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RESEARCH ON MULTIPLE IMPROVEMENT PATHS OF INNOVATION PERFORMANCE IN REGIONAL INNOVATION ECOSYSTEM BASED ON FUZZY QUALITATIVE COMPARATIVE ANALYSIS

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Abstract. Prioritizing the development of regional innovation ecosystems (RIE) is essential for advancing China's innovation-driven strategy. This study investigates how combinations of innovation elements, namely resources, services, achievements, and environment, affect regional innovation performance. Drawing on both innovation value-chain and ecosystem perspectives, we analyze the data from 31 Chinese provinces using fuzzy-set qualitative comparative analysis (fsQCA) and artificial neural networks (ANN). Our findings identify five distinct configurations that lead to high innovation performance and three that result in low or medium performance. High performance configurations include: resource achievement dual drive, outcome driven, and resource driven. Low performance configurations include talent shortage type, service deficiency type, and resource service dual weakness type. These results illustrate the principle of equifinality, indicating that different regions can achieve similar innovation outcomes through different pathways, and they underscore both the substitutability of certain elements and the synergy among them. Theoretically, the study advances configurational approaches in innovation research by integrating ecological and value-chain perspectives. Practically, it provides differentiated policy insights, suggesting that regions should tailor their innovation strategies to leverage specific strengths and thereby foster high-performance outcomes.

Keywords: regional innovation ecosystem, innovation value chain, innovation performance, fsQCA, value co-creation.

JEL Classification: O31, R11, L14.

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1. Introduction

Regional innovation plays an essential role in achieving quality development and implementing the innovation development strategy (Hansen & Birkinshaw, 2007; Yang et al., 2023a). Regional Innovation Ecosystems (RIE), as a crucial form of regional innovation, explore the activities and procedures of regional innovation from an ecological perspective (Zhang & Wang, 2021). RIE is part of a meso-level innovation ecosystem (Adner & Kapoor, 2016; Oh et al., 2016), which refers to the innovation subjects such as enterprises, governments, and research institutions, achieve value creation and sharing.

The RIE realizes value co-creation by coordinating the relationship between innovation subjects, and utilizing the interaction between subjects, resources and environment (Liu & Wang, 2021).

The establishment of regional innovation centers is an extension of the national innovation strategy, which is conducive to the common development of the inter-regional economy (Li & Zhang, 2019; Zhang & Wang, 2021). RIE emphasizes ecological interaction and value creation in space. From the perspectives of innovation ecosystem and innovation value chain, regional innovation ecosystem has the following new characteristics.

The first characteristic is the ecological allocation of innovation elements. The value creation process encompasses the overall effects of interactions among entities, resource exchange, energy flow, relationship evolution, and comprehensive interaction (Li & Zhang, 2019). During this process, innovative elements in the ecosystem form ecological relationships such as mutualistic symbiosis (Long & Liu, 2021). Therefore, the theory of innovation ecology can comprehensively explain the interaction of innovation elements in regional innovation ecosystems.

Another characteristic is the complication of value creation. With the promotion of regional innovation nationwide, a new pattern of regional innovation development in China has been restructured (Zhu et al., 2021). Building a fully effective and mutual symbiosis regional innovation system has become a key factor for accelerating regional development (Zhang & Wang, 2021). The RIE frequently exchanges energy, materials, and information with the external environment. The various subsystems in the system mutually promote and constrain each other, forming a variety of nonlinear and complex positive and negative feedback mechanisms (Ruan & Chen, 2024). The interactions among subsystems lead to the complexity and diversity of knowledge, as well as technological and economic value-creation paths in the system. However, under the combined influence of the ecological configuration of innovation factors and the complexity of value creation, the paths for RIE value co-creation are diverse. Diversified paths result in inefficient allocation of innovation factors, hinder value creation, and affect the overall effectiveness of regional innovation. Therefore, it is of theoretical significance and practical applications to study the ecological and complex characteristics of RIE and explore the multiple ways of value creation of RIE.

In summary, this study contributes to the literature in several important ways. First, it integrates the innovation value chain and innovation ecosystem perspectives to construct a unified, process-ecological framework for understanding value creation within regional innovation ecosystems. This integration helps bridge the conceptual gap between innovation inputs, intermediaries, and systemic interdependencies. Second, the study introduces a novel methodological approach by combining fuzzy-set Qualitative Comparative Analysis (fsQCA) with Artificial Neural Networks (ANN), offering a more robust analysis of causal complexity and condition importance. Third, by identifying both high- and low-performance configurations and their distinctive features, the research provides actionable insights for regional policy-makers and business strategists seeking to enhance innovation performance through differentiated, context-sensitive strategies.

2. Literature review

Our research involves the following three aspects. Firstly, the regional innovation ecosystem. Secondly, value co creation and regional innovation performance. Thirdly, fsQCA analysis method.

2.1. Research on regional innovation ecosystems

The existing literature studies have highlighted that innovation subjects in regions interact with each other and the environment, achieving value creation through basic research, technological innovation, and commercial applications (Long et al., 2023). The innovation path is transitioning from mechanical and engineering to organic and ecological development, with the change of science and technology and the innovation environment (Long & Liu, 2021; Zhang & Wang, 2021). Innovation ecosystems represent a new paradigm incorporating the concept of ecosystems from biology into innovation management (Liu & Wang, 2021). However, as a form of innovation ecology, the population and relationships in innovation ecosystems differ from those in ecosystems in biology, and the ecological relationships and evolutionary mechanisms of the latter cannot be applied (Jagódka & Snarska, 2023). Exploring innovation ecosystems ecological characteristics is necessary (Gao & Tan, 2021). At the same time, there are frequent interactions and matching, and synergistic cooperation among innovation elements in the system (Yang et al., 2023b; Xie & Liu, 2021), including innovation subjects, innovation resources, and the innovation environment because the RIE is characterized by diverse symbiosis, self-organized evolution, and open synergy. The innovation process exhibits complex interactions, and the construction of the system needs to follow a systematic and coordinated perspective (Tang et al., 2021). Therefore, the RIE has the characteristics of ecology and complexity, and it is urgent to research to seek the ecological linkage among innovation subjects, resources, environment, and other elements from the perspective of ecological and complex integration.

2.2. Research on regional innovation performance and value co creation

Regarding value creation and regional innovation performance, value creation is the process of interaction and collaboration among subjects in the innovation ecosystem to create value (Kulkov et al., 2023; Nylund et al., 2024), and it is presented in multidimensional forms such as technical value, social value, and economic value. There were differences in the focus of the existing study participants (Ritala et al., 2013), such as the heterogeneity of the impact of industrial structure adjustment on innovation performance in different regions and spatial spillover effects. As research progresses, more innovation elements have been included in the study scope as causal conditions, such as the multiple concurrent factors influencing regional innovation levels, including innovation foundations, industry clusters, and their synergistic matching (Zhu et al., 2021). Regional innovation performance is driven by the synergy among innovation subjects, resources, and environment (Xie & Liu, 2021). The multiple concurrencies of conditions such as government efficiency, human resources, financial services, public services, market environment, and innovation environment form diverse configurations that improve region innovation performance (Tura et al., 2017). Thus, with the advancement of the division of labor and collaboration among innovation subjects in the region, it is imperative to thoroughly analyze the interactive effects of the elements of the "innovation value chain," explore the path of regional innovation value creation, and obtain innovation performance.

While existing studies often explore the individual effects of resources or services on innovation, few have examined their interactive impacts. This study fills this gap by employing a configurational approach to analyze the interplay between resources, achievements, services, and the environment.

2.3. Research on fsQCA

In terms of research methodology, traditional statistical analysis methods based on the reductionism perspective treat the whole as a sum of its parts when conducting investigations, which makes it difficult to deeply explore the nonlinear relationship between system elements and innovation performance (Zhang et al., 2022). In contrast, the Fuzzy Set Qualitative Comparative Analysis (fsQCA) method is beneficial for exploring the intricate causal mechanisms that drive innovation performance in RIE (Xie & Liu, 2021). Therefore, the fsQCA method provides a new research method for exploring multi-factor interaction and value creation in regional innovation, and we use the method to explore the complex configurations that proceed with innovation performance in RIE and analyze the effects of innovation elements on innovation performance in RIE.

Based on the new characteristics of value creation in RIE, it is evident that value creation in RIE is influenced by various factors involving innovative subjects, their relationships, and the environment. There is an urgent need to explore the efficiency of regional innovation and integrate the ecological relationships of innovation elements and value creation into a unified whole for analysis. However, the existing research on value creation in RIE has some gaps. Firstly, previous studies have focused on the interactions among certain actors, such as resources and environment. However, there is no consensus on the innovation value chain elements that affect regional innovation performance, and the ecological relationships between these elements need further exploration. Secondly, existing research have not integrated the differentiated combinations of the innovation value chain elements and the value creation into a unified analysis, which is insufficient for giving full play to the overall innovation efficiency of the system. These research gaps hinder the systematic understanding of the value creation path in RIE and the full release of innovation efficiency, thus calling for further in-depth research.

The configuration method has advantages in revealing the interaction relationships between multiple factors in a system (Furnari et al., 2021; Nylund et al., 2024). We have constructed a comprehensive framework for analyzing RIE value creation, integrating perspectives from the innovation value chain and innovation ecology. This framework considers the ecological and complex characteristics inherent in China's RIE value creation process. We categorize the innovation performance generated by value creation into high innovation performance and low/medium innovation performance. By collecting data from 31 provinces in China as a case study, we use the fsQCA method to explore the configuration conditions and mechanisms that drive the differences in RIE innovation performance, and reveal the value creation path under the interaction of multiple conditions.

2.4. Literature summary

Previous studies have applied fsQCA to identify the driving factors of regional innovation performance (Tang et al., 2021; Zhang et al., 2020; Xie & Liu, 2021). However, existing research still presents several limitations. First, prior work mainly focuses on the interactions between specific elements such as innovation resources and the environment, without reaching a consensus on which components of the innovation value chain are most influential in shaping regional innovation performance. In addition, the ecological relationships among these elements remain insufficiently explored. Second, current studies have not yet incorporated the differentiated combinations and value creation mechanisms formed through the interplay of innovation value chain elements into a unified analytical framework. This gap limits a comprehensive understanding of how to fully enhance the system's overall innovation efficiency.

To address the limitations of previous research, this article proposes improvements through the following methods: To address the limitations of previous research, this study introduces several key innovations: (1) We integrate the Innovation Value Chain (Chen et al., 2022; Long et al., 2018) with the Innovation Ecosystem perspective (Liu & Wang, 2021), constructing a comprehensive four-dimensional framework-encompassing resources, services, outcomes, and environment-that captures both processual dynamics and ecological interdependencies. (2) In addition to the traditional fsQCA approach, we employ Artificial Neural Networks (ANN) in combination with SHAP interpretability to assess the relative importance of each condition and account for case-level heterogeneity, thereby enhancing the robustness of our causal analysis. (3) By systematically examining the substitution and complementarity among innovation elements, we identify multiple equifinal path, such as resource – achievement dual-drive and outcome – environment substitution, which provide deeper insights into the configurational mechanisms that shape regional innovation performance.

3. Theoretical background

3.1. How to improve the innovation performance of RIE

Basesd on the analysis of the relevant concepts and new features of RIE value creation in the previous text, theories such as innovation value chain, innovation ecology, and configuration provide new perspectives for improving the innovation performance of RIE. Previous studies on the innovation value chain suggest that the innovation value chain is a description of the innovation process from the perspective of knowledge elements, including knowledge acquisition, processing, and output (Fiss, 2011). A complete innovation value chain in RIE includes innovation policy, original innovation research and development, technology innovation application, technology innovation services, and other innovation elements (Hansen, 2007). Innovative elements iterate through complex interactions and associations to promote value creation. From the perspective of innovation ecology (Liu & Wang, 2021), symbiotic relationships in innovation ecosystems reflect interactions, coexistence, and co-evolution among different entities, and promote the exchange and allocation of information, knowledge, technology, and other resources (Shang et al., 2024). By integrating the symbiosis idea into the innovation value chain and coordinating and integrating the resources (Gao & Tan, 2021), services (Tura et al., 2017), achievements (Long et al., 2023), environment (Gao & Tan, 2021), and other elements of the innovation value chain, it is conducive to exploring the diversified ecological relationships formed by the elements on the innovation chain, such as the Partial Symbiosis and Reciprocal Symbiosis (Tura et al., 2017; Xie & Liu, 2021). Extant studies also show that configuration theory is conducive to identifying the combined relationships of factors, such as interdependence, co-produce results (Shang et al., 2024). From a configuration perspective, it emphasizes integrating various elements that influence the value creation chain in RIE into a unified framework and realizing value creation by analyzing the interaction and collaboration among these elements. Therefore, the perspective of the innovation value chain is expected to depict the chain of value creation. The innovation ecosystem perspective can reveal the ecological relationships among innovation elements, and it is expected to explore the complex path of multi-factor combination in value creation from the perspective of configuration.

Therefore, we integrate the symbiosis of ecological relationships and the multiple paths formed by coordinating various innovative elements into the same framework to reveal the diversity and complexity of value creation paths. Firstly, this framework reflects the diversity of regional innovation and development, such as differences in regional endowments and environmental factors. Secondly, it emphasizes the non-linear circular thinking and ecological relationships that connect and match various elements. Thirdly, by combining the innovative elements of RIE, the dynamic process of value creation between different elements is depicted.

3.2. Theoretical framework

3.2.1. Integration of innovation value chain and innovation ecosystem perspectives

The innovation value chain conceptualizes the innovation process from the perspective of knowledge flow, typically encompassing stages such as knowledge acquisition, processing, and output. In the context of regional innovation ecosystems, this value chain extends across a broader set of interconnected elements, including policy environment, basic research, applied innovation, and innovation service systems. These components interact dynamically to collectively promote innovation-driven value creation.

Meanwhile, from the perspective of innovation ecology, the ecosystem is characterized by symbiotic relationships among diverse actors, emphasizing interdependence, co-evolution, and resource sharing across organizational boundaries. These symbioses foster the exchange and optimal allocation of innovation-critical resources such as knowledge, information, and technology.

By integrating the ecological logic of symbiosis into the sequential structure of the innovation value chain, this study proposes a novel theoretical framework in which key innovation elements – resources, services, outcomes, and environment – are not only positioned along a transformation sequence, but also embedded within an ecological network of mutual influence. This integration enables the exploration of diverse inter-elemental relationships, such as biased symbiosis (mutual association without conflict) and reciprocal symbiosis (mutual reinforcement). Specifically, in ecological terms, biased (partial) symbiosis refers to a relationship in which two elements are interrelated, and the growth or development of one does not hinder, but also does not necessarily promote, the other. In contrast, mutualistic symbiosis describes a cooperative interaction in which both parties benefit and reinforce one another's growth. These concepts differ fundamentally from traditional economic relationships, which are often transactional, competitive, or based on short-term efficiency goals. Ecological relationships emphasize co-evolution, adaptive interdependence, and systemic resilience, making them particularly suitable for describing innovation systems where actors and elements (e.g., policies, services, outcomes) evolve together over time. By applying these distinctions to the innovation value chain, our framework captures not only the directionality of value creation, but also the quality and sustainability of inter-element linkages. This offers a richer lens for understanding how innovation ecosystems thrive under varying structural configurations.

3.2.2. Research framework

The significance of innovation performance and innovation value chain is increasing, and local governments must better understand RIE. Based on the previous research, it is beneficial to integrate the symbiotic relationships in the innovation ecosystem into the innovation value chain and collaborate with innovation elements to study diverse value co-creation paths. Existing research has developed comprehensive models, including various innovative elements in RIE. However, further work is needed to explore the role of innovative elements and their interrelationships in promoting innovation performance.

Therefore, we examine the innovation performance in RIE by revealing the configuration of causal factors. The relationship between two factors (such as X, Y) is complex, and the presence of one factor (X) may lead to the presence of another factor (Y), indicating its sufficiency. Furthermore, even if factor X does not exist, factor Y may still exist. Therefore, the existence of X is a sufficient but unnecessary condition for Y. In the presence of other factors, X may be necessary but not sufficient to cause Y.

We assume that there is a synergistic effect between innovation elements when explaining innovation performance in RIE. There are theoretically many optimal configurations. On the contrary, there are multiple equally effective causal condition configurations, which may include different combinations of innovative elements. Depending on their combination, they may or may not explain high or low/moderate innovation performance.

We tend to select and adjust key influencing factors within the dimensions of resources, services, outcomes, and environment (Chen et al., 2022), and explore the ecological and complex characteristics of RIE from multiple perspectives of innovation value chain and innovation ecology. To discern the degree of abnormal impact of different factors on RIE value creation, we subdivided the four main conditions of innovation resources, services, achievements, and environment in the system into eight secondary conditions, and proposed a theoretical model (Figure 1) to illustrate value creation in RIE. In addition, these conditions are integrated into a whole for configuration analysis, thereby clarifying the role and path of each condition.

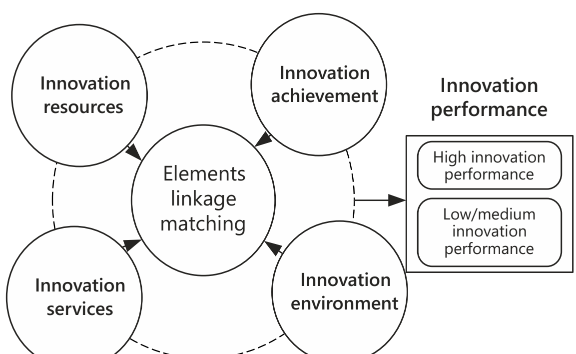

Figure 1. The integrated analysis framework of value creation in RIE

To conceptualize these relationships, we propose a comprehensive theoretical model (Figure 1) illustrating our interrelated construct sets. Alternative sets of causal conditions may explain a result equally, drawing on complexity theory and the principle of equifinality (Woodside, 2014). These conditions may be combined in sufficient configurations to explain the outcome (Fiss, 2007). Innovation resources, services, achievements, and environment are critical causal conditions in RIE for understanding regional innovation capacity. Thus, they may interact in various configurations.

In addition, configuration theory proposes the principle of causal asymmetry, which means that the presence or absence of causal conditions for the occurrence of a result depends on how that condition is combined with other conditions (Fiss, 2011). Causal asymmetry indicates that the causal conditions that explain the existence of a result cannot be assumed to be a mirror of the conditions explaining the result's existence (Fiss, 2011). For instance, alternative configurations for innovation performance in RIE may include high innovation resources in one configuration and low innovation resources in different configurations. Therefore, the same outcome may be positively or negatively influenced by specific factors, depending on how it combines with other factors. In addition, the impact of innovative resources, services, outcomes, and environment on RIE innovation performance is not entirely independent, and explaining the allocation of results does not necessarily mean that their reversal can also explain the lack of the same results.

4. Research design

4.1. Methodology

In this study, we employ fuzzy-set Qualitative Comparative Analysis (fsQCA), a method that integrates set theory and logical principles with qualitative comparative methods (Yang et al., 2023a). FsQCA has been widely applied in various disciplines, including business (Shah et al., 2022), information systems, technology adoption, and regional innovation.

Building on prior literature (Shang et al., 2024), we adopt fsQCA to the relationship between regional innovation ecosystems and innovation performance for three reasons. Firstly, Traditional regression analysis primarily estimates the net effect of individual independent variables, yet the co-creation of value within regional innovation ecosystems results from the interplay of multiple factors rather than isolated or dual-factor effects. fsQCA effectively captures these higher-order interactions, allowing for the examination of interdependencies among three or more variables. Secondly, while conventional regression methods seek a single optimal explanatory pathway, fsQCA acknowledges that multiple equifinal configurations can lead to the same expected or unexpected outcome. By employing fsQCA, researchers can systematically explore diverse configurational patterns of antecedent conditions within regional innovation ecosystems and their varying impacts on value creation. Thirdly, traditional regression models, which typically rely on large-sample analyses to derive generalizable patterns, often overlook case-specific heterogeneity. In contrast, fsQCA accounts for asymmetric relationships between conditions and outcomes, as well as asymmetric causal mechanisms, thereby offering a more nuanced understanding of heterogeneity across cases.

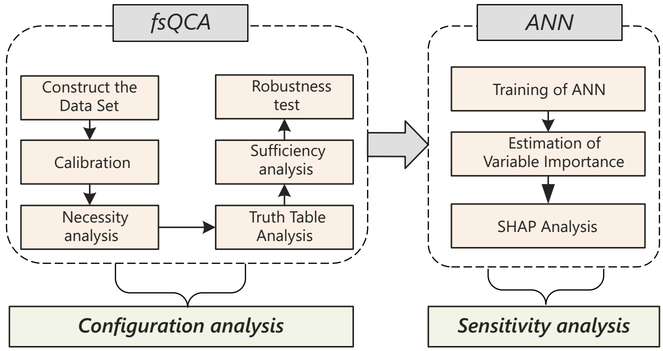

Figure 2. Research process and basic steps

This methodological strength enhances the capacity to uncover distinct causal configurations that underpin the dynamics of regional innovation ecosystems.

The research flowchart of this article is shown below to clearly illustrate the process of using fsQCA and ANN methods. Figure 2 shows the research process of this article.

4.2. Sample selection and data sources

We integrate the innovation value chain (Chen et al., 2022; Long et al., 2018) and Innovation Ecosystem (Liu & Wang, 2021) developed a comprehensive analytical framework for RIE value creation. Based on previous data collection and analysis (Tang et al., 2021), and following the requirements of fsQCA for sufficient number of cases and data availability (Zhang et al., 2022), we applied this method to 31 provinces in China to explore RIE value creation and its impact on innovation performance. Our data comes from five databases, including the "China Statistical Yearbook", "China Science and Technology Statistical Yearbook", and "China Torch Statistical Yearbook" of the National Bureau of Statistics. The data has been validated across sources, and some differences in indicator data are based on the "China Statistical Yearbook". We also used the least squares linear interpolation method to estimate sporadic missing values (Liu et al., 2024) and obtained a balanced panel dataset of 30 provinces from 2010 to 2023.

4.3. Measurements

4.3.1. Outcome of regional innovation

Innovation Performance (IP). Technological innovation is a comprehensive manifestation of regional innovation, reflecting the effectiveness of achievement transformation. We use technology market revenue, new product sales revenue, and high-tech product export trade volume to measure innovation performance (Chen et al., 2022), and refer to existing research (Zhang et al., 2022) to set weights to calculate innovation performance.

4.3.2. Causal condition

Innovation Resources (IR). It is measured by R&D personnel (RDP) and R&D investment (RDC). Numerous studies have examined the fact that innovation resources play a primary role in most regional development. It refers to the human and financial resources invested to support innovation activities (Tang et al., 2021). R&D personnel is an important input element in innovation activities (Fan et al., 2021). Investment in R&D funding is an essential guarantee for knowledge and technological innovation (Zhang et al., 2021; Li et al., 2023). The full-time equivalent of R&D personnel is an internationally standard indicator for measuring human resources (Tang et al., 2021). In this paper, the full-time equivalent of R&D personnel is used to measure the supply of R&D personnel (RDP), R&D investment (RDC) is measured by internal expenditure on R&D to assess this indicator (Yang et al., 2023b).

Innovative Services (IS). Innovation services are expected to form ecological relationships such as commensalism and mutualism with innovation resources. Previous research has examined the fact that innovation services mainly play a complementary or alternative role by providing capital, human resources, and information (Zhao et al., 2021). Specialized personnel services can provide resources such as talents for regional innovation, while financial services are an essential guarantee for regional innovation performance enhancement (Zhang et al., 2022), both provide ecological support for value creation in RIE. Financial Service (FS) mainly refers to investment and financing services, including venture capital and incubator funds. This paper uses the total amount of incubator funds to represent this indicator. Personnel Service (PS) provides professional services for technical innovation and entrepreneurial capabilities. The number of entrepreneurial mentors is used to measure the indicator.

Innovation Achievements (IA). We measure innovation outcomes through the number of Scientific Papers (SP) and research and development projects (RD). Existing research indicates that every 10000 scientific papers can serve as the scientific output of innovative achievements, measuring the knowledge level of a region. It reflects the textual output of innovative achievements and measures the knowledge level of a region. In addition, the number of research and development projects reflects the application of technological innovation and demonstrates its application value (Li & Zhu, 2021). These two factors describe the scientific output and application level of RIE. It is measured by the number of Scientific Papers (SP) and R&D projects (RDT) to measure innovation achievements. Previous research has shown that scientific papers per 10,000 people serve as a textual representation of innovation achievement, measuring the knowledge level of a region, and it reflects the textual output of innovation achievements and measures the knowledge level of a region (Zhang et al., 2021). In addition, the number of R&D projects reflects the application of technological innovation and demonstrates its practical value (Li & Zhu, 2021). These two factors depict the RIE's scientific achievement output and application level.

Innovation Environment (IE). It is a crucial causal condition determining a region's high or low/medium innovation capability (Fernandes et al., 2020). It is formed with government R&D funding (GOV) and market openness degree (ROD) (Zhang & Wang, 2021). ROD partly determines the extent of open innovation in a region, while the GOV affects the investment in regional innovation. The ratio of regional total imports and exports to regional GDP represents ROD. GOV is represented by the proportion of government funding to internal expenditure of R&D, the share of government R&D investment in R&D internal expenditure (Zhang & Wang, 2021; Yuko & Junichi, 2018). Together, these two factors form the ecological conditions that support regional innovation.

4.4. Data calibration

Calibration is the process of assigning membership degrees to cases based on predefined set thresholds, typically defined by three qualitative anchor points: full membership, the crossover (intersection), and full non-membership. Given the absence of universal external standards for regional innovation performance and innovation ecosystems – and recognizing that these concepts are inherently relative and require inter-subjective comparison – this study adopts the quantile direct calibration method. Following the approach of existing research (Yang et al., 2023a), the upper quartile (75%), median (50%), and lower quartile (25%) of the eight antecedent conditional variables (innovation resources, innovation services, innovation achievements, and innovation environment), as well as the innovation performance outcome variable, are used as the full membership, crossover, and full non-membership calibration points, respectively. Non-high innovation performance is calibrated by taking the complement of high innovation performance. Compared with mean-based calibration, median calibration minimizes the influence of extreme values. Moreover, cases with values exactly equal to the median are fine-tuned to a membership score of 0.499, thereby preventing redundancy in the solution set due to "partial membership" in configuration analysis (Ragin, 2010). The calibration points for each variable are presented in Table 1 below.

Following the data calibration, the researcher runs the fsQCA algorithm, which produces a truth table, and the truth table is sorted based on frequency and consistency (Ragin, 2010). Frequency describes the number of observations for each possible combination, while consistency refers to the degree to which cases correspond to the set-theoretic relationships expressed in a solution (Fiss, 2011). The threshold for consistency is set at the recommended threshold of 0.9 (Du & Jia, 2017). The combinations above the consistency threshold fully explain the outcome, which means that the variable is considered to have passed the necessity test. Then, coverage determines the empirical relevance of the consistent subset.

Table 1. Variable calibration anchor points

			Fully subordinate points	Intersection points	Non affiliated points
Outcome		IP	0.993	0.709	0.369
Conditions	Innovation resources	RDC	0.968	0.679	0.426
		RDP	0.982	0.731	0.410
	Innovation achievement	RDT	1.035	0.685	0.418
		SP	1.153	0.630	0.437
	Innovative services	FS	0.710	0.563	0.492
		PS	1.164	0.668	0.433
	Innovation environment	GOV	1.279	0.659	0.270
		ROD	1.262	0.573	0.421

5. Data analysis

5.1. Analysis of necessity

The results from the configuration analysis with fsQCA are presented in Table 2. The internal expenditure of R&D funds in innovation resources, the full-time equivalent of R&D personnel, and the government R&D funding in the innovation environment have passed the necessity test, with the consistency of 0.935, 0.935, and 0.914, respectively. These three conditions constitute the necessary conditions for RIE's high innovation performance. The coverage of the three conditions are all above 0.85, which can explain the results well.

In the analysis of low/medium innovation performance in the innovation ecosystem, it is found that the consistency of the absence of full-time equivalent R&D personnel (corresponding to the supply of R&D personnel) is 0.914. The coverage is 0.938, which is more significant than the recommended threshold of 0.85, indicating a robust explanatory effect. Therefore, the absence of this condition is necessary for the configuration pathway of low/medium innovation performance in the innovation ecosystem. The results of the necessity analysis confirm the asymmetry in the shared causal conditions between high and low/medium innovation performance in China's RIE.

Table 2. Necessity analysis value creation in RIE

Outcomes		High innovation performance		Low/medium innovation performance	
Conditions		Consistency	Coverage	Consistency	Coverage
Innovation resources	RDC	0.935	0.881	0.270	0.278
	~RDC	0.234	0.227	0.884	0.937
	RDP	0.934	0.908	0.247	0.263
	~RDP	0.241	0.227	0.913	0.938
Innovation achievements	RDT	0.898	0.889	0.249	0.270
	~RDT	0.263	0.242	0.898	0.905
	SP	0.696	0.677	0.386	0.411
	~SP	0.395	0.371	0.697	0.715
Innovative services	FS	0.784	0.801	0.298	0.333
	~FS	0.347	0.311	0.822	0.806
	PS	0.824	0.836	0.271	0.300
	~PS	0.310	0.280	0.852	0.841
Innovation environment	GOV	0.914	0.858	0.277	0.284
	~GOV	0.238	0.231	0.862	0.916
	ROD	0.774	0.795	0.310	0.348
	~ROD	0.365	0.326	0.817	0.798

5.2. configuration analysis

Like necessity analysis, consistency and coverage are essential criteria to measure the establishment of a configuration causality. Studies have shown that a consistency level of 0.75 (Du & Jia, 2017) is generally considered the minimum threshold for consistency. To improve the credibility of calculation results, some scholars have set the consistency threshold to 0.8 (Fiss, 2011). Determining the frequency threshold depends on the sample size, and the frequency threshold 1 is sufficient for small and medium-sized samples (Fiss, 2011). Therefore, this paper determines reasonable configuration analysis thresholds after considering these practical aspects. The consistency level of causal conditions should be higher than 0.75, the consistency threshold for truth table analysis is 0.8, and the frequency threshold is 1.

According to the analysis results in Section 5.1, in the configuration analysis of high innovation performance in RIE, variables such as internal expenditure on R&D funding, the full-time equivalent of R&D personnel, personnel services, and market openness are set to a present state. In contrast, the other conditions are set to a present or absent state. Besides, in the configuration analysis of low/medium innovation performance in RIE, variables such as internal expenditure on R&D funding, the full-time equivalent of R&D personnel, and market openness are set to absent. In contrast, the remaining conditions are set to present or absent state. Complex, parsimonious, and intermediate solutions are obtained through fsQCA 3.0 software. Following existing research practices (Fiss, 2011), we classified different configuration patterns and summarized the results of the configuration analysis of value creation in RIE in Tables 3–4.

Table 3. Configuration of high innovation performance in RIE

Outcome		High performance				
Configuration		1	2	3	4	5
Innovation resources	RDC		●	●	●	●
	RDP		•	•	•	•
Innovation achievements	RDT	●		●	●	●
	SP	•	•	⊗	⊗	⊗
Innovative services	FS	⊗	•	⊗	⊗	
	PS	⊗	•	•	•	•
Innovation environment	GOV		•	•	•	•
	ROD	•				⊗
Consistency		0.987	0.959	0.920	1.000	0.977
Raw coverage		0.156	0.460	0.170	0.487	0.259
Unique coverage		0.078	0.059	0.026	0.071	0.035
Overall solutions consistency		0.945				
Overall solutions coverage		0.733				

Note: (●) indicates the presence of core conditions. (⊗) indicate the absence of core conditions. (•) indicates the presence of auxiliary condition, (⊗) indicates the absence of auxiliary condition. Blank space indicates a "do not care" condition.

Table 4. Configuration of low/medium innovation performance in RIE

Outcome		Low/Medium performance				
Configuration		6	7	8	9	10
Innovation resources	RDC	⊗	⊗	⊗	•	⊗
	RDP	⨂	⨂	⨂		⨂
Innovation achievements	VPA	⊗	⊗	⊗	•	●
	SP		⊗	•	⊗	●
Innovative services	FS		⊗	⊗	⨂	⨂
	PS	⊗	⊗		•	⊗
Innovation environment	GOV	⊗	⊗	⊗	•	⊗
	ROD	⊗		⊗	●	●
Consistency		0.999	0.998	1.000	0.839	0.973
Original coverage		0.666	0.568	0.203	0.103	0.072
Unique coverage		0.130	0.087	0.029	0.058	0.031
Overall solutions consistency		0.975				
Overall solutions coverage		0.883				

Note: (●) indicates the presence of core conditions. (⨂) indicate the absence of core conditions. (•) indicates the presence of auxiliary condition, (⊗) indicates the absence of auxiliary condition. Blank space indicates a "do not care" condition.

Solutions 1–5 present combinations that lead to high innovation performance in RIE (Table 3). In detail, the coverage of the overall solution is 0.733, and the consistency level of the individual solution and the overall solution is higher than 0.9, which is higher than the acceptable standard of QCA research consistency level of 0.75. Therefore, they can explain the result cases well. At the same time, we also examined the negated outcome, which tests for having low/medium innovation performance (solution 6–10). The consistency level of the individual solution and the overall solution is higher than 0.8, and the coverage of the overall solution is 0.883, refers to the coverage and the consistency level being able to explain the result cases well. Therefore, Tables 3–4 are combinations of sufficient conditions for high (low/medium) innovation performance in RIE.

5.2.1. Configuration analysis of high innovation performance in RIE

The high innovation performance of RIE produces five configurations under the joint action of innovation resources, services, achievements, and environment, which are presented in Table 3. In addition, we divided the five configurations into three types.

(i) Resource-achievement dual-drive type (as shown in Figure 3). Based on solutions 3–5 in Table 3, this category of configuration shares two core conditions: the internal expenditure of R&D funds and the number of R&D projects. The two conditions belong to innovation resources and innovation achievements. In detail, innovation resources (personnel and funding) and innovation environments lead to high innovation performance when innovation achievements and innovation services are absent, regardless of the other factors, shown in solution 3 in Table 3. This solution can explain 17.0% of the cases (e.g., Hebei). Next, the result from solution 4 shows that when innovation resources, achievement, and services are present, high innovation performance may be achieved with greater regional openness, regardless of the degree of government R&D support. This type can explain 48.7% of the cases (e.g., Jiangsu, Zhejiang, Guangdong, Shanghai, and Hubei). In addition, the presence of innovation resources and innovation environments leads to high innovation performance when innovation achievements (a large number of R&D projects but a small number of scientific papers per 10,000 people) and services (financial service) are absent, regardless of the other factors, which is shown in solution 5 in Table 3 and this configuration can explain 25.9% of the cases (e.g., Jiangxi and Fujian).

Taking configuration 4 as an example, typical regions of this configuration include eastern coastal provinces such as Shanghai, Guangdong, Jiangsu, and Zhejiang. These regions are economically developed and have obvious capital advantages, which can guarantee the R&D capital investment. Besides, these regions are also gathered talent intensively. Provinces have successively introduced preferential policies such as raising wages, welfare benefits, and project funds to gather R&D talents, providing primary ecological conditions such as human resources and capital resources for regional innovation. This confirms, to a certain extent, the top five rankings of comprehensive indicators in the "China Regional Innovation Capability Evaluation Report 2021": Guangdong, Beijing, Jiangsu, Shanghai, and Zhejiang. Therefore, the region's innovation resources and achievements form an interrelated and mutually promoting ecological relationship, which is expected to achieve high innovation performance. This combination has a specific reference value for other provinces to improve regional innovation performance. It belongs to the ecological relationship of Reciprocal Symbiosis, which means the elements of innovation are interrelated and promote each other.

As shown in Figure 3, the characteristic of the resource achievement dual drive type is the coexistence of strong R&D investment and high innovation achievements. The underlying mechanism can be interpreted as a virtuous cycle of input-output reinforcement. Substantial investment in innovation resources enables continuous knowledge production, while the successful generation of outputs (such as patents and scientific publications) enhances the region's innovation reputation, thereby attracting further investment and talent. This synergy forms a feedback loop that sustains and amplifies innovation performance.

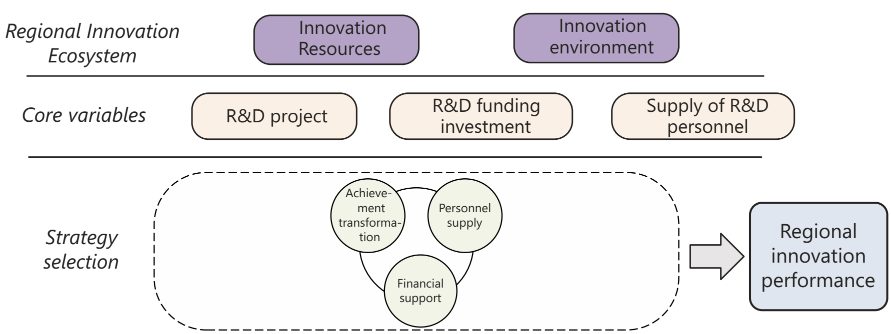

Figure 3. Resource-achievement dual-drive type

(ii) Achievement-driven type (as shown in Figure 4). the core condition of this configuration is the number of R&D projects that belong to innovation achievements. Combining sufficient innovation achievements leads to high innovation performance with high openness, even without innovative services. This path explains 15.6% of the cases (e.g., Chongqing), suggesting that innovation achievements are a core condition for a configuration that leads to high innovation performance. Taking Chongqing as an example, the leading industries in Chongqing include automobiles, electronic information, equipment manufacturing, and materials industries, most of which can be classified as high-tech. In recent years, the city has produced fruitful innovation achievements by deploying innovation chains around the industrial chain. Compared to developed provinces in the eastern region, Chongqing has a relatively limited accumulation of innovation resources but has achieved specific innovation performance. This type belongs to the ecological relationship of Partial Symbiosis, which means innovation achievements are associated with other innovation elements, and their growth does not harm other elements.

As shown in Figure 4, the characteristic of achievement driven is the existence of high innovation achievements. The mechanism at work here may reflect prior accumulation or external spillovers, namely, regions with legacy research institutions or strong university systems may produce consistent outputs despite lacking comprehensive ecosystem support. Additionally, this configuration implies a reliance on output legitimacy: visible achievements signal innovative capacity, attract policy attention, and indirectly improve the region's access to additional resources and collaborations, thereby sustaining performance in a more output-centric manner.

(iii) Resource-driven type (as shown in Figure 5). The core condition of this configuration is R&D expenditure, which belongs to innovation resources. Solution 2 indicates that innovation resources (sufficient funding) and comprehensive innovation services lead to high innovation performance when supported by government R&D funding and a specific scale of innovation achievements (number of R&D projects). This combination explains 46.0% of the cases (e.g., Beijing, Shanxi). Taking Beijing and Shanxi as examples, their shared characteristics are high-level universities and many R&D talents, coupled with relatively abundant research and development funding support. Both have developed rich innovation resources and have achieved high innovation performance as a result. This type belongs to the Partial Symbiosis ecological relationship, which means that innovation resources are associated with other innovation elements, and their growth does not harm other elements.

As show in Figure 5 the resource-driven configuration is characterized by the presence of strong innovation inputs, such as R&D funding and personnel, despite weaker outcomes or ecosystem support. The mechanism at play here is one of scale-based compensation, in other words, extensive resource inputs can offset shortcomings in innovation services or policy environment, at least in the short term. This configuration is often seen in regions with strong top-down investment or strategic national projects, where performance is driven by the intensity of input rather than ecosystem coordination. While effective, its long-term sustainability may depend on improved system integration.

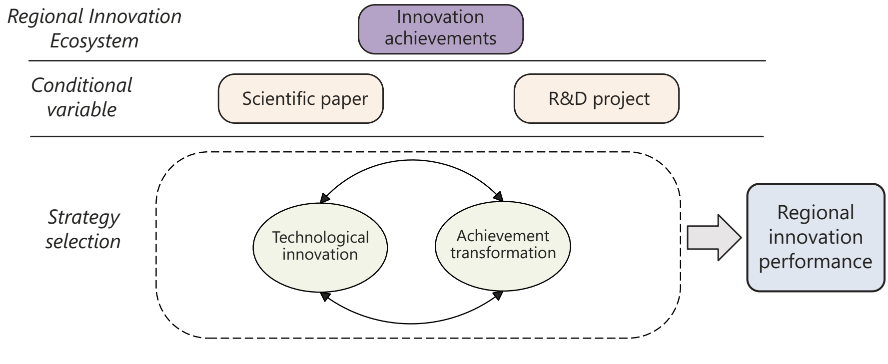

Figure 4. Achievement-driven type

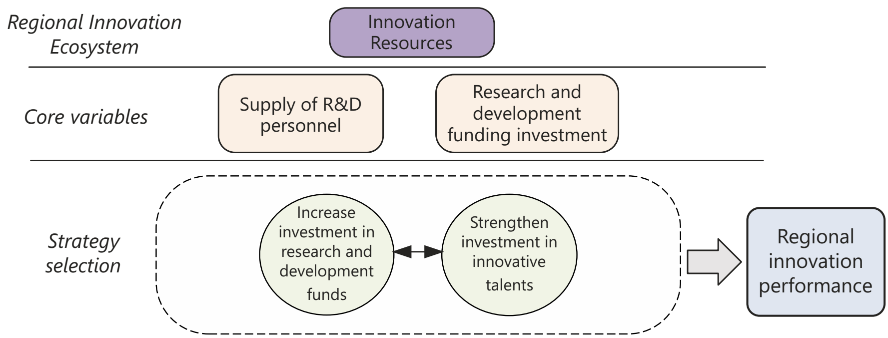

Figure 5. Resource-driven type

5.2.2. Configuration analysis of low/medium innovation performance in RIE

The low/medium innovation performance of RIE produces five configurations under the joint action of innovation elements, which are presented in Table 4. In addition, we divided the five configurations into three types.

(i) Talent scarcity type. Solution 6–8 in Table 4 indicates that RIE's lack of innovation resources, innovation environment, and innovation services will lead to low/medium innovation performance. This pathway explains 66.6% of the cases (e.g., Qinghai, Yunnan, Ningxia, Shanxi, Jilin). Besides, solution 7 demonstrates that the absence of innovation resources, achievements, and services, with low government R&D funding, will result in low innovation performance, and this combination can explain 56.8% of the cases (e.g., Tibet, Xinjiang, Hainan, Guangxi, Inner Mongolia, Yunnan, Qinghai, Gansu); Finally, in solution 8, even if there is sufficient innovation achievement (the number of scientific and technological papers per 10,000 people), when the innovation environment is not good, lack of the innovation resources with the low quality of innovation service, it may result in low innovation performance. This combination can explain 20.3% of the cases (e.g., Heilongjiang, Ningxia). Taking Yunnan Province as an example, its dual shortcomings in the supply of innovative talents and investment of innovative funds have led to the rupture of the innovation ecological chain, which in turn suppresses the output of regional innovation achievements and makes it difficult to achieve high innovation performance.

(ii) Service deficiency type. Based on solution 9 in Table 4, we examine that sufficient investment in innovation resources (e.g., R&D funds) but insufficient innovation achievements (sufficient R&D projects but lack of papers), and shortcomings in innovation services (sufficient entrepreneurial mentors but lack of incubation funds) can result in lower innovation performance, even with a conducive innovation environment. This combination can explain 10.3% of the cases (e.g., Fujian). Take Fujian Province as an example, although it has made significant investments in research and development, gaps in innovation services and a shortage of industrial incubation funds hinder the commercial transformation of R&D projects and limit innovation performance.

(iii) Resource-service dual shortage type. Based on solution 10 in Table 4, the core conditions of this type of configuration are the absence of the total amount of incubation funds and the full-time equivalent absence of R&D personnel. This combination indicates that the presence of innovation achievements is still difficult to achieve high innovation performance when the innovation environment is not good (high market openness but insufficient government R&D funding) with innovation resources and services absent; this combination can explain 7.2% of the cases (e.g., Liaoning). Take Liaoning Province as an example: while its market openness is relatively high, it lacks sufficient support for innovative resources. This dual deficiency in resources and services creates a "negative synergy" effect, hindering the achievement of high innovation performance.

These configurations demonstrate that low innovation performance is not merely a result of resource scarcity, but often stems from poor alignment and lack of synergy among innovation elements. A balanced ecosystem – rather than the mere presence of individual inputs – is key to sustaining regional innovation.

5.2.3. Alternative relationship analysis

Through horizontal comparative analysis of the implementation path of high-performance regional innovation, it is found that there is a dynamic equivalent substitution mechanism among the four elements of innovation resources, innovation achievements, innovation services, and innovation environment, which is specifically manifested as:

(1) By comparing configuration 2 (resource driven) and configuration 3 (resource outcome dual drive), we found that R&D projects (RDT) and Funding Services (FS) can form functional substitutes with scientific research outcomes (SP). For example, when the system has sufficient research and development funding (RDC) and talent supply (RDP), even if the number of research and development projects is insufficient, high-level scientific and technological achievements (such as scientific papers) and specialized funding services can still effectively fill the gap and maintain the continuity of the innovation value chain.

(2) Comparing configuration 4 (resource environment balance type) and configuration 5 (service support type), we got that under the dual guarantee of innovation resources (RDC, RDP) and research and development projects (RDT), the region can offset the negative impact of insufficient conversion rate of scientific research results by strengthening the innovation environment (such as increasing government funding GOV) or improving innovation services (such as expanding incubation funds FS), and achieve "substitution of weak elements".

5.3. Robustness test

We adopt two methods for robustness testing. Firstly, adjust the consistency threshold for adequacy testing. The fsQCA method is based on set theory, and is considered robust when the research conclusion remains unchanged but the path slightly changes. Referring to Liu and Wang's (2021) research, we adjusted the consistency threshold in the sufficiency analysis from 0.8 to 0.05, while keeping the configuration of high innovation performance and non-high innovation performance unchanged, as shown in Table 5, indicating the robustness of our research results. Secondly, the quantification method about replacing variables. To further demonstrate the robustness of our study, we use alternative quantification strategies for robustness testing, such as recalibrating innovation achievements with the number of valid invention patents and R&D projects. The fsQCA results based on alternative indicators are consistent with the findings of this study, with only some edge conditions changing, as shown in Table 6, indicating that the variable definitions in this study are effective and the research results are robust.

5.4. Artificial neural analysis

Based on previous research (Yang et al., 2023b; Li et al., 2022), our study verifies the importance of each indicator through Artificial Neural Network (ANN) method, and trains and tests based on layer perceptron (MLP). To avoid overfitting, this study used a 10 fold cross validation method for training (90% of the data was used for training and 10% for validation). The output and hidden layers of the ANN model were automatically generated by SPSS, and the results are shown in Figure 6.

Table 5. Robustness test with improved consistency threshold of 0.85

Configuration	high innovation performance					Low/Medium performance			
	1	2	3	4	5	6	7	8	9
RDC	●	●	●	⊗	•	⊗	⊗	⊗	•
RDP	●	●	●	⊗	•	⊗	⊗	⊗	•
VPA	●	●		•	•	⊗	⊗	•	•
SP	⊗	•	•	•			•	•	⊗
FS	⊗	•	•	⊗	•			⊗	⊗
PS	•	•	•	⊗	•	⊗			•
GOV	•	•	•	⊗	●	⊗	⊗	⊗	•
ROD				•	●	⊗	⊗	⊗	⊗
Consistency	0.919	1.000	0.959	0.982	0.988	1.000	0.986	1.000	0.803
Raw coverage	0.170	0.486	0.459	0.076	0.541	0.644	0.543	0.196	0.108
Unique coverage	0.025	0.071	0.058	0.027	0.072	0.126	0.078	0.027	0.064
Overall solutions consistency	0.947					0.958			
Overall solutions coverage	0.756					0.856			

Table 6. Robustness testing with adjusting quantitative methods

Outcome	high innovation performance			Low/Medium performance	
Configuration	1	2	3	6	7
RDC	●	●	⊗	⊗	⊗
RDP	●	●	⊗	⊗	⊗
VPA	•		⊗	⊗	⊗
SP	•	⊗	●		•
FS		●	⊗		
PS	•	●	⊗	⊗	
GOV	•	•	⊗	⊗	⊗
ROD		•	•	⊗	⊗
Consistency	0.97	0.887	0.968	0.933	0.924
Raw coverage	0.898	0.681	0.082	0.606	0.159
Unique coverage	0.014	0.553	0.031	0.054	0.088
Overall solutions consistency	0.991			0.919	
Overall solutions coverage	0.811			0.722	

The prediction accuracy of ANN neural network is shown in the Table 7, the average MRE value is relatively small during the training and testing process, while the ANN neural network has a higher prediction accuracy.

Table 7. Prediction accuracy of artificial neural network model

Neural	MAE	RMSE
ANN1	0.046	0.648
ANN2	0.010	0.131
ANN3	0.060	0.813
ANN4	0.032	0.427
ANN5	0.011	0.158
ANN6	0.071	0.927
ANN7	0.057	0.827
ANN8	0.002	0.193
ANN9	0.078	0.901
ANN10	0.049	0.691

The sensitivity analysis of the artificial neural network model constructed in this article is shown in Table 8. For regional innovation performance, the most important input neuron is R&D funding investment.

Table 8. Sensitivity analysis

Neural network	RDC	RDP	RD	SP	IS	PS	GOV	ROD
ANN1	0.118	0.521	0.109	0.008	0.071	0.002	0.024	0.146
ANN2	0.016	0.316	0.123	0.125	0.245	0.013	0.064	0.099
ANN3	0.370	0.402	0.010	0.049	0.031	0.009	0.001	0.127
ANN4	0.259	0.455	0.013	0.003	0.052	0.037	0.057	0.124
ANN5	0.350	0.317	0.040	0.072	0.025	0.035	0.091	0.071
ANN6	0.046	0.359	0.216	0.033	0.016	0.099	0.001	0.231
ANN7	0.332	0.409	0.034	0.039	0.037	0.034	0.035	0.080
ANN8	0.248	0.180	0.050	0.169	0.046	0.153	0.096	0.058
ANN9	0.255	0.268	0.232	0.083	0.030	0.076	0.028	0.027
ANN10	0.116	0.416	0.053	0.079	0.033	0.074	0.025	0.204
Average relative importance	0.211	0.364	0.088	0.066	0.059	0.053	0.042	0.117

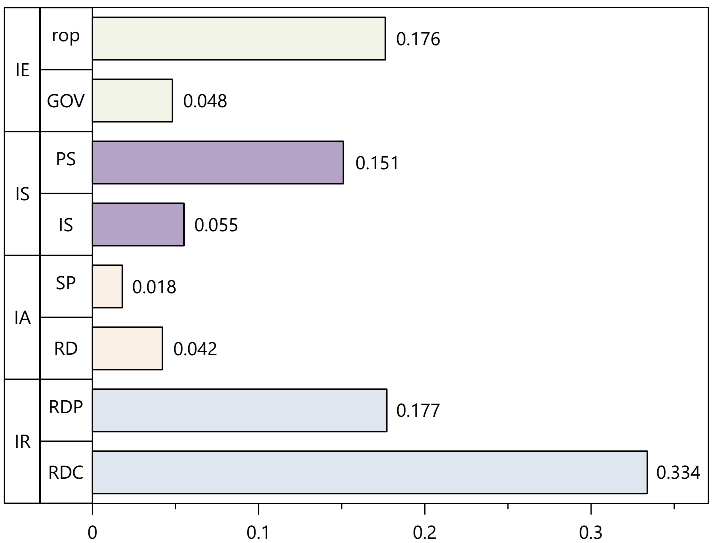

Figure 6. Ranking of regional innovation ecosystem importance

Our research further introduces the interpretable learning model SHAP to further explain the ANN analysis results, as shown in Figure 6. Among them, R&D funding and R&D personnel supply are important factors affecting regional innovation performance, which is consistent with the sensitivity analysis in the previous section.

6. Discussion

Our study explained how elements such as innovation resources, services, outcomes, and environment in China's regional innovation ecosystem affect innovation performance. Previous studies have mainly focused on the interactions between factors such as resources and environment, without considering the ecological relationships between different innovation factors, nor integrating the differentiated combinations of innovation value chain elements and value creation into the same analytical framework. Therefore, it is difficult to systematically understand the value co-creation path of regional innovation ecosystems. Findings are as follows.

(1) There are five value creation allocation paths for the existence of high innovation performance. It promotes the development of innovation value chain and ecological theory by constructing mutually beneficial symbiotic (resource result driven) and partially symbiotic (resource driven and result dependent) ecological relationships of innovative elements. Solutions 1–5 demonstrate how high innovation resources (R&D funding) and high innovation achievements (number of R&D projects) can overcome low innovation services and create high innovation performance, regardless of the level of innovation environment. This indicates that when a region effectively invests in innovation resources and achieves sufficient innovation results, the importance of innovation services to innovation performance decreases. In addition, this article reveals that internal R&D expenditures, full-time equivalent R&D personnel, and government R&D funding support are necessary conditions for achieving high innovation performance in RIE. It also indicates that the symbiotic development of innovative achievements and innovative resources is conducive to improving regional innovation performance. Innovative resources are indispensable for achieving high innovation performance. Internal R&D expenditures and the number of R&D projects are crucial for high innovation performance and are individual or common core conditions.

(2) Regardless of the level of innovation services, insufficient investment in innovation resources and inadequate innovation achievements in a region can lead to low innovation performance. In addition, a necessary condition for low innovation performance in RIE is a lack of research and development personnel.

(3) Innovative elements can achieve high innovation performance in RIE through equivalent substitution. For example, regions with abundant innovation resources and a favorable innovation environment can achieve high innovation performance by weakening the impact of innovation achievements and services. When a region's innovation resources, achievements, and services can be maintained at a high level, regardless of whether the government provides research and development support, the region will achieve high innovation performance. When a region has abundant innovative achievements and high regional openness, it can reduce the impact of innovative services and achieve high innovation performance.

(4) By comparing the high-performance and non-high performance paths, it can be concluded that the Resource Achievement Dual Drive Type highlights the synergistic role of resources and achievements, suggesting that regions combining strong resource endowments with effective knowledge application achieve superior innovation performance. Conversely, the Talent Scarcity Type underscores the critical role of human capital, as its absence severely limits regional innovation potential.

7. Conclusions

This study investigates how value is co-created in Regional Innovation Ecosystems (RIE) by integrating the perspectives of innovation value chain and innovation ecosystem. Using data from 31 Chinese provinces, we constructed a four-dimensional analytical framework encompassing innovation resources, services, outcomes, and environment. The study used fuzzy-set Qualitative Comparative Analysis (fsQCA) and Artificial Neural Networks (ANN) to explore multiple configuration paths that influence regional innovation performance.

The findings reveal that high innovation performance can be achieved through several distinct combinations of conditions, illustrating the principle of equifinality. Innovation resources and outcomes were identified as core conditions in most high-performing configurations, while services and environment often acted as complementary or substitutive elements. In contrast, configurations lacking critical elements, particularly innovation outcomes or supportive environments were associated with low or medium performance.

This research contributes to the literature by offering a more integrative and systematic framework to understand value creation within RIE. Methodologically, it demonstrates the utility of combining fsQCA with ANN-based interpretability tools to uncover complex causal configurations. The findings also provide practical insights for policymakers, suggesting that different regions may achieve innovation success through differentiated paths aligned with their unique strengths and resource conditions.

However, the study has several limitations. It relies on secondary, cross-sectional data at the provincial level, which may mask micro-level heterogeneity. Additionally, although fsQCA offers configurational insight, it does not fully address causal identification or unobserved confounders.

Future research could address these limitations by collecting longitudinal data at finer spatial scales and employing advanced causal inference approaches, such as panel QCA, dynamic configurational modeling, or machine learning–based IV construction. These enhancements would further improve the robust.

8. Research value

8.1. Theoretical values

In summary, the theoretical contributions of our paper are mainly reflected in the following two aspects.

Firstly, our study integrates the innovation value chain and innovation ecosystem perspectives into a unified analytical framework that captures both structural and ecological dimensions of value creation. This framework addresses previous research gaps by illustrating how innovation resources, services, outcomes, and environment jointly shape regional innovation performance through complex interdependencies. Secondly, it enriches methodological approaches in this field by combining fuzzy-set Qualitative Comparative Analysis (fsQCA) with Artificial Neural Networks (ANN). This hybrid approach improves the explanatory power and interpretability of configurational results, providing a novel way to explore multi-factor causality in complex innovation systems.

8.2. Practical values

The configurational analysis reveals that different regions achieve innovation performance through varying combinations of conditions. Therefore, a one-size-fits-all policy approach would be insufficient. Instead, policy measures should be tailored to the specific strengths and weaknesses of each regional configuration.

For areas with strong R&D investment and output performance, efforts should shift toward improving the efficiency of outcome transformation. This includes establishing dedicated technology transfer institutions, incentivizing industry–university collaborative research, and implementing performance-based funding mechanisms to encourage the commercialization of research outcomes. In regions where institutional and environmental support is the dominant driver of innovation performance, but innovation services remain weak, policymakers should focus on enhancing the local innovation service infrastructure. This could involve expanding public incubators, innovation service vouchers, and platforms for specialized talent and technical guidance, particularly for small and medium-sized enterprises.

In underperforming regions, where innovation resources are present but disconnected from outcomes due to missing service or environmental support, policy efforts should emphasize integrated ecosystem development. Rather than increasing R&D input alone, it is essential to improve regulatory transparency, optimize funding allocation mechanisms, and foster innovation-oriented spatial planning. Building regional innovation clusters, promoting cross-regional collaboration, and developing professional intermediaries such as technology brokers may help close the coordination gap.

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References

Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, *31*(3), 306–333. https://doi.org/10.1002/smj.821

Chen, Y., Huang, S., & Wang, S. (2022). The operational efficiency of China's regional innovation ecosystem: Based on the perspective of the innovation value chain. *Science Research Management*, *43*(7), 11–19.

Dai, S. (2025). Understanding automation's impact on ecological footprint: Theory and empirical evidence from Europe. *Environmental and Resource Economics*, *88*, 503–532. https://doi.org/10.1007/s10640-024-00938-y

Du, Y., & Jia, L. (2017). Configuration perspective and Qualitative Comparative Analysis (QCA): A new path in management research. *Management World*, *23*(6), 155–167.

Fan, F., Dai, S., Zhang, K., & Ke, H. (2021). Innovation agglomeration and urban hierarchy: Evidence from Chinese cities. *Applied Economics*, *53*(54), 6300–6318. https://doi.org/10.1080/00036846.2021.1937507

Fernandes, C., Farinha, L., Ferreira, J. J., Asheim, B., & Rutten, R., (2020). Regional innovation systems: What can we learn from 25 years of scientific achievements?. *Regional Studies*, *55*(3), 377–389. https://doi.org/10.1080/00343404.2020.1782878

Fiss, P. C. (2007). A set-theoretic approach to organizational configurations. *The Academy of Management Review*, *32*(4), 1180–1198. https://doi.org/10.5465/amr.2007.26586092

Fiss, P. C. (2011). Building better causal theories: A fuzzy set approach to typologies in organization research. *Academy of Management Journal*, *54*(2), 393–420. https://doi.org/10.5465/amj.2011.60263120

Furnari, S., Crilly, D., Misangyi, V., Greckhamer, T., Fiss, P. C., & Aguilera, R. V. (2021). Capturing causal complexity: Heuristics for configurational theorizing. *The Academy of Management Review*, *46*(4), 778–799. https://doi.org/10.5465/amr.2019.0298

Gao, S., & Tan, J. (2021). The continuous evolution mechanism of innovation ecosystem: Based on the perspective of government and enterprises. *Studies in Science of Science*, *39*(5), 900–908. https://doi.org/10.16192/j.cnki.1003-2053.2021.05.009.

Hansen, M. T., & Birkinshaw, J. (2007). The innovation value chain. *Harvard Business Review*, *85*(6), 121–130.

Jagódka, M., & Snarska, M. (2023). Regional disparities as a result of differences in human capital and innovativeness on the example of Poland. *Technological and Economic Development of Economy*, *29*(2), 696–716. https://doi.org/10.3846/tede.2023.18536

Kulkov, I., Ivanova-Gongne, M., Bertello, A., Makkonen, H., Kulkova, J., Rohrbeck, R., & Ferraris, A. (2023). Technology entrepreneurship in healthcare: Challenges and opportunities for value creation. *Journal of Innovation & Knowledge*, *8*(2), Article 100365. https://doi.org/10.1016/j.jik.2023.100365

Li, B., Xu, Z., Wu, H., Hong, N., & Skare, M. (2023). Open innovation: A research framework and case study of Huawei. *Technological and Economic Development of Economy*, *29*(1), 278–306. https://doi.org/10.3846/tede.2023.17843

Li, F., Aw, E. C.-X., Tan, G. W.-H., Cham, T.-H., & Ooi, K.-B. (2022). The Eureka moment in understanding luxury brand purchases! A non-linear fsQCA-ANN approach. *Journal of Retailing and Consumer Services*, *68*, Article 103039. https://doi.org/10.1016/j.jretconser.2022.103039

Li, S., & Zhu, S. (2021). Has technology evaluation effectively promoted regional technological innovation – from a policy driven perspective. *Science Research Management*, *42*(7), 11–21.

Li, X., & Zhang, X. (2019). Research on the impact of regional innovation ecosystem symbiosis on regional science and technology innovation. *Studies in Science of Science*, *37*(5), 909–918. https://doi.org/10.16192/j.cnki.1003-2053.2019.05.017.

Li, Y.-R. (2021). The technological roadmap of Cisco's business ecosystem. *Technovation*, *29*(5), 379–386. https://doi.org/10.1016/j.technovation.2009.01.007

Liu, Y., & Wang, Q. (2021). New paradigm of innovation management research: Innovation ecosystem management. *Science of Science and Manage of S.&.T.*, *42*(10), 20–33.

Liu, P., Zhu, B., Yang, M., & De Baets, B. (2024). High-quality marine economic development in China from the perspective of green total factor productivity growth: Dynamic changes and improvement strategies. *Technological and Economic Development of Economy*, *30*(6), 1572–1597. https://doi.org/10.3846/tede.2024.22018

Long, Y. Gu, X. & Liao, Y. (2018). Research on master-slave coordination of industrial technology innovation based on knowledge ecological transformation. *Science and Technology Management*, *39*(2), 104–115.

Long, Y., & Liu, P. (2021). Study on coordination of industrial technology ambidextrous innovation in knowledge ecology spiral. *Kybernetes*, *50*(12), 3246–3268. https://doi.org/10.1108/K-07-2020-0479

Long, Y. Zeng, Q., & Chen, Q. (2023). An innovation subsidy of industrial generic technology based knowledge niche debugging. *Engineering Letters*, *31*(3), 47–59.

Nylund, P. A., Brem, A., Chaudhary, P., & D'alberti, F. (2024). The impact of crisis on interecosystemic innovation: Dynamics of enel's hydrogen ecosystem. *International Journal of Innovation Management*, *28*(1–2), Article 2450006. https://doi.org/10.1142/S1363919624500063

Oh, D.-S., Phillips, F., Park, S., & Lee, E. (2016). Innovation ecosystems: A critical examination. *Technovation*, *54*, 1–6. https://doi.org/10.1016/j.technovation.2016.02.004

Ragin, C. (2010). *Redesigning social inquiry*: *Fuzzy sets and beyond*. University of Chicago Press.

Ritala, P., Agouridas, V., Assimakopoulos, D., & Gies, O. (2013). Value creation and capture mechanisms in innovation ecosystems: A comparative case study. *International Journal of Technology Management*, *63*(3/4), 244–267. https://doi.org/10.1504/ijtm.2013.056900.

Ruan, R., & Chen, W. (2024). Research on the impact of geographic distance on corporate technology for social good: From the perspective of institutional environment and regional innovation capability. *Journal of Cleaner Production*, *457*, Article 142391. https://doi.org/10.1016/j.jclepro.2024.142391

Shah, A. k., Yu, J., Sukamani, D., & Kusi, M. (2022). Influence of agile leadership on project success; a moderated mediation study on construction firms in Nepal. *Engineering Letters*, *30*(2), 463–476.

Shang, M., Jia, C., Zhong, L., & Cao, J. (2024). What determines the performance of digital transformation in manufacturing enterprises? A study on the linkage effects based on fs/QCA method. *Journal of Cleaner Production*, *450*, Article 141856. https://doi.org/10.1016/j.jclepro.2024.141856

Tang, K., Ouyang, J., Zhen, J., & Ren, H. (2021). How does the regional innovation ecosystem drive innovation performance – Qualitative comparative analysis of Fuzzy set based on 31 provinces and cities. *Science of Science and Management of S.*&*.T.*, *42*(7), 53–72.

Tura, N., Kutvonen, A., & Ritala, P. (2017). Platform design framework: Conceptualisation and application. *Technology Analysis* & *Strategic Management*, *30*(8), 881–894. https://doi.org/10.1080/09537325.2017.1390220.

Woodside, A. G. (2014). Embrace perform model: Complexity theory, contrarian case analysis, and multiple realities. *Journal of Business Research*, *67*(12), 2495–2503. https://doi.org/10.1016/j.jbusres.2014.07.006

Wu, L.-C. (2023). Formulated optimal solution for EOQ Model with Fuzzy Demand. *International Journal of Computer Science*, *50*(3), 890–898.

Xie, X., & Liu, X. (2021). Evaluation and prediction of ecological niche suitability of regional innovation ecosystem: An empirical study based on data from 30 provinces and cities in China from 2009 to 2018. *Studies in Science of Science*, *39*(9), 1706–1719.

Yang, G., Bai, X., & Yang, S. (2023a). Analysis strategy configurations in risk taking using fuzzy set qualitative comparative analysis model. *Technological and Economic Development of Economy*, *29*(3), 981–1004. https://doi.org/10.3846/tede.2023.18779

Yang, Y., Chen, W., & Gu, R. (2023b). How does digital infrastructure affect industrial eco-efficiency? Considering the threshold effect of regional collaborative innovation. *Journal of Cleaner Production*, *427*, Article 139248. https://doi.org/10.1016/j.jclepro.2023.139248

Yuko, O., & Junichi, L. (2018). An empirical analysis of the dependence structure of international equity and bond markets using regime-switching Copula Model. *International Journal of Applied Mathematics*, *48*(2), 191–205.

Zhang, M., Li, B., & Yin, S. (2020). Configurational paths to regional innovation performance: The interplay of innovation elements based on a fuzzy-set qualitative comparative analysis approach. *Technology Analysis and Strategic Management*, *32*(12), 1422–1435. https://doi.org/10.1080/09537325.2020.1773423

Zhang, S., & Wang, Q. (2021). Exploratory research on the regional innovation development path of the same way but different road – configuration analysis based on the theoretical framework of innovation system symbiosis. *Studies in Science of Science*, *39*(2), 233–243.

Zhang, Y., Song, W., Wu, X., Zhang, W., & Zhang, J. (2021). The multiple concurrent causal relationships and multiple paths of technological innovation driving industrial upgrading. *Science Research Management*, *42*(12), 19–28.

Zhang, Z., Wang, L., & Song, Y. (2022). How does the business environment ecology drive urban innovation performance – Qualitative comparative analysis of Fuzzy set based on innovative cities. *R* & *D Management*, *34*(3), 24–40.

Zhao, F., Hu, S., Liu, Q., Chen, Y., & Hu, W. (2021). Factor identification, configuration configuration and breakthrough path of high incubation performance of science and technology Business incubator: Multi factor configuration analysis based on fsQCA. *Science* & *Technology Progress and Policy*, *38*, 8–17.

Zhu, G., Sai, F., & Qin, Z. (2021). Identification of key influencing factors and development paths of innovation level in China's provinces: A qualitative comparative analysis based on Fuzzy set. *Science of Science and Manage of S.*&*.T.*, *42*(9), 52–70.