et al. (2002) to introduce GDP per capita as an important indicator of regional knowledge stock. It has been widely established in contemporary literature that the GDP per capita reflects a region's ability to translate its knowledge stock into a realized state of economic development, despite being a common indicator of regional knowledge stock (Chen et al., 2013).

(2) Micro-innovation environment: The regional innovation environment refers to the factors that guarantee the promotion of regional innovation activities, as well as improve regional innovation performance. In addition, the micro-innovation environment encompasses the institutional environment, the economic environment, and the socio-cultural environment (Wang et al., 2019). While, Hou et al.

(2014) argue that the sociocultural environment is difficult to quantify, therefore the institutional environment and economic environment are more suitable for studying the impact of regional innovation capacity. Considering the availability of data, this paper uses regional entrepreneurship structure, infrastructure development levels and urbanization rate to measure the micro-innovation environment in the province.

(3) Government-industry-university-research linkage: The linkage between government, industry, university and research has a significant impact on innovation performance. Several scholars often reflect this linkage between industry, university, and research by the proportion of enterprise capital in the internal expenditure of R&D funds of universities (Li & Zhu, 2007). Likewise, the government's influence on regional innovation performance is mainly reflected in the degree of attention and support to the education, science, and technology sectors of the economy (Meng & Wang, 2013). Since most of the higher education schools in Gansu are located in Lanzhou city (which has 30 schools), while the rest of the cities have only one higher education school (except Tianshui city which has four schools), this paper uses the ratio of government investment in education and, science and technology to general budget expenditure to measure the link between government, industry, academia, and research.

3.3. Descriptive Statistics of Variables

In this paper, the sample area of the study comprises the 14 municipalities and states in Gansu Province. The 14 cities and prefectures in Gansu Province are representative in terms of geographical location, economic development, and innovation status. This representativeness is crucial for a comprehensive understanding of innovation performance in underdeveloped regions. The sample encompasses diverse types of urban and prefectural areas, spanning from relatively developed cities to comparatively underdeveloped regions. This diversity aids in capturing variations in innovation performance across different economic environments. The selection of these cities and prefectures also takes into account data accessibility. Ensuring the collection of sufficient and reliable data is integral to ensuring the effectiveness of the study. The sample choice considers maintaining representativeness while ensuring that the sample size is adequate to support in-depth exploration of the research questions. Through statistical analysis, we ensure that the sample size is sufficient to support the reliability of research conclusions. Considering these factors comprehensively, the choice of the 14 cities and prefectures in Gansu Province as the sample region aims to render the study more representative, comprehensive, and capable of providing an in-depth understanding of the factors influencing innovation performance in underdeveloped regions. Furthermore, the datasets of the variables were obtained from the Gansu Development Yearbook 2019 (i.e., based on 2018 data), the Statistical Yearbook of the 14 cities and states in Gansu Province (i.e., based on 2018 data) as well as the publicly available data from the official websites of the 14 cities and states in Gansu Province, as well as the data provided by relevant departments. Over and above that the sample data were assigned values through the measurement method specified in Table 1, in which four variables, namely industry, facilities, education, and science needed to be calculated indirectly from the datasets, while the remaining five datasets were queried directly. Going further, the descriptive statistics of variables (i.e., the mean, standard deviation, minimum and maximum values) of the sample dataset from the 14 cities and states in Gansu Province were measured using fsQCA software, as shown in Table 2. Based on the statistical result computation, the maximum value of regional innovation performance is very high, while the minimum value was low. This indicates that there are large differences in the innovation performance of different cities and states. To a large extent, the influencing factors, which comprises eight (8) variables are discrete. This indicates that there are very large differences between various regions, which makes it necessary to propose specific paths to enhance regional innovation performance in response to the heterogenous attributes of provinces across China.

Table 2. Descriptive Statistics of Variables

Variable	Mean	Std. Dev.	Minimum	Maximum
Knowledge	37205.21	28706.08	12447	119418
Money	69324.07	129508.3	1264	523714
Human	1586.643	3172.568	83	12862
Industry	0.2316429	0.1446489	0.1046	0.5737
Facilities	0.4933214	0.2458405	0.1048	0.9411
City	0.50705	0.1816305	0.34	0.9365
Education	0.1672357	0.0251369	0.1228	0.2114
Science	0.004128571	0.002626086	0.0013	0.013
Patent	1978	2603.027	208	10708

3.4. Data Calibration

Variable calibration is a prerequisite for qualitative comparative analysis of fuzzy sets, therefore data calibration was performed via the conversion of the raw values of each variable to its degree of affiliation in the set. In this paper, the antecedent and outcome variables were calibrated using the direct calibration method, where a fully affiliated point indicates a value where the case is fully affiliated with the target set. Also, a crossover point indicates a value where the case is neither in the target nor in the non-target set. While a fully unaffiliated point indicates a value where the case is not affiliated with the target set. On top of that, the calibration anchors for the antecedent and outcome variables (i.e., full membership, cross-over point, and full non-membership) were set at the upper quartile (i.e., 75%), median, and lower quartile (i.e., 25%) of the sample data, respectively, which is consistent with previous studies. The calibration anchors are shown in Table 3.

Table 3. Calibration Anchor Points for Variables

Variables	Fully affiliated points (affiliation = 0.75)	Crossover point (affiliation = 0.5)	Fully unaffiliated points (affiliation = 0.25)
Knowledge	48058.5	27616.5	18876.75
Money	59785.25	33544.5	6007.25
Human	1213	700.5	321
Industry	0.287075	0.1711	0.119275
Facilities	0.614075	0.5254	0.301375
City	0.58795	0.4198	0.36615
Education	0.18975	0.1662	0.15235
Science	0.004175	0.0038	0.003
Patent	1652.5	1073	759

4. Results and Discussion

4.1. Result Analysis

Necessity Analysis

Fuzzy set qualitative comparative analysis requires testing the necessity of individual variables before conducting conditional grouping analysis. This is because it is essential to measure the extent to which a single conditional variable explains the outcome variable. In fsQCA, if a condition is present when the outcome occurs, then that condition is necessary for the outcome (Rihoux & Ragin, 2008). Besides, the variable is considered necessary for the outcome to occur when the consistency score is greater than 0.9. The use of the fsQCA 3.0 statistical software made it possible to accurately analyze the consistency of the variables. The results of the analysis are shown in Table 4.

Table 4. Analysis of Necessary Conditions

	Consistency	Coverage
Knowledge	0.614138	0.646512
~Knowledge	0.453608	0.407947
Money	0.748159	0.719547
~Money	0.332842	0.325648
Human	0.918999	0.925816
~Human	0.212077	0.198347
Industry	0.637703	0.647235
~Industry	0.427099	0.396717
Facilities	0.511046	0.479282
~Facilities	0.562592	0.565089
City	0.718704	0.690240
~City	0.381443	0.373737
Education	0.565537	0.577444
~Education	0.488954	0.451701
Science	0.658321	0.654465
~Science	0.438881	0.415621

Note: "~" indicates that the condition is absent.

From the consistency results in Table 4, the consistency of the variable R&D human input intensity (represented by the proxy Human) exceeds the threshold level of 0.9 and constitutes a necessary condition for regional innovation performance. This indicates that the improvement of regional innovation performance depends on R&D human input intensity. Correspondingly, the variable denoting R&D human input intensity had a consistency level of above 0.9, which surpasses the threshold level of consistency. However, seven (7) variables did not meet the necessary conditions for the improvement of regional innovation performance, thus, these variables could not adequately explain the outcome variable alone. It was therefore considered necessary to conduct a group analysis of these variables in the subsequent study.

Histogram Analysis

To identify effective paths to improve regional innovation performance, it was considered necessary to conduct a histogram analysis of variables that did not meet the necessary conditions. Before conducting the histomorphic analysis, a fuzzy set truth table was constructed. As suggested by Rihoux and Ragin (2008), a consistency threshold of 0.8 and a case threshold of 1 were used to construct the fuzzy truth table. Standard Analysis of the truth table was carried out using fsQCA 3.0 statistical

software. Congruently, three types of results were obtained: complex solution, parsimonious solution, and intermediate solution. Referring to Fiss (2011), the intermediate solution is taken as the result of the analysis. However, the conditions that appear in both the intermediate solution and the parsimonious solution are defined as the "core condition", while the conditions that appear only in the intermediate solution but not in the parsimonious solution are defined as the "peripheral condition". As shown in Table 5, the fsQCA analysis yielded five paths to improve regional innovation performance in the Gansu Province of China. The overall consistency in the group analysis indicated the degree that the conditioned group explains the outcome variable, while the overall coverage is used to indicate the number of cases that the condition variable can explain (Zhang & Du, 2019). Coincidentally, the consistency index of all five (5) histories in this study were higher than 0.9, indicating that these five histories were sufficient conditions to enhance regional innovation performance. Similarly, the consistency index of the overall solution was 0.992788, further indicating that these five histories sufficiently enhanced regional innovation performance too. Nevertheless, the coverage of the solution was 0.608247. This implied that these 5 histories explain about 61% of the enhanced regional innovation performance. Consequently, Table 5 symbolically presents each of the groupings that enhance regional innovation performance in detail below.

Table 5. Grouping of Regional Innovation Performance

Antecedent conditions	Intermediate solutions				
	Configuration1	Configuration2	Configuration3	Configuration4	Configuration5
Knowledge	●	⊗	⊗	●	●
Money	⊗	●	⊗	●	●
Industry	⊗	●	●	⊗	●
Facilities	⊗	⊗	⊗	⊗	●
City	●	●	⊗	●	●
Education	⊗	⊗	●	⊗	●
Science	⊗	⊗	●	●	●
Consistency	0.983871	0.968421	1	1	1
Original coverage	0.089838	0.135493	0.126657	0.131075	0.278351
Unique coverage	0.0427099	0.100147	0.0883653	0.0824743	0.232695
Consistency of the overall solution	0.992788				
Overall solution coverage	0.608247				

Note:●=core condition, ●=auxiliary condition, □=core condition absent, □=auxiliary condition absent

Based on the core conditions of the five (5) groupings and the explanatory logic of the cases behind them, this study identified four (4) paths to enhance regional innovation performance in the Gansu Province of China, which are as follows: the knowledge-driven path, the urbanization-led path, the industrial structure optimization path, and the comprehensive development path. These critical paths are explained below in relation to the relevant theories and corresponding cases in this study.

(1) Knowledge-driven path.

Global growth, which is built on the three pillars of economic, social, and environmental sustainability, depends on knowledge economies emerging. (Estevão et al., 2022). In configuration 1, the knowledge stock is the core element, while the urbanization rate is the supporting condition. The

results reveal that a city with a high knowledge stock and low industrial value added as a percentage of GDP can still achieve high regional innovation performance when it has low R&D investment, low infrastructure development, as well as a low government emphasis and support for education, science, and technology, complemented by a high urbanization rate. This path explained about 8.9% of the urban cases, while 4.2% of the cases can be explained by only this path. A typical case of this path is Jiuquan. Interestingly, in 2018 Jiuquan achieved a per capita gross regional product of 8016 USD (based on the 2018 average exchange rate), which is an increase of 4.2% (Gansu Development Yearbook, 2019). Impressively, the urbanization rate of Jiuquan's resident population area exceeded 60% for the first time in 2017, which is 13.88 percentage points higher than the average for Gansu Province in China (Liu, 2018). Consistent with prior studies, the Jiuquan region exploited its strong ability to translate its readily available knowledge base into a stimulant that enhances the state of economic development in the region. This is therefore a good case study of how to develop the economy, as well as improve innovation performance in relatively backward regions. This pathway, by emphasizing the significance of knowledge accumulation and urbanization rate, can stimulate innovation and economic development even when other conditions are relatively low, providing a viable trajectory for underdeveloped regions.

(2) Urbanization-led path.

A. In configuration 2, the urbanization rate is the core condition, while the regional industrial structure and R&D investment intensity are the marginal conditions. The diagrammatic representation of the histogram suggests that for cities with low levels of knowledge stock (i.e., GDP per capita), infrastructure development, and government emphasis and support for education, science and technology, but high regional industrial structure and R&D funding intensity, higher regional innovation performance can be generated if the city’s potential is strengthened. That said, 13.5% of city cases can be explained by this histogram path, of which 10% of the cases can be explained by only this path. Nevertheless, the typical case of this path is Baiyin. In recent years, Baiyin has accelerated urban and rural construction, improved urban infrastructure, as well as improved the urban ecological environment. At the same time, given that the Baiyin municipal government recognizes that innovation is an important driving force in leading economic development, it is actively building the Lanbai National Independent Innovation Demonstration Zone, and also actively enhancing regional innovation. In addition, the city is strategically enhancing regional economic development through such paths as collaborative development between industry, academia, and research. Thus, increasing their chances of success via adherence to the path of talent, which is supported by a talent guarantee mechanism. The urbanization rate is a core condition, and even when other conditions are relatively low, achieving high innovation performance is still possible by enhancing urban potential. This discovery highlights the crucial role of urbanization in enhancing innovation performance, emphasizing the importance of effectively guiding urban development potential during the process of urbanization to drive innovation.

B. In configuration 4, urbanization rate is the core condition, and knowledge stock, R&D investment intensity, and the level of government attention and support for science and technology are the marginal conditions. This grouping suggests that a city with a high urbanization rate, coupled with a high stock of knowledge, R&D investment intensity, and government emphasis and support for science and technology, can generate high regional innovation performance, even if the regional industrial structure, level of infrastructure development, and government emphasis and support for education is low. This path was responsible for 13.1% of the city cases, of which 8.2% could only be explained by this path. Furthermore, the typical case under this path is Zhangye. In 2017, the urbanization rate of Zhangye City was 45.76%, an increase of 1.83 percentage points over 2016, and in 2018, the urbanization rate reached 47.55%, which is an increase of 1.79 percentage points over 2017, with both years increasing at the top of the bureau in the province (Zhangye Finance Bureau, 2019). Similarly, the leading industry in Zhangye is tourism. While vigorously developing traditional tourism, Zhangye has made efforts to build an outdoor sports experience area and an international camping base, which was named one of the "Top 10 Destinations for Sports Tourism in China". Hence, based on their

outstanding record of achievement and performance, the city has been able to achieve good results. In the future, Zhangye City insists on implementing an innovation-driven development strategy, and also makes every effort to promote scientific and technological innovation, with the number of patent applications, authorizations, the development of high-tech enterprises, and other key tasks ranking among the top in the province (Zhangye Finance Bureau, 2019). A high urbanization rate, coupled with high knowledge reserves, research and development investments, and government attention, can yield high innovation performance even when other conditions are relatively low. The significance of this sub-pathway lies in highlighting how knowledge reserves and government support interact with urbanization during the process, collectively driving innovation.

(3) Industrial structure optimization path.

Configuration 3 indicates that in cities with a high level of government attention and support for education, science, and technology, even with a low level of knowledge stock, R&D funding intensity, infrastructure development, and urbanization rate, high regional innovation performance can still be realized if the government pays attention to the optimization of the regional industrial structure. This path was described for 12.6% of the city cases, of which 8.8% of cases can be explained by only this path. Over time, Qingyang City has been gradually optimizing its industrial structure. This began after the founding of New China 70 years ago. Consequently, the city's development has been able to trigger a directional shift from the traditional model of predominantly primary industries to predominantly secondary and tertiary industries, with the share of primary industries decreasing from 90.7% in 1949 to 10% in 2018. Conversely, the share of secondary and tertiary industries has increased from 9.3% in 1949 to 90% in 2018 with the secondary industry accounting for about 50.2% of the total. In the energy development sector of the economy, Qingyang upholds the concept of green development, despite accelerating the creation of two 100-billion circular economy chains for the oil and coal industry (Gansu, 2019). The government of Qingyang attaches great importance to the development of education and, science and technology, which has led to the attainment of encouraging results so far. In a scenario characterized by high government attention to education, science, and technology, high innovation performance can be achieved through the optimization of industrial structure, even when other conditions are relatively low. This pathway underscores the importance of government-guided optimization of industrial structure in enhancing innovation performance, providing policymakers with a robust basis for decision-making.

(4) Comprehensive development path.

In configuration 5, a reasonable regional industrial structure and a high level of government attention and support for education, science, and technology are the core conditions, while the rest are auxiliary conditions. This pathway suggests that, under the premise of a reasonable regional industrial structure and high government emphasis and support for education, science and technology, high knowledge stock, R&D funding, and human investment intensity, a high level of infrastructure development and high urbanization rate would lead to high-level regional innovation performance. Besides, this path explains 27.8% of the city cases, while 23.2% of cases can be explained by only this path — with the highest unique coverage rate of all paths. Quite remarkably, Lanzhou City belongs to this development path, where it has achieved good results in regional innovation in 2018. Given that Lanzhou is the capital city of Gansu Province, it has more resources than other municipalities in the province, as well as more innovation investment, deeper cooperation between industry, academia, and research, and a superior innovation environment. On top of that, after the establishment of the Lanbai (Lanzhou-Baiyin) Self-Innovation Zone, which gained the Central government's approval, the regional innovation performance of Lanzhou City has improved significantly. A rational regional industrial structure and high government attention to education, science, and technology, combined with elevated knowledge reserves, research and development funding, talent investment, and advanced infrastructure development along with a high level of urbanization, can achieve a high level of innovation performance.

This comprehensive development pathway provides cities with a holistic developmental framework, encompassing various facets such as industrial structure, government support, knowledge reserves, among others. This is crucial for formulating long-term development plans, enabling cities to achieve balanced development on multiple fronts.

Robustness Tests

Due to the fact that different coding techniques can have an impact on the ensuing results analysis, this study conducted a robustness test on the first analysis results in order to improve the reliability of the study. Drawing on the methodology of Zhang and Du (2019), this study applied consistency level adjustments to conduct the robustness test (i.e., by increasing the consistency level from 0.8 to 0.9). The results revealed that the findings of this study were robust.

4.2. Discussion and Implications

Practical and Managerial Implications

The following policy implications were uncovered in an attempt to find a path to improve regional innovation performance under the framework of regional innovation systems in Gansu Province in China:

Raise the level of urbanization. For less developed regions in Gansu Province, low urbanization level is still an important factor impacting both economic and social development. Therefore, the government should re-strategize, and firmly champion urbanization construction, as well as establish a sound mechanism for integrated urban-rural development, improve the urban system, and also support sound urban functions in Gansu Province.

Improve the industrial structure. The industrial structure of Gansu Province varies greatly from city to city and across states. Hence, there is a dire need to give considerable attention to regional advantages, develop regional characteristic development paths, as well as ensure that the rationalization of the industrial structure of the Province is prioritized. This is considered important because it enhances regional economic capabilities, and also narrows the gap in regional innovation levels between developed and less-developed regions in Gansu Province.

Theoretical Implications

Previous studies on the enhancement of regional innovation capacity have mainly been conducted from a single-factor or multi-factor perspective, and have not explored multiple concurrent causality in complex matters. fsQCA methodology emphasises multiple concurrent, asymmetric causality, providing a new approach to identify complex causal relationships in the enhancement of regional innovation capacity in RIS.

This study is the first to analyse the multiple pathways of regional innovation capacity enhancement in Gansu, a relatively backward region of China, unveiling the "black box" of multiple pathways of regional innovation capacity enhancement and overcoming the shortcomings of previous studies from the perspective of a single variable. On the one hand, it enriches and improves the research and RIS theory on the enhancement of regional innovation capacity in relatively backward regions, and on the other hand, it provides a policy analysis framework and theoretical reference for promoting RIS construction and enhancing regional innovation capacity from the perspective of RIS in relatively backward regions.

Economic and Social Implications

Regional innovation capacity has a significant regional economic growth effect. Regional innovation capacity not only has an impact on the economic growth of the region, but also on the economic growth of its surrounding areas (Li, 2012). As economic growth is increasingly dependent on the ability to innovate in science and technology, relatively backward regions should focus on strategies that are tailored to local conditions, increase investment in R&D in backward regions, improve

urbanisation levels and optimise industrial structures, so as to improve their regional innovation capacity in general.

Since the reform and opening up, China's economic development has shown a highly imbalanced trend. The economic development of the western region has obvious disadvantages. However, in today's world, innovation has become an important factor in promoting economic and social progress. RIS theory not only provides a theoretical basis and method for achieving social development, but also provides an important grip for government management. It is necessary to conduct in-depth research on the improvement of regional innovation capabilities from the RIS perspective in relatively backward regions, It is of great significance for promoting the overall economic and social progress of relatively backward regions.

This study unveils a perspective distinct from previous research, asserting that the enhancement of innovation performance in relatively backward regions is not confined to a singular path but can be achieved through diverse avenues. This offers a novel viewpoint compared to literature predominantly examining the subject from either a single-factor or multi-factor perspective. Moreover, the study emphasizes core conditions across multiple configurations, such as knowledge-driven, urbanization-led, and industrial structure optimization, providing a more comprehensive framework for understanding the formation of regional innovation capabilities. Furthermore, this research adopts a more nuanced and comprehensive perspective by employing the fsQCA method to intricately analyze the pathways for improving innovation performance in underdeveloped regions. This addresses the shortcomings of prior studies in scrutinizing innovation paths in disadvantaged areas, resulting in more specific and practical strategic recommendations for underdeveloped regions. By focusing on the entire Gansu Province, this study overcomes the limitations in regional selection observed in previous research, thereby enhancing the universality and practicality of the study.

In the analysis of pathways to enhance regional innovation performance in Gansu Province, this study reveals distinct developmental trajectories, providing crucial insights for formulating practical policies and investment objectives. Firstly, for the knowledge-driven path, it is recommended to concentrate resources to bolster knowledge reserves and promote innovation capabilities. This involves fostering research and development, supporting education, and creating an environment conducive to the development of knowledge-based industries. Specific measures may include establishing special funds to incentivize research projects, increasing remuneration for research personnel, and constructing innovative science and technology parks.

Secondly, the urbanization-led path emphasizes growth driven by urbanization, with a focus on investing in urban infrastructure, urban development potential, and industrial structure upgrading. Strategies include attracting talent and promoting innovation. In practice, governments can formulate urban planning policies, increase investments in urban infrastructure development, and encourage high-tech enterprises to establish a presence in urban areas.

The industrial structure optimization path centers on optimizing the industrial structure through green development. It advocates for government-guided evolution of industries toward higher value-added sectors while providing financial incentives and collaboration opportunities. To achieve this goal, policies such as tax reductions, the establishment of a green industry fund, and the promotion of green collaboration among enterprises can be implemented.

Finally, the comprehensive development path suggests comprehensive investment in knowledge creation, research and development, and infrastructure. It aims to ensure a balanced industrial structure and achieve all-encompassing improvement in innovation performance through promoting collaboration and implementing long-term urban planning strategies. Governments can increase investments in research institutions and businesses, encourage collaboration between academia and industry, and guide urban planning to ensure coordinated development of infrastructure and industrial layout.

These practical recommendations are tailored to the specific characteristics and requirements of each pathway, providing decision-makers with targeted and actionable strategic directions to drive balanced improvements in innovation and economic development across multiple dimensions in Gansu Province.

5. Conclusion and Outlook

5.1. Research Conclusion

Based on the RIS framework that was developed for this study, the economic growth theory, and the histotypic perspective (i.e. the multi-dimensional path analysis that were used to explore the configuration of multiple influencing factors, and to distinguish between core and peripheral conditions), the paths of regional innovation performance enhancement were explored for their histotypic effects. However, since the regional innovation systems of different cities are different, it leads to different paths for the enhancement of regional innovation performance. Correspondingly, four paths to enhance regional innovation performance were identified, namely the knowledge-driven path, the urbanization-led path, the industrial structure optimization path and the comprehensive development path.

5.2. Shortcomings and Outlook

This study systematically delineates the key elements of pathways for enhancing regional innovation. Through an in-depth analysis of Gansu Province cases, we not only emphasize the diversity of pathways but also delve deeper into the core conditions behind each pathway, providing a new perspective and insights for expanding the theoretical framework in this field. The enhancement of innovation in relatively backward regions is not confined to a singular path; rather, it can be achieved through various approaches. This research prominently highlights four pathways for innovation enhancement: the knowledge-driven path, the urbanization-led path, the industrial structure optimization path, and the comprehensive development path. Each pathway influences the improvement of innovation performance to varying degrees. By thoroughly exploring the core elements of different innovation enhancement pathways in Gansu Province, this study not only extends the theoretical framework in the field but also offers new avenues for future research. Furthermore, it focuses on distilling practical policy recommendations to provide clear guidance for specific investments and policy objectives for each innovation enhancement pathway. This furnishes policymakers with actionable guidelines, aiding in the effective translation of research findings into tangible policies and actions, thereby facilitating the robust implementation of strategies for regional innovation enhancement in relatively backward areas.

Additionally, this study acknowledges certain limitations in its sample and data. Future research might consider selecting more diverse geographical regions to ensure broader applicability of the research outcomes. Further exploration of the mechanisms and causal relationships behind the identified innovation pathways could deepen our understanding of factors contributing to the enhancement of innovation performance. Additionally, conducting studies over a longer time span could track the long-term evolution of innovation performance, providing in-depth insights into the sustainability and changes in pathways over time.

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