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How to Improve Regional Innovation Quality From the Perspective of Green Development? Findings From Entropy Weight Method and Fuzzy-Set Qualitative Comparative Analysis

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ABSTRACT Innovation is increasingly becoming the most crucial and effective way to tackle climate change and environmental pollution. Recently, innovation quality has received continuous attention from scholars, entrepreneurs and policymakers. It is necessary to measure innovation quality from the perspective of green development. Based on the statistics data of 30 provincial-level innovation systems in China, this study comprehensively evaluates regional innovation quality and identifies the configuration of factors which could lead to high regional innovation quality. Firstly, this study establishes an indicator system of measuring regional innovation quality which includes seven indicators from three aspects of technological, economic and ecological benefit of innovative activities, and entropy weight method is used to comprehensively evaluate regional innovation quality. The result reveals there are big differences between different regions in China in innovation quality. In terms of three economic regions in China, innovation quality in the eastern region is the highest, followed by the central region and the lowest in the western region. Then, fuzzy-set qualitative comparative analysis method is applied, which uncovers three configurations of factors that could lead to high regional innovation quality. Finally, the conclusion of this study provides policy pathways for improving regional innovation quality.

INDEX TERMS Regional innovation quality, configuration of factors, entropy weight method, fuzzy-set qualitative comparative analysis, china, green development perspective.

I. INTRODUCTION

Facing increasingly serious climate change and environmental pollution, every country in the world takes active measures to deal with them and seek for green development. Undoubtedly, innovation is increasingly becoming the most effective way to achieve green development goals and is considered as the main drivers of economic growth as well [1], [2]. As we all know, technology innovation is a double-edged sword, bringing with it both benefits and hazards. With the continuous improvement of technology level, the way of life and production is changed, making life more convenient, and productivity more efficient. Meanwhile, the scale of human impact has been greatly increased by technological development, but the serious environmental problems like severe climate change, chemical pollution, disappearance of natural forests, and loss of biodiversity, have threatened the functional and structural integrity of ecosystems, which to an extent also risk the collapse of human societies [3]. Therefore, the quality of innovation deserves close attention, and how to improve innovation quality from the perspective of green development has become an increasingly important issue.

In recent years, as the world's most populous country, and the second largest economy in the world, China is undergoing serious environmental problems including frequent pollution and haze [2]. China's environmental pollution mainly comes from the atmospheric pollutants and discharge of industrial wastewater [2]. As the innovation-driven development strategy has been implemented and the goal of pursuing high-quality economic development has been set

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in China, it is urgently needed to evaluate the quality of innovation-driven development. In terms of quality, it has been recognized by scholars to extend the scope of quality to ecological aspects, which emphasizes the harmonious development of nature, society and economy [4]. In respect to the quality of innovation, existing researches mainly define innovation quality from the perspective of enterprises themselves [5]–[7], but ignore the impact of enterprise innovation on the natural environment, and fail to examine the innovation quality of enterprises from the perspective of green development.

In addition, in existing researches, it is scarce to define and evaluate innovation quality from the perspective of regional innovation systems. The geographic agglomeration of innovative activities differs between regions, which highlights the significance of the regional innovation systems for analyzing innovation activities [8], [9]. It is suitable for China to analyze innovation quality of provincial-level innovation systems for the reason that each province in China has different innovation resource endowments, regional industrial policy, and technical devotion, and more importantly data on innovation activities are available annually in each province [10]. In the perspective of regional green development, technological, economic and ecological benefit of innovative activities in regional innovation systems are all relatively high. Therefore, this study builds indicators system in which the seven indicators come from three aspects of technological, economic and ecological benefit of innovative activities, and uses entropy weight method to measure the innovation quality of provincial-level innovation systems in China. In respect to influence factors of regional innovation quality, this study chooses eight factors from the perspective of regional innovation system. As there is the relationship of mutual penetration and influence between different influence factors of regional innovation quality, it is inadaptable to explore the effect of factors on regional innovation quality using traditional statistical approaches for the reason that traditional statistical approaches are focused on net effect between variables. However, the fuzzy set qualitative comparative analysis (fsQCA) method is suitable for investigating the promotion mechanism of regional innovation quality, as it allows the combined analysis of the factors that lead to a certain outcome [11].

The purpose of this study is to identify the development situation and the improving path of regional innovation quality in China. Therefore, based on the above analysis, this study considers 30 provincial-level innovation systems in the year of 2016 as research object. Entropy weight method is used to evaluate regional innovation quality comprehensively and the fsQCA method is adopted to explore the configurations of factors for improving regional innovation quality.

This study makes several contributions as follows. At first, with past studies focusing on the economic and technological benefits of innovation quality and neglecting the ecological benefits of innovation quality, this research provides new insights into the evaluation of regional innovation quality from the perspective of green development, which will provide a theoretical foundation for regional policymakers to accelerate high-quality economic development. Moreover, existing studies tend to use statistical regression method to explore the influencing mechanism of innovation quality, which ignores the interaction between influencing factors. This study makes up for the limitations of existing research by utilizing the fsQCA method to identify the configurations of factors for improving regional innovation quality, which will help regional governments in China effectively confirm the improving path of regional innovation quality. At the same time, it will offer an important reference for other developing countries to achieve high-quality development.

This study is arranged as follows. Following the introduction in section 1, the next section discusses the theoretical background and summarizes literature review. In section 3, the research methods including entropy weight method and fuzzy-set qualitative comparative analysis method are introduced, and the materials including the measurement of variables and data source are described. The research results are discussed in section 4. Section 5 presents the key findings, theoretical and policy implications of this study. Limitations and future research are proposed in section 6.

II. THEORETICAL BACKGROUND

A. REGIONAL INNOVATION QUALITY

What is quality? Unlike standard factors, such as value, momentum, and size, ''quality'' lacks a commonly accepted definition, some practitioners define quality to be various signals or combinations of signals [12]. The concept of quality has gone through the evolution from focusing on products, customers and related parties to focusing on the natural environment, which is the concept of ecological quality [4]. Ecological quality advocates to introduce the concept of ecology into the whole process of quality formation, not only considering the quality of expected products, but also considering the control of unexpected products to pursue the comprehensive benefits of ecology and economy [4]. With respect to the concept of innovation quality, there are three levels: a product/service level, a process level and an enterprise level [5], [6]. The concept of innovation quality therefore allows making a statement regarding the aggregated innovation performance in every domain within an organization by comparing the result, being it a product, process or service innovation, with the potential and considering the process on how the result has been achieved [5]. With respect to innovation quality of industry, the innovation quality of high-tech industry is the degree to which the innovation of high-tech industry meets the development requirements of the industry itself and the related medium and low technology industries, including innovation generation quality, innovation application quality, innovation diffusion quality and innovation transformation quality [7]. So far, the concept of innovation quality has been not focused on ecological and green development dimensions in existing researches. Regions are increasingly recognized as key loci of national and supra-national innovation performance [13], [14]. It is necessary to measure innovation quality from a perspective of regional innovation systems. From the perspective of regional innovation system, the quality of innovation should not only consider the benefits of innovation subjects, but also take into account the development of the whole system. Besides, changing users' needs are an important factor in provoking innovation activities and promoting innovation quality [15]. Therefore, in our research, regional innovation quality refers to the extent to which the innovation achievements meet users' needs and promote the level of green development of regional innovation systems. Innovation activities will bring three benefits to the regional innovation systems, including technological benefit, economic benefit and ecological benefit. Therefore, this study measures regional innovation quality using multiple indicators which come from three aspects of technological benefit, economic benefit and ecological benefit of regional innovation activities.

In our research, regional innovation quality is synthesized by the multiple indicators and their weight values which were calculated by entropy weight method. Therefore, regional innovation quality synthesized indexes could reflect regional innovation quality comprehensively from a perspective of green development.

B. INFLUENCE FACTORS OF REGIONAL INNOVATION QUALITY

1) INDUSTRIAL STRUCTURE

Region is a complex innovation system, which includes innovation subjects, innovation resources and innovation environment [16]. Innovation subjects includes enterprises, universities, scientific research institutions and financing institutions and so on, in which enterprises are most important innovation subjects for the reason that they could make innovation achievement realize economic value truly, and the technological capabilities of a nation's enterprises are the key source of their competitive power [17]. To promote high-quality economic development, the Chinese government has focused its efforts on promoting the transformation and upgrading of the industrial structure. In this aspect of innovative subject, industrial structure has a profound impact on the improvement of innovation quality. In this study, industrial structure is considered as important influence factor of regional innovation quality.

2) INNOVATION INPUT

Whatever the subject of innovation is, innovation resources are essential. Innovation input resources including research and development (R&D) expenditure and R&D personnel play critical role in promoting level of innovation output [18], [19]. Similarly, R&D expenditure and R&D personnel are considered as important influence factors for improving regional innovation quality in this study.

3) GOVERNMENT PARTICIPATION

In addition to innovation subjects and resources, innovation environment also plays an important auxiliary role in improving regional innovation quality. Regional innovation environment includes regional culture, regional politics and regional institution [16], in which governmental participation in innovative activities is one critical factor of regional innovation quality for developing countries. Besides more direct interventions in relation to specific innovations, government imposes standards and regulations, making domestic interaction more efficient [15]. The improvement of regional innovation quality cannot be separated from the active participation of the government, which includes government financial support for innovation and government regulation of environment [20]. Governmental financial support for innovation is significant determinant of innovation quality for the reason that a large number of money is needed for regional innovative subjects to carry out innovative activities [21]. Environmental regulation could effectively reduce carbon emissions and other pollutants [22] and promote the sustainable development of economy [22], [23]. Therefore, Governmental financial support for innovation and environment regulation are regarded as important factors of regional innovation quality in our research.

Besides, innovation environment like regional digitization, openness and marketization also are indispensable factors for promoting innovation quality in regional innovation systems.

4) DIGITIZATION

With the wide application of digital technology, regional digitization level has a great effect on regional innovation quality, because that digital technology can provide firms with important information about what consumers really need by obtaining a large number of data related to their behaviors and product usage (e.g. through big data and Internet of things) [25], [26].

5) OPENNESS

In the era of open innovation, international trade can improve the level of innovation [27], and exports and imports served as channels for technology spillovers are positively associated with innovation performance in Chinese high-tech firms [28]. Therefore, regional openness has a positive effect on innovation quality [29].

6) MARKETIZATION

In China, the market plays a decisive role in the allocation of innovative resources and it could choose the innovation subjects according to their innovation quality. The marketization degree has significant positive influence on regional innovation quality in China [30].

According to Lundvall' innovation system theory, the process of innovation is regarded as the outcome of a complex interaction [15]. Therefore, these aforementioned factors interact and influence innovation quality in regional innovation systems, rather than each factor affecting innovation quality alone. The conceptual framework in this study is shown as Figure 1.

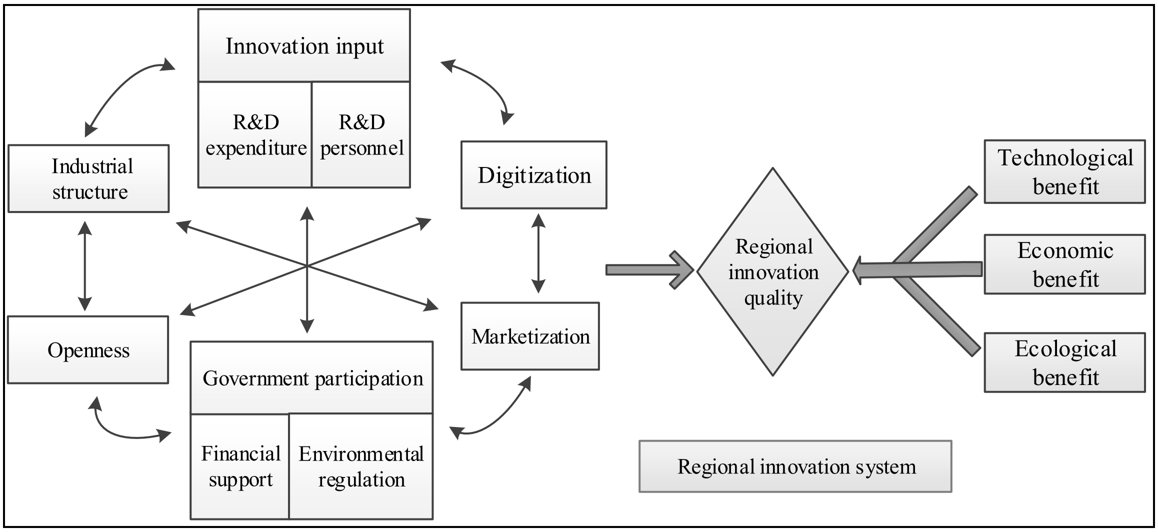

FIGURE 1. The conceptual framework.

III. METHODS AND MATERIALS

A. ENTROPY WEIGHT METHOD

The entropy weight method is an objective method for determining the weight of evaluating indicators, which has been widely used in many fields such as economy, engineering, finance and so on [31]. For different types of data, weight calculation can be divided into subjective method and objective method. Subjective method including analytic hierarchy method, subjective weighting method, Delphi method and comparison weighting method, mainly depends on experts' experience, which will likely lead to biased results by personal judgement. Objective method including entropy weight method, mean square method, principal component analysis method, coefficient of variation method, mainly relies on data collected, which has high accuracy in weight identification [32]. Therefore, this study adopted entropy weight method to determine the weight of evaluating indicators because of the advantage of fully focusing on the initial data of the sample. Information entropy can measure the disorder degree of a system and the amount of useful information that data provides [31], [33]. When the difference of the value among the evaluating objects on the same indicator is higher, while the entropy is smaller, it manifests that this indicator provides more useful information than other indicators, accordingly, the weight value of this indicator will be higher. On the other hand, if the difference is smaller and the entropy is higher, the relative weight will be smaller [31], [33].

Before carrying out the entropy weight method, it is needed to make all indicators dimensionless when not all indicators are positive. Dimensionless method includes standardized treatment method, linear proportional method, extreme value processing method, vector gauge method, and efficiency coefficient method. It has been proved by other studies that extreme value processing is the best method among the aforementioned methods [34]. Therefore, our research uses extreme value processing method to make each indicator dimensionless.

The calculation process of the entropy weight method is as follows [31], [35]:

(1) Making each indicator dimensionless using extreme value processing method

Among these indicators, to which the bigger the better, there are

$$\gamma_{ij} = \frac{x_{ij} - x_{i\min}}{x_{i\max} - x_{i\min}} \tag{1}$$

Which the smaller the better, there are

$$\gamma_{ij} = \frac{x_{i\max} - x_{ij}}{x_{i\max} - x_{i\min}} \tag{2}$$

where, $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$; γ_{ij} is the normalized value of the j-th evaluation indicator of the i-th evaluation object; x_{ij} is the original value of the j-th evaluation indicator of the i-th evaluation object before standardization; $x_{i\min}$ and $x_{i\max}$ are the minimal and the maximal value of the j-th indicator, respectively.

(2) Calculating the weight of each evaluation indicator p_{ij}

$$p_{ij} = \frac{\gamma_{ij}}{\sum_{i=1}^{n} \gamma_{ij}} \tag{3}$$

(3) Calculating the indicator entropy value e_j

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{4}$$

where, $k > 0$, $e_j > 0$, $k = 1/\ln n$, When

$$p_{ij} = 0, p_{ij} \ln p_{ij} = 0.$$

(4) Calculating the difference coefficient of the indicator g_j

$$g_j = 1 - e_j \tag{5}$$

(5) Determining the weight value of each indicator a_j

$$a_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{6}$$

(6) Calculating comprehensive evaluation value of each evaluation object v_i

$$v_i = \sum_{j=1}^{m} a_j p_{ij} \tag{7}$$

In this study, v_i refers to the regional innovation quality of i-th regional innovation system.

B. FUZZY-SET QUALITATIVE COMPARATIVE ANALYSIS

To analyze the improving path of regional innovation quality by considering the interactions between multiple factors, traditional statistical methods have limitations because they focus on net effects of factors on a certain outcome and fuzzy-set qualitative comparative analysis method has advantages in this respect. Fuzzy-set qualitative comparative analysis method is based on set-theory, which is a kind of qualitative comparative analysis method built by Ragin in 1987 [36]. The method of qualitative comparative analysis is divided into three categories according to the types of variables: clear-set qualitative comparative analysis, multiple value qualitative comparative analysis and fuzzy-set qualitative comparative analysis. The focus of this method is on set relation between outcome variable and causal variables rather than correlational connections between dependent variable and independent variables like the regression method [11]. QCA regards case studied as configuration of conditions to analyze the set relation between causal variables and outcome variable of each case. As the data used in this study is continuous, fuzzy-set qualitative comparative analysis (fsQCA) is more suitable than the other two, because fsQCA is based on fuzzy set theory and can transform the variables to values between 0 and 1 through calibration procedures [37]. fsQCA approach can provide parsimonious, intermediate and complex solutions based on both easy and difficult counterfactuals. In general, intermediate solutions are preferred because they are often the most interpretable [11].

Because fsQCA method is built on logic and not on probabilities, it do not have coefficients of determination or significance testing [38]. Instead, the models are appraised on the basis of consistency with respect to the proportion of observations that yield the dominant outcome [39] and coverage which assesses the proportion of cases following each path [11]. The consistency can determine whether the causal condition is a necessary condition for the outcome variable. The formula that measures the consistency of the subset relationship for a necessary condition is [11]:

$$Consistency(Y_i \le X_i) = \sum(\min(X_i, Y_i)) / \sum(Y_i) \tag{8}$$

where X_i means the membership score of case i in the causal condition, Y_i means the membership score of case i in the outcome variable. When all Y_i values are less than or equal to their corresponding X_i values, this formula returns a value of 1.0. Conventionally, a condition is ''necessary'' if its consistency score exceeds the threshold of 0.9 [40]. A necessary condition means that whenever the outcome occurs, the causal condition also occurs [41]. When performing fsQCA model, necessary condition should need to be removed in advance.

C. MEASUREMENT OF VARIABLES

1) OUTCOME VARIABLES

Regional innovation quality was considered as outcome variable when performing fsQCA method. In this study, regional innovation quality is a synthesized index which has been synthesized by multiple indicators on behalf of technological, economic and ecological benefit of innovative activities, respectively.

In the aspect of technological benefit, patents are generally regarded as the best indicator to measure the level of technological innovation [38], [42]. Patents include invention patents, utility model patents and appearance design patents, among which invention patents have the highest technical content and their innovation quality is relatively high. The proportion of the number of invention patents granted to the total number of patents granted is regarded as the proxy variable of regional innovation quality in the aspect of technological benefit [43]. The higher the proportion is, the higher regional innovation quality is.

In the aspect of economic benefit, the sales revenue of new products can measure the acceptance of innovation achievements in the market and reflect the economic value of innovation achievements [44], this paper uses the ratio of new product sales revenue to main business revenue to represent the innovation quality in the aspect of economic benefits. The higher the ratio is, the higher the degree to which the new products developed in the region meet users' needs, and thus the higher regional innovation quality is.

Innovation will improve the region's ecological environment and mitigate climate change, such as reducing energy consumption, waste gas and water emission [45], [46]. In the aspect of ecological benefit, energy consumption, waste water and waste gas emissions per unit of output can represent the level of innovation quality. The less energy consumption, waste gas and water emission per unit of output is, the higher the innovation quality is. In this study, we chose five indexes to measure regional innovation quality in the aspect of ecological benefit, they are energy consumption per unit of output, waste water discharge per unit of output, SO_2 emission per unit of output, nitrogen oxide emission per unit of output and dust emission per unit of output. The output of regional innovation system refers to gross regional domestic product in this study. In our research, regional innovation quality is synthesized by the aforementioned seven indexes and their weight values which are calculated by entropy weight method.

2) CAUSAL VARIABLES

The influence factors of regional innovation quality were considered as the causal variables in fsQCA model. The measurement of each variable is described as follows.

In terms of industrial structure, this study measured industrial structure from the perspective of industrial structure optimization. The optimization of the industrial structure is the process of the transformation from the primary industry to the secondary industry and then to the tertiary industry [47], which will reduce environment pollution and improve regional innovation quality in ecological aspect. The characteristic of optimization of the industrial structure is that the proportion of primary industry is gradually declining and the growth rate of tertiary industry is higher than that of secondary industry [47]. Therefore, this study measured optimization of industrial structure adapting "the ratio of tertiary industry to secondary industry" [47], [48]. With respect to innovation resource, R&D expenditure refers to the total amount of R&D expenditure on basic research, applied research and experimental development in this study. In the existing researches, there are two indicators to represent R&D personnel——the number of R&D personnel and R&D personnel full-time equivalents [38]. Because the latter is more indicative of the actual workload of R&D personnel than the former, this study chooses R&D personnel full-time equivalents to measure R&D personnel.

Referring to the study of Li, governmental financial support for innovation was measured by "the proportion of local fiscal expenditure on science and technology in GDP" [49]. With respect to the measurement of environmental regulation, there are so many proxies including the number of environmental regulation policy [50], investment in environmental governance [51], environmental policy performance [52] and so on. This study adopted environmental policy performance to measure environmental regulation level for the reason that environmental policy performance can truly measure the effect of environmental regulation, the comprehensive utilization of solid waste was employed to be a proxy indicator of environmental regulation [52].

Digitization level was measured by "the whole society fixed assets investment in information transmission, computer service and software industry" [53], [54]. Marketization degree was measured by "the proportion of the number of non-state-owned employees in the total number of employees" [50]. Regional openness was measured by trade openness, which was calculated by the ratio of total import and export trade to regional GDP [47], [51].

D. DATA SOURCE

The dataset used in this research is the statistical data of 30 provincial-level innovation systems in China (considering the practical situation of data shortage, we exclude the Tibet Autonomous Regions, Taiwan Province and Special Administrative Regions of Hong Kong and Macau). In this study, 30 provinces are included to evaluate regional innovation quality in China. However, 27 provinces are included to identify the configuration of factors for reaching high regional innovation quality for the reason that the raw data of proxy variable of environmental regulation in provinces of Hebei, Hainan and Qinghai are difficult to obtain. The relevant data were obtained from the China Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Statistics Yearbook on Environment, China Energy Statistical Yearbook, China Labor Statistical Yearbook and statistical yearbooks of provinces, municipalities and autonomous regions in China. The data of sample were chosen at the year of 2016, for the reason that the data from China Energy Statistical Yearbook only were updated to 2016. Only one year data in this study is used to analyze the regional innovation quality and its improving path, which is limited by the characteristic of fuzzy-set qualitative comparative analysis because this method is suitable for cross-section data.

TABLE 1. Seven indicators and their weights.

Aspects	Indicators	Weight
Technological benefit	The proportion of the number of invention patents granted to the total number of patents granted	0.1484
Economic benefit	The proportion of new product sales revenue to main business income	0.2648
Ecological benefit	Energy consumption per unit of output	0.1101
	Waste water discharge per unit of output	0.1891
	SO_2 emissions per unit of output	0.0778
	Nitrogen oxide emissions per unit of output	0.1088
	Dust emission per unit of output	0.1010

IV. RESULTS AND DISCUSSION

A. WEIGHT CALCULATION RESULT

Before evaluating innovation quality in each regional innovation system, entropy weight method was used to give weight of seven indicators chosen in our research. According to the initial indicators of 30 provinces, municipalities and autonomous regions in China in 2016, the weight value of each evaluation indicator was calculated. Seven indicators and their weights are showed in Table 1.

It can be seen in Table 1 that the weight value of the indicator "the proportion of new product sales revenue to main business income" is highest at 0.2648. Compared with the weight value of the indicator "the proportion of new product sales revenue to main business income", the weight value of the indicator "the proportion of the number of invention patents granted to the total number of patents granted" is smaller at 0.1484, which manifests the difference of innovation quality in technological benefit of innovative activities among different regions in China is smaller than that of innovation quality in economic benefit of innovative activities. New product sales depends on the commercialization of innovation achievements. It shows that there exists a large gap between different regions in China in the commercialization

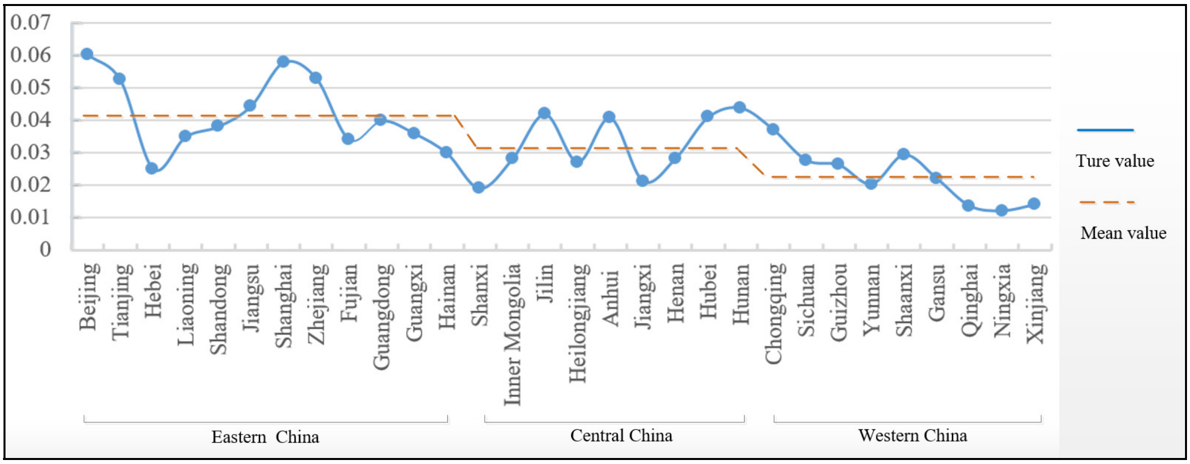

FIGURE 2. Regional innovation quality of 30 provincial-level innovation systems in China in 2016.

of innovation achievements, which should be taken seriously by regional governments.

In ecological benefit of innovative activities, waste water discharge per unit of output has the highest weight of 0.1891, while SO_2 emissions per unit of output have the lowest weight of 0.0778, which indicates that the difference of waste water discharge per unit of output among 30 provincial-regions in China is high and the difference of SO_2 emissions per unit of output are relatively small. Besides, the weight values of energy consumption per unit of output, nitrogen oxide emissions per unit of output, and dust emission per unit of output are similar, which shows the same difference in three indicators between different regions in China.

B. REGIONAL INNOVATION QUALITY CALCULATTION RESULT

Based on the weight value of seven indicators above, regional innovation quality of 30 provinces, municipalities and autonomous regions in China was calculated. Practically, regional innovation quality is a synthesized index composed of seven indicators, which are shown in Figure 2.

In this study, innovation quality refers to comprehensive innovation quality from three aspects of technological, economic and ecological benefit of innovative activities. As shown in Figure 2, in terms of innovation quality, there are big differences between different regions in China. From the perspective of provincial distribution, innovation quality of Beijing, Shanghai, Zhejiang, Tianjin is high, whose innovation quality value all has exceeded 0.05, while innovation quality of Qinghai, Ningxia, Xinjiang is low, whose innovation quality value all is lower than 0.02, which is consistent with their economic development. In terms of three economic regions in China, innovation quality in the eastern region is the highest, followed by the central region and the lowest in the western region, in which the mean value of innovation quality is 0.0422, 0.0323 and 0.0225, respectively.

In the eastern region, such as Beijing and Shanghai, there are abundant innovation resources and superior innovation environment, which leads to higher innovation quality in these regions. On the contrast, in the central and western regions, innovation resources are relatively scarce and innovation environment is limited, which may inhibit the improvement of regional innovation quality to some extent. In order to improve regional innovation quality, it is necessary to raise the level of multiple influence factors simultaneously, for the reason that the realization of innovation quality needs the joint action of many factors. In the next section, we will try to find what factors, in combination, lead to high level of regional innovation quality.

C. TRANFORMING DATA INTO FUZZY SETS

In order to perform fsQCA model, we should firstly transform the original interval-values of data into fuzzy-set value. There are two methods to calibrate data, namely direct method and indirect method. It is common that researchers use direct method to calibrate data. The direct method uses three qualitative anchors to structure calibration: the threshold for full membership (fuzzy score = 0.95), the threshold for full non-membership (fuzzy score = 0.05), and the crossover point (fuzzy score = 0.5) [11]. The three qualitative anchors are set based on the researchers' theoretical and substantive knowledge. This study sets three scale values (10th, 50th and 90th percentiles) as qualitative anchors of each variable, which codes membership as fully out of the set if a region shows values of the 10th percentile or below and fully in the set if a region shows values of the 90th percentile or higher. The crossover point is set at the 50th percentile of each variable, which is at the median. The three qualitative anchors are shown in Table 2.

D. ANALYSIS OF NECESSARY CONDITIONS

Before analyzing the configurations of influence factors for achieving regional innovation quality, we firstly have analyzed whether any single influence factor is "necessary condition" for achieving innovation quality. In Table 3, "$\sim$ riq" means the absence of regional innovation quality that is the

TABLE 2. Three qualitative anchors of each variable.

Variables	abbreviation	Full non-membership	Crossover point	Full membership
Regional innovation quality	riq	0.0180	0.0349	0.0540
R&D expenditure	rdf	700465	4195554	16582470
R&D personnel	rdp	22688.2	94755	404372
Governmental support	gov	0.0024	0.0032	0.0107
Environmental regulation	envi	0.3912	0.6411	0.9236
Marketization	mar	0.3992	0.5737	0.8028
Openness	open	0.0527	0.1209	0.7415
Digitization	data	66.9120	223.23	356.3760
Industrial structure	ind	0.8739	1.1176	1.9794

TABLE 3. Analysis of necessary conditions.

Variables	riq		~riq	
	Consistency	Coverage	Consistency	Coverage
rdf	0.7484	0.8372	0.3809	0.4784
rdp	0.7555	0.8263	0.4027	0.4944
gov	0.6627	0.6622	0.5042	0.5656
envi	0.8600	0.7939	0.4418	0.4571
mar	0.8435	0.7535	0.4832	0.4845
open	0.7727	0.8057	0.4439	0.5196
data	0.6761	0.7009	0.4811	0.5599
ind	0.5660	0.6349	0.5028	0.6331

low level of regional innovation quality. It can be seen from Table 3 that the consistency score of influence factors all are smaller than the threshold of 0.9, which indicates all influence factors are not necessary conditions for achieving regional innovation quality, whether the level of regional innovation quality is high or not. Therefore, all variables have undergone the next step.

E. CONFIGURATION OF FACTORS FOR REGIONAL INNOVATION QUALITY

In this study, the software fs/QCA 3.0 was employed to perform the fsQCA model. The minimum solution frequency was set at 1 and the consistency cutoff for the solution was set at (≥0.80), which is higher than the minimum recommended threshold of 0.75 [11]. The intermediate solution of fuzzy-set qualitative comparative analysis was chosen as configuration of factors for regional innovation quality, and the core causal conditions were conditions which appeared in both the intermediate solution and the parsimonious solution, and the contributing causal conditions were conditions which only appeared in the parsimonious solution. The results of the fsQCA are shown in Table 4.

As shown in Table 4, there exists three different configurations of factors for achieving high regional innovation quality, namely H1, H2 and H3. Three configurations of factors for achieving high regional innovation quality all get an acceptable consistency, which are all higher than 0.8. The total solution coverage is 0.6014, which accounts for larger proportions of related regions. In the three configurations of factors, R&D expenditure, R&D personnel and marketization exist in three configurations and are all core causal condition, which indicates the important role of R&D expenditure, R&D personnel and marketization in realizing high regional innovation quality. Besides, environmental regulation as the contributing causal condition exists in two configurations of factors for achieving high regional innovation quality with

TABLE 4. Configuration of factors for high regional innovation quality.

Variables	H1	H2	H3
rdf	●	●	●
rdp	●	●	●
gov	⊕	•	•
envi	•	•	⊕
mar	●	●	●
open		•	⊕
data	•		⊕
ind	⊕	•	⊕
Consistency	0.8631	0.9938	0.9578
Raw coverage	0.3073	0.3773	0.1784
Unique coverage	0.1360	0.2256	0.0582
Solution consistency		0.9172	
Solution coverage		0.6014	
Frequency cutoff		1	
Consistency cutoff		0.8863	

Note: Large full circles (●) indicate the presence of a core causal condition, large crossed-out circles (⊕) indicate the absence of a core causal condition, small full circles (•) indicate the presence of a contributing causal condition, small crossed-out circles (⊕) indicate the absence of a contributing causal condition, the blank cells represent "don't care" conditions.

the sum of unique coverage of 0.3616, which indicates that environmental regulation also is a key factor for realizing high regional innovation quality. In the first configuration H1, the combination of high level of R&D expenditures, R&D personnel, environmental regulation, marketization degree and digitization and low level of governmental support and industrial structure can generate high regional innovation quality, in which R&D expenditure, R&D personnel and marketization serve as the core causal conditions, environmental regulation, digitization, governmental support and industrial structure serve as the contributing causal conditions.

In the second configuration H2, the combination of high level of R&D expenditures, R&D personnel, governmental support, environmental regulation, marketization degree, openness and industrial structure can constitute sufficient condition for reaching high regional innovation quality, in which R&D expenditure, R&D personnel and marketization degree act as the core causal conditions, governmental support, environmental regulation, digitization, openness and industrial structure are the contributing causal conditions. In the third configuration H3, the combination of high level of R&D expenditures, R&D personnel, governmental support, marketization degree and low level of environmental regulation, digitization, openness and industrial structure can generate high regional innovation quality. Among the causal conditions, R&D expenditures, R&D personnel and marketization degree act as the core causal conditions, governmental support, environmental regulation, digitization, openness and industrial structure act as the contributing causal conditions. Comparing configuration H3 with configuration H1, it is easy to find that high environmental regulation and high digitization can be substituted by high governmental support for reaching high regional innovation quality on condition that R&D expenditure, R&D personnel and marketization degree exist at a high level in regional innovation systems. In order to reconfirm that configuration of factors could achieve high regional innovation quality rather than depending on a single factor, this study calculates configuration of factors for low regional innovation quality, which are shown in Table 5.

It can be seen from Table 5 that there are five different configurations of factors for low regional innovation quality, namely L1, L2, L3, L4 and L5. Besides, the absence of environmental regulation is in all five configurations and acts as the core causal condition, which indicates the lack of environmental regulation is an important reason for the failure of regional innovation quality and further proves the important role of environmental regulation in promoting regional innovation quality. In the first configuration L1, the combination of low level of R&D expenditures, R&D personnel, governmental support, environmental regulation, marketization degree and openness leads to low level of regional innovation quality, while in the second configuration L2, the combination of low level of R&D expenditures, R&D personnel, environmental regulation, marketization degree, openness and digitization leads to low level of regional innovation quality. In the third configuration L3, the combination of low level of R&D expenditures, R&D personnel, governmental support, environmental regulation, marketization degree, digitization and high level of industrial structure leads to low level of regional innovation quality, in which R&D expenditures, R&D personnel, environmental regulation and marketization degree serve as the core causal conditions, governmental support, digitization and industrial structure serve as the contributing causal conditions.

TABLE 5. Configuration of factors for low regional innovation quality.

Variables	L1	L2	L3	L4	L5
rdf	⊕	⊕	⊕	⊕	•
rdp	⊕	⊕	⊕	⊕	•
gov	⊕		⊕	•	⊕
envi	⊕	⊕	⊕	⊕	⊕
mar	⊕	⊕	⊕	•	⊕
open	⊕	⊕		•	⊕
data		⊕	⊕	⊕	•
ind			•	⊕	•
Consistency	0.9145	0.9482	0.9805	1	0.9725
Raw coverage	0.5021	0.5637	0.3165	0.1799	0.1484
Unique coverage	0.0231	0.1015	0.0126	0.0154	0.0154
Solution consistency			0.9172		
Solution coverage			0.6519		
Frequency cutoff			1		
Consistency cutoff			0.9217		

Note: the meaning of symbol in Table 5 is same to that of Table 4.

In the fourth configuration L4, the combination of low level of R&D expenditures, R&D personnel, environmental regulation, digitization, industrial structure and high level of governmental support, marketization degree and openness leads to low level of regional innovation quality, in which R&D expenditures, R&D personnel and environmental regulation serve as the core causal conditions, governmental support, marketization degree, openness, digitization and industrial structure serve as the contributing causal conditions. In the fifth configuration L5, the combination of high level of R&D expenditures, R&D personnel, digitization, industrial structure and low level of governmental support, environmental regulation, marketization degree and openness leads to low level of regional innovation quality. Among the causal conditions, marketization degree and environmental regulation act as the core causal conditions, the rest of the factors act as the contributing causal conditions.

Overall, in five configurations of factors for low regional innovation quality, if R&D expenditures, R&D personnel, environmental regulation and marketization degree are absent, they would act as the core causal conditions in configurations, which demonstrates their significant role in promoting regional innovation quality again. In the fourth configuration L4, the combination of high level of governmental support, marketization degree and openness cannot lead to high level of regional innovation quality, the reason may be lack of R&D expenditures, R&D personnel through a comparison of configuration L4 with configuration H3. If a regional innovation system lacks R&D expenditures, R&D personnel, it will lose the incentive and ability to innovate, even though governmental support, marketization degree and openness are high. Besides, in the fifth configuration L5, the combination of high level of R&D expenditures, R&D personnel, digitization and industrial structure cannot lead to high level of regional innovation quality, the reason may be lack of high marketization degree and high environmental regulation through a comparison of configuration L5 with configuration H1. Although R&D expenditures, R&D personnel, digitization and industrial structure are high in regional innovation systems, the lack of marketization degree will reduce competition of innovative production in the market and the lack of environmental regulation will affect the ecological benefit of innovative product, therefore, under the circumstances it is difficult to improve regional innovation quality from the perspective of green development. Then, comparing Table 5 with Table 4, we can find that the combination of high level of R&D expenditures, R&D personnel and marketization degree is necessary to realize high regional innovation quality.

V. DISCUSSION

A. KEY FINDING

The purpose of this study was to evaluate regional innovation quality in China from a perspective of green development and explore the configurations of factors for achieving high regional innovation quality. Based on the statistical data of provincial-level innovation systems in China, entropy weight method and fuzzy-set qualitative comparative analysis method were employed to achieve the objectives of our research. There are several key findings as follows. Firstly, there exists a big gap between different provinces in innovation quality. Innovation quality of Beijing, Shanghai, Zhejiang, Tianjin is high, while innovation quality of Qinghai, Ningxia, Xinjiang is low, which is consistent with their economic development. In terms of three economic regions in China, innovation quality in the eastern region is the highest, followed by the central region and the lowest in the western region.

Secondly, there are three configurations of factors for achieving high regional innovation quality. First is the combination of high level of R&D expenditures, R&D personnel, environmental regulation, marketization degree and digitization and low level of governmental support and industrial structure, second is the combination of high level of R&D expenditures, R&D personnel, governmental support, environmental regulation, marketization degree, openness and industrial structure, third is the combination of high level of R&D expenditures, R&D personnel, governmental support, marketization degree and low level of environmental regulation, digitization, openness and industrial structure, which all are sufficient conditions for reaching high regional innovation quality. R&D expenditures, R&D personnel and marketization degree are included in three configurations and act as the core causal conditions. Moreover, environmental regulation exists in two configurations of factors for achieving high regional innovation quality with a high unique coverage.

Thirdly, five configurations of factors for leading to low regional innovation quality reconfirm the important role of configurations of some factors in improving regional innovation quality. If one of R&D expenditures, R&D personnel and marketization degree is deficient, it is impossible for regional innovation systems to achieve high regional innovation quality. Besides, we find that the lack of environmental regulation is an important reason for the failure of regional innovation quality.

B. THEORETICAL IMPLICATIONS

Our researches have several theoretical implications. Above all, it is vital to evaluate innovation quality from the perspective of green development. Existing research on innovation quality mainly focuses on product innovation to meet the needs of users and bring profits to enterprises [5]–[7], which will lead to a greater environmental cost. Based on the perspective of green development, not only do innovative products meet the needs of users better, but the impact of innovation on the regional environment is also reduced. The one theoretical contribution of this study is to shed light on a new perspective in terms of the evaluation of regional innovation quality. In addition, the influence mechanism of regional innovation quality is expanded from single factor to combination of multiple factors. It is difficult for regional innovation systems to promote regional innovation quality just through raising the level of one factor, but it requires the joint improvement of multiple factors, which is different from the findings of previous studies obtained by statistical regression method [43]. Compared with statistical regression method, which can determine the net effect of a single factor on innovation quality, the fsQCA method is more practical to determine the configuration factors of innovation quality. Another theoretical contribution of this study is to confirm what factors, in combination, drive high level of regional innovation quality.

C. POLICY IMPLICATIONS

There are several policy implications for regional governments to improve regional innovation quality from the perspective of green development. Firstly, it is not enough and inappropriate to evaluate regional innovation quality only depending on technical progress and economic income generated by regional innovative activities, environmental change caused by innovation is worthy of attention. Therefore, governments should evaluate regional innovation quality in comprehensive aspects including technological, economic and ecological benefit of innovative activities. Secondly, there exist three configurations of factors for achieving high regional innovation quality, in these circumstances, regional governments can choose the most appropriate path to achieve high innovation quality according to the existing innovation resource in the regions. Finally, the combination of R&D expenditures, R&D personnel, and marketization degree exists every configurations of factors for achieving high regional innovation quality, which give policy implications that regional governments should keep these three factors at a high level to improve innovation quality. Meanwhile, the lack of environmental regulation is an important reason for the failure of regional innovation quality, for the reason that there is the absence of environmental regulation in all five configurations of factors for low regional innovation quality. It tells us that the level of environmental regulation needs to be improved to avoid low innovation quality.

VI. LIMITATIONS AND FUTURE RESEARCH

This study has some limitations that should be solved by future research. Firstly, the number of indicators measuring regional innovation quality is limited. For technological benefits there is chosen only one indicator – the number of patents. But innovative activities are not documented only by patents. Moreover, the economic benefits are represented also only by one indicator. Innovative could be connected not only with the development of new products, but also with the development of production technologies, innovation of processes, et al. Therefore, the number of indicators representing the technological and economic benefits of innovation activities should be increased in the future study. Secondly, this study has measured regional innovation quality from the three aspects of technological, economic and ecological benefits of innovative activities. Specially, innovation may bring social benefits to the region like the reduction of unemployment rate, the improvement in people's income and consumption levels, and the increase in people's happiness, which will be concerned by future research. Thirdly, the configurations of factors for reaching high regional innovation quality may vary by the scale of regional innovation systems, therefore, in the future research, the scale of regional innovation systems will be considered as contextual variable in fsQCA model to verify our findings. Finally, the influence factors of regional innovation quality are various and complex, this study only has chosen eight influence factors. Future study will extend the influence factors of regional innovation quality such as the characteristics of innovation subjects, regional financial development level, urbanization degree, et al.

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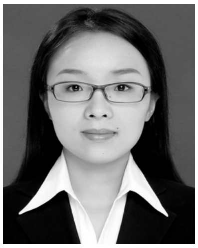

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