Study on the Regional Differences and Promotion Models of Green Technology Innovation Performance in China: Based on Entropy Weight Method and Fuzzy Set-Qualitative Comparative Analysis

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This work was supported in part by the National Natural Science Foundation of China under Grant 71562029 and Grant 71862029, and in part by the Heilongjiang Province Philosophy and Social Science Research Planning Project under Grant 18GLE476.

ABSTRACT The coordinated development of green technology innovation performance among regions is of great significance for China’s sustainable development. Therefore, it is necessary to explore the evaluation and promotion modes for green technology innovation performance. Based on the data of 30 provinces in China, this paper comprehensively evaluates regional green innovation performance and determines the factor configurations that can achieve high green technology innovation performance. This paper constructs an index system of green technology innovation from four aspects (economy, innovation, environment, and social welfare) and measures the results by the entropy weight method. The results show that green technology innovation performance decreases from the eastern region to the western region. At the province level, Ningxia, Qinghai, and Xinjiang have lower performance, while Beijing, Zhejiang and Shanghai have higher performance. The fuzzy set qualitative comparative analysis method reveals five configurations that achieve high green technology innovation performance. Specifically, regions with high green technology innovation performance tend to be those with high environmental regulation intensity and high innovation input. When environmental regulation and innovation input are both high, regions should fully consider the technology spillover effect of foreign direct investment. When energy prices is high, regions should give full play to the technology spillover effect of FDI and the transformation of market demand to reduce the pressure of production costs.

INDEX TERMS Green technology innovation performance, promotion model, regional difference, entropy weigh method, fsQCA, configuration.

I. INTRODUCTION

China is facing serious environmental and energy challenges following the economic miracle realized by its long-term adopting of an extensive economic development model [1]. The contradiction between energy supply and demand continues to intensify, and the environmental carrying capacity exceeding the limit makes the development model difficult to maintain [2]. Moreover, the contradiction between environmental protection and economic development is more prominent in China than in other countries due to the inherent shortage of ecological environment resources and rigid constraints on economic growth [3]. Therefore, coordinating the relationship between environmental protection and economic development in the new normal stage of economic development has become a key concern in academic circles and among policy makers.

Green technology innovation (GTI) is a key way to achieve a fundamental “decoupling” between economic development and environmental pollution and resource
consumption [4]. GTI promotes industrial upgrades to achieve high-quality economic development and simultaneously reduces the use of fossil fuels to achieve environmental protection [5]. The European Commission defines GTI as a general term to refer to technologies, processes and products that follow ecological principles and ecological economic laws; save resources and energy; avoid, eliminate or reduce environmental pollution; and minimize negative ecological effects [6]. GTI is an effective means of breaking the constraints of resources and environment and promoting sustainable development. However, China is a vast territory, and there are differences in available resources, economies, and other factors among regions. Several questions about these differences are of interest, for example, how to accurately measure and compare differences in regional GTI performance, and what the underlying reasons for the regional differences. Therefore, it is of great significance to grasp the current situation and promotion modes of regional GTI performance to subsequently formulate green innovation policies and realize coordinated development according to local conditions.

Scientific evaluation of GTI performance is the key to grasp regional differences in GTI performance. Different from traditional innovation, GTI is endowed with the expectation that it can reduce environmental pollution by virtue of new knowledge and new technology, which has social impacts [7]. Namely, GTI can provide not only economic benefits and innovation effects, but also environmental and social benefits. Therefore, GTI performance should be evaluated in terms of the economy, innovation, environment, and social welfare. However, previous studies have mainly evaluated GTI from the perspective of inputs and outputs, which does not fully reflect GTI performance [8], [9].

Successful GTI needs to balance the various driving forces in the innovation chain. Rennings [10] believes that there are three types of factors influencing innovation: technology-driven, market-driven, and environmental regulation, which provide a relatively complete framework. Many scholars have examined the effects of these three types of factors on GTI [11]–[15]. As in the development of smart cities, it is necessary to integrate different influencing factors of a region as a system; that is, the mutual diffusion and influence among influencing factors cannot be ignored [16]. However, traditional statistical methods only explore the “net effect” and are unable to explore the configuration effects of influencing factors on outcome variables, making it difficult to explain the reasons for regional differences in GTI performance.

The purpose of this study is to determine whether there are regional differences in China’s GTI performance and the factor configurations that lead to regional differences. Therefore, this paper takes 30 provinces in China as samples to carry out the following research: First, based on the dual attributes of innovation and green, the GTI performance evaluation system is constructed from the four aspects of the economy, innovation, environment, and social welfare and is calculated by the entropy weight method. The result is used to determine whether there are differences in regional GTI performance. Second, the fuzzy set qualitative comparative analysis (fsQCA) method explores the “multiple interactions” and “configuration paths” of influencing factors, making up for the traditional regression methods’ inability to analyze the configuration effects of influencing factors on outcome variables. Therefore, this paper adopts the fsQCA method and integrates the matching perspective of technology-driven, market-driven, and environmental regulation to explore the factor configurations leading to high (no-high) GTI performance. The result defines the reasons for regional differences in GTI performance.

The contributions of this paper are reflected in the following aspects. The GTI performance evaluation system is constructed from four aspects (economy, innovation, environment, and social welfare), which enriches and expands the research in this field. The fsQCA method is adopted in this paper, which goes beyond the study of “net effect”, clarifies the configuration effect of influencing factors, and expands the research methods in the field of GTI.

II. LITERATURE REVIEW
A. INDEX AND EVALUATION OF GTI
GTI research mainly involves GTI capability, GTI efficiency, and GTI performance. First, in terms of GTI capability. Guo et al. [17] measured the GTI capability from energy conservation and emission reduction. Li et al. [18] calculated the GTI capability from input capability and output capability. Sun et al. [19] adopted an entropy weight-TOPSIS method to measure the green innovation input, green innovation output capability, green innovation environment capability and green diffusion capability. Second, in terms of GTI efficiency, Liu et al. [20] measured the GTI efficiency of China’s high-tech industrial clusters from input and output. Huang and Wang [21] incorporated environmental pollution in the measurement and investigated the impact of high-speed rail on green innovation efficiency. Third, in terms of GTI performance. Wang and Cheng [8] measured the GTI performance from environmental performance and innovation performance. Some scholars have used single indexes for measurement, such as green process patents [22] and toxic gas emissions [23].

These studies provide a reference value, but there are still some deficiencies. First, some of the studies regarded GTI capability, GTI efficiency and GTI performance as interchangeable concepts, which is not conducive to the development of this field. Second, the evaluations are mainly constructed from the perspective of input and output, while other indicators are ignored.

B. INFLUENCING FACTORS OF GTI
According to the research of Rennings [10], scholars discussed the impact of technology-driven [12], market-driven [11], [15] and environmental regulation [24], [25] on GTI and used the structural equation method, the quantile regression method, the DEMATEL method and the Tobit
model for testing [15], [19], [23]. However, previous studies have mainly focused on the “net effect” of single factor on GTI and ignored the matching effects among multiple factors.

In the term of technology-driven. Zhang et al. [26] pointed out that technological readiness contributed significantly to green innovation. Luo et al. [27] indicated that technological progress and technological efficiency were the main reasons for efficiency improvement.

In the term of market-driven. Lin et al. [28] found that market demand positively affected green product innovation within Vietnam’s motorcycle industry. Clausen and Fichter [11] indicated that market forces effectively explained innovation diffusion.

In the term of environmental regulation. Environmental regulation can induce innovation, competition, and market entry [29], make up for or eliminate the “compliance cost”, and achieve green development. Cai et al. [30] indicated that environmental regulation positively stimulated GTI. In contrast, under static conditions, the autonomous response of enterprises is optimal [31], and the intervention of environmental regulation inevitably increases production costs [32], forcing producers to invest in pollution control, squeezing out R&D investment and hindering improvement at the innovation level. Ezzi et al. [33] pointed out that environmental regulation increased pollution control costs and weakened competitiveness. Furthermore, due to the influence of industrial development, market environments, and other factors, this relationship cannot be determined [34], [35].

C. INNOVATION AND ENVIRONMENTAL ISSUE
Technological innovation refers to the process of initial commercialization of new products, new processes, and new technologies [36], which achieve high-quality economic development and environmental pollution control by reducing carbon emissions and promoting the development of new energy [37], [38]. Koçak and Ulucak [39] indicated that R&D expenditures could reduce CO₂ emissions. Zhu et al. [40] believed that renewable energy technological innovation played an important role in controlling air pollution.

Moreover, empirical evidence on the role of GTI in maintaining the balance between promoting economic growth and reducing environmental pollution is gradually increasing. Du and Li [5] indicated that GTI positively affected carbon productivity in high-income economies. Du et al. [41] found that the impact of GTI on CO₂ emissions was non-linear, and the mitigation effect became significant for economies whose income levels exceeded a threshold.

These studies have explored the impacts of innovation on environmental problems but ignored the matching effect of multiple factors.

III. MEASUREMENT OF GTI PERFORMANCE
A. EVALUATION SYSTEM OF GTI PERFORMANCE
Innovation performance refers to the achievements made by the subject through a series of innovation and invention activities, including economic performance, innovation performance and social performance [42]. Different from traditional innovation, green innovation has the dual attributes of innovation and environmental sustainability. Green innovation achieves energy conservation and environmental protection through new products, new services, new processes, or new management systems [7], emphasizing the importance of not only for economic growth and new technology, but also for protecting the ecological environment [20].

This paper argues that GTI can not only improve resources utilization efficiency, reduce production costs and energy consumption, and improve labor and economic productivity, but also reduce the generation and emission of pollutants and improve the ecological environment. Therefore, based on the research of Brettel et al. [42], this paper incorporates environmental performance into the evaluation and measures GTI performance from four aspects: economic performance, innovation performance, environmental performance, and social performance.

First, for economic performance, the goal of GTI is to reduce pollution and maximize profits, which is reflected in the reduction of production costs and pollution control costs, and an increase in market share and the sales rate of new products. Second, for innovation performance, green process innovation or green product production carried out by new technologies can be reflected by the number of patents and green products. Third, for environmental performance, GTI can reduce pollutant emissions and energy consumption and reduce pressures on the ecological environment, such as wastewater discharge and solid waste discharge. Fourth, for social performance, green innovation not only increases the knowledge stock of the whole society but also contributes to increasing labor productivity and employment opportunities. Finally, this paper adopts the entropy weight method to determine the weighted value of each index and obtain a comprehensive value of GTI performance. The value is used to judge whether there are differences in GTI performance among regions within China.

B. ENTROPY WEIGHT METHOD AND INDICATOR
The entropy weight method is an objective method that takes the information entropy as the criterion of weight determination. According to the variation degree of each index, the entropy weight method calculates the entropy weight of each index by using information entropy, and then modifies the whole index through the entropy weight to obtain more objective index weighted values. The smaller the information entropy of a certain index is, the greater the amount of information it can provide, and the greater the weighted values. Conversely, if the entropy weight value of an index is larger, this indicates that the index can provide less information, and the weight is also smaller [43]. The calculation steps are as follows:

**Step 1: Raw Data Standardization**
Assuming that there are $m$ objects and $n$ indexes, the original matrix $Y = (y_{ij}), (i = 1, 2, ...m; j = 1, 2, ...n)$ can be
constructed. Then, the indicators are standardized.

\[ y_{ij} = \frac{y'_{ij} - \min(y'_{ij})}{\max(y'_{ij}) - \min(y'_{ij})} \]

\( y'_{ij} \) is the value of object \( i \) in index \( j \). \( \max(y'_{ij}) \) and \( \min(y'_{ij}) \) represent the maximum and minimum values of the index, respectively. Compressing the index value into an interval \([0, 1]\) gives the new matrix \( Y = (y_{ij}) \). \( i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \).

**Step 2:** Calculate the fixed indicator weight

\[ p_{ij} = y_{ij}/ \sum_{i=1}^{m} y_{ij} \]

**Step 3:** Calculate the indicator entropy \( e_{ij} \) of item \( j \)

\[ e_{ij} = -1/ \ln(m) \sum_{i=1}^{m} p_{ij} \ln p_{ij}, \quad (j = 1, 2, \ldots, n) \]

If \( p_{ij} = 0 \), then \( p_{ij} \ln p_{ij} = 0 \).

**Step 4:** Calculate the indicator weight

\[ w_{j} = (1 - e_{j})/ \sum_{j=1}^{n} (1 - e_{j}) \]

where, \( 1 - e_{j} \) represents information entropy redundancy

**Step 5:** Calculate the comprehensive evaluation value

\[ GTI_{i} = \sum_{j=1}^{n} w_{j} p_{ij} \]

In this study, GTI performance is the comprehensive value measured by economic performance, innovation performance, environmental performance, and social performance. Specific indicators are as follows:

**Economic performance:** the sales revenue of new products reflects the acceptance degree of the market for innovative achievements and represents the economic benefits of innovative achievements [44]. This paper adopts the ratio of new product sales revenue to sales expenses.

**Innovation performance:** patents cover almost all technical fields and occur almost simultaneously with innovation [45], [46]. Invention patents are new technical schemes for a product, method, or its improvements, which have high technical content. Therefore, this paper uses the ratio of the number of invention patents granted to the total number of patents granted to measure innovation performance.

**Environmental performance:** GTI can reduce pollutant emissions and energy consumption [47]. Therefore, the wastewater discharge per unit of output, sulfur dioxide emission per unit of output, smoke and dust emission per unit of output and the energy consumption per unit of output are selected to reflect the environmental performance.

**Social performance:** social welfare is mainly reflected in the quality of life, involving employment, social security, and other factors. Limited by the availability of data, this paper uses the increase in employment and social security to measure social performance.

**C. EVALUATION RESULTS AND ANALYSIS**

Based on the original data of evaluation indicators of 30 provinces, the entropy weight method is used to calculate the weight of each indicator. The results are shown in Table 1.

As shown in Table 1, the weight of economic performance is highest, at 0.2954, while the weight of innovation performance is 0.1458, which is significantly lower than the weight of economic performance. This phenomenon indicates that the difference in the economic performance of GTI performance among different regions in China is obviously greater than the difference in innovation performance. Namely, there is a significant gap in the degree of marketization of innovation achievements among regions.

In terms of environmental performance, the weight of the wastewater discharge per unit of output is highest, at 0.1470, with the other three indicators having similar weight values. These results show that there is a large difference in wastewater discharge in different regions, while the discharges of the other three pollutants are similar.

In terms of social performance, the weight of the social security increase is slightly higher than the weight of the employment increase, which indicates that the difference among GTI activities in increasing social security is significantly greater than that in increasing employment.

According to the standardized values and weighted values, the comprehensive values of GTI performance for the 30 provinces in 2017 were calculated. The results are shown in Table 2 and Figure 1.

As shown in Table 2 and Figure 1, the GTI performance in different regions of China is quite different. At the province level, Ningxia, Qinghai, and Xinjiang have lower GTI performance, while Beijing, Zhejiang and Shanghai have higher performance. From the perspective of the three economic
TABLE 2. GTI performance evaluation index and index weight.

| Region          | Eastern value | Central value | Western value |
|-----------------|---------------|---------------|---------------|
| Beijing         | 0.7958        |               |               |
| Tianjin         | 0.6969        |               |               |
| Hebei           | 0.4609        |               |               |
| Liaoning        | 0.5038        |               |               |
| Shanghai        | 0.7294        |               |               |
| Jiangsu         | 0.6652        |               |               |
| Zhejiang        | 0.7509        |               |               |
| Fujian          | 0.4794        |               |               |
| Shandong        | 0.5019        |               |               |
| Guangdong       | 0.5861        |               |               |
| Hainan          | 0.3948        |               |               |
| Mean value      | 0.5983        |               | 0.3498        |
| National average|               | 0.4884        |               |

regions, the average GTI performance in the eastern region is 0.5983, which is significantly higher than the national average of 0.4884; the average in the central region is 0.4843, which is slightly lower than the national average; and the average in the western region is 0.3585, which is significantly lower than the national average. Overall, the GTI performance decreases from the eastern region to the central and western regions.

The improvement of regional GTI performance requires raising the level of multiple influencing factors simultaneously because the realization of GTI performance requires the synergistic effect of multiple factors. Thus, this paper explores in the next section how different factors combine to lead to high GTI performance.

IV. THE PROMOTION MODEL OF GTI PERFORMANCE

A. FUZZY SET QUALITATIVE COMPARATIVE ANALYSIS METHOD

As an empirical method for complex social problems induced by multiple antecedents, qualitative comparative analysis (QCA) uses Boolean algebra to explore combinations of social problems [48]. QCA adopts a holistic perspective, which is more in line with the interdependence and multiple conjunctural causation of management practices. The holistic perspective of the QCA method is rooted in configuration thinking, which holds that “organizations cannot be understood through isolated analysis of components, which should be understood as clusters of interrelated structures and practices rather than subunits or loosely bound entities” [49].

As a subtype of the QCA method, the fsQCA method is more advantageous in factor complexity and causal asymmetry, which fully considers the subtle effects of varying degrees of factors on the result. Using the fsQCA method, researchers detect the consistency and coverage of the result of different configurations. The formulas are as follows:

\[
\text{Consistency (} X_i \leq Y_i \text{)} = \frac{\sum \text{min} (X_i, Y_i)}{\sum X_i} \\
\text{Coverage (} X_i \leq Y_i \text{)} = \frac{\sum \text{min} (X_i, Y_i)}{\sum Y_i}
\]

\(X\) represents the set of conditional variables combination, and \(Y\) represents the set of case result. Consistency examines the extent to which \(X\) can constitute a sufficient condition for \(Y\), namely, the extent to which the \(X\) set can derive the result of the \(Y\) set. Coverage examines the extent to which \(X\) can constitute the necessary condition for \(Y\), namely, the extent to which the \(X\) set can be guaranteed to be the only path to \(Y\). Coverage varies from 0 to 1, the closer to 1 means \(X\) is the only path to \(Y\).

This paper adopted the fsQCA method for analysis for the following reasons: First, the influencing factors of GTI performance are interrelated, and QCA can effectively meet the associated analytical challenges by not considering the net impact of a single variable on the outcome variable [50] but by focusing on similar or dissimilar configurations composed of multiple factors that have explanatory power for the outcome variable [51].

Second, taking 30 provinces in China as the sample, it can neither meet the needs for large samples for quantitative research nor summarize the development rules through case studies. However, the results of the QCA method depend on whether representative samples are included, and the 30 samples are moderate enough to meet the needs of the QCA method.
Third, in a country as vast and with as much regional characteristic diversity as China, factors in different regions are obviously different and are difficult to completely define by the binary assignment of 0 or 1. However, fsQCA can apply continuous or interval scale variables and effectively compensate for the defects of binary assignment [49], [52].

B. SELECTION OF INFLUENCING FACTORS
According to research by Rennings [10], there are three types of factors influencing GTI: technology-driven, market-driven, and environmental regulation. Therefore, this paper determines the influencing factors from these aspects.

1) IN ASPECT OF TECHNOLOGY-DRIVEN
Organizational innovation resources are an important internal factor for GTI. First, technical capability is an important internal resource that allows organizations to develop new products and new processes, and its improvement cannot be separated from innovation input. Innovation input is the fundamental guarantee for improving innovation capacity and long-term economic growth. Innovation input includes innovation personnel and innovation capital, this paper uses the R&D personnel and internal expenditure of R&D funds as the proxy indicator [53], and the min-max standardized treatment is used to obtain the comprehensive value.

Second, in addition to improving technical capacity through internal resource inputs, the introduction of external technology introduction can also improve technical capacity. As an important way to acquire external technology, foreign companies can bring advanced technology and management experience to host countries. Foreign investment refers to the investment behavior of foreign enterprises or foreign individuals in China for profit and their influence on market players’ innovation activities or pollution emissions. This study adopts the amount of FDI as the proxy indicator.

2) IN ASPECT OF MARKET-DRIVEN
Based on market theory, the market is an important factor that drives innovation entities to carry out GTI. First, market demand plays an important role in driving green technology innovation [14]. Market demand includes both domestic market demand and foreign market demand [47]. This study adopts regional per capita income levels and export delivery values as proxy indicators, and the min-max standardized treatment is used to obtain the comprehensive value.

Second, as a basic production factor, the marketization of energy prices directly affects production costs. The gradual increase in energy prices can drive market players to develop or introduce new technologies [54] and shift from simple reliance on energy resources to high-level capital and talent elements to optimize and upgrade the factor structure. This paper adopts the purchase price index of raw materials and fuels as the measurement indicator for energy prices. In 2011, the China Statistical Yearbook changed the purchase price index of raw materials and fuels to the purchase price index of industrial producers. Therefore, this paper adopts the purchase price index of industrial producers as the indicator.

3) IN ASPECT OF ENVIRONMENTAL REGULATION
Based on institutional theory, scholars have conducted extensive research on the relationship between environmental regulation and GTI. Previous studies used proxy indicator to measure environmental regulation, including pollution control capacity [55], pollutant emissions [56], pollution control investment [34], environmental legislations [57], comprehensive index [58], environmental regulation performance [59], and others. According to the data availability, this paper adopts the ratio of solid waste utilization to solid waste generation as the indicator.

In summary, technology is the direct driving force of GTI, market and environmental regulation being situational factors for GTI. Furthermore, GTI is a complex interactive process where factors interact and influence GTI performance. Therefore, the research framework of this paper is shown in Figure 2.

![FIGURE 2. The research framework.](image)

C. DATA SOURCES
Considering the usability of data, this study selected 30 provinces in China in 2017 as the research objects (excluding Tibet, Hong Kong, Macau, and Taiwan). GDP, patent application, foreign direct investment, energy prices, per capita income level and export delivery value are from the China Statistical Yearbook. The indicator data of energy consumption comes from the China Energy Statistical Yearbook. The statistical data of research and development investment and R&D personnel are from the China Statistical Yearbook on Science and Technology. Pollutant indicators such as wastewater discharge are from the China Environmental Statistics Yearbook. The number of employees is from the China Labor Statistics Yearbook, and the number of social securities is from the China Civil Affairs Statistics Yearbook. The ratio of sales revenue of new product to sales expenses is from the China Regional Innovation Capability Evaluation Report.

It should be noted that the 2019 China Regional Innovation Capacity Evaluation Report reflects the situation of China’s provinces in 2017. Therefore, the latest data available is 2017. Furthermore, this paper only uses one year of data to conduct the research to follow the current characteristics of the fsQCA method, which is suitable for cross-sectional data.

V. THE RESULTS OF fsQCA
A. CALIBRATION
For all factors, the original value was translated into a fuzzy membership score, ranging from 0.0 (full exclusion,
non-membership) to 1.0 (full inclusion, membership) [60]. Three key anchors were set: the full membership threshold, the crossover point threshold, and the non-membership threshold [48]. If original value overrides the 95% values, which is treated as a full membership point; if original value overrides the 50% values, which is treated as a crossover point; and if the original value overrides the 5% values, which is treated as a full non-membership. According to the research, the upper quartile, mean value, and the lower quartile were set as the calibration values [49], as shown in Table 3.

**TABLE 3. Calibration value.**

| Variable                      | Abbreviation | Calibration value |
|-------------------------------|--------------|-------------------|
|                               |              | upper quartile    | mean value | lower quartile |
| environmental regulation      | ER           | 0.8183            | 0.5690     | 0.4776        |
| innovation input              | II           | 0.2628            | 0.1704     | 0.0632        |
| foreign direct investment     | FDI          | 2715.9491         | 905.998    | 385.0074      |
| market demand                 | MD           | 0.5339            | 0.4861     | 0.4528        |
| energy prices                 | EP           | 110.65            | 107.4      | 104.8         |
| GTI performance               | GTIP         | 0.5972            | 0.4837     | 0.3883        |

**B. NECESSITY TEST**

The necessity test was performed on factors before the configuration analysis [48] to determine whether any single factor is a necessary condition for achieving GTI performance. It can be seen from Table 4 that the consistency level of all factors is lower than 0.9, which suggests that all factors are not necessary condition for achieving GTI performance, regardless of the GTI performance level.

**TABLE 4. Results of necessity test.**

| Variable   | GTI | -GTI | Variable   | GTI | -GTI |
|------------|-----|------|------------|-----|------|
|            | consistency | coverage | consistency | coverage |       |
| ER         | 0.782 | 0.804 | ER         | 0.285 | 0.295 |
| ~ER        | 0.315 | 0.304 | ~ER        | 0.812 | 0.790 |
| II         | 0.826 | 0.840 | II         | 0.275 | 0.283 |
| ~II        | 0.295 | 0.288 | ~II        | 0.845 | 0.830 |
| FDI        | 0.807 | 0.840 | FDI        | 0.305 | 0.320 |
| ~FDI       | 0.347 | 0.331 | ~FDI       | 0.848 | 0.816 |
| MD         | 0.596 | 0.617 | MD         | 0.451 | 0.472 |
| ~MD        | 0.490 | 0.469 | ~MD        | 0.634 | 0.613 |
| EP         | 0.810 | 0.772 | EP         | 0.364 | 0.350 |
| ~EP        | 0.317 | 0.331 | ~EP        | 0.762 | 0.802 |

**C. RESULTS OF FACTORS CONFIGURATION**

After calibration and necessity test, a truth table to define the sample distribution was established [48]. In this process, two criteria were determined, the consistency threshold and the frequency threshold, and less representative of configurations are excluded [34]. As per common practice, the consistency threshold should be more than 0.75, and the frequency threshold should be defined according to the number of samples [48]. In this paper, the frequency threshold was set as 1, and the consistency threshold was greater than or equal to 0.85. Following previous studies, this paper selects the intermediate solution to explain the final configuration. According to the condition classification of Fiss [49], the conditions in the parsimonious solution are defined as the core conditions, and the conditions that appear in the intermediate solution but are eliminated from the parsimonious solution are defined as the peripheral conditions. Table 5 shows the configuration results for GTI performance.

As shown in Table 5, there are five configurations for achieving high GTI performance (H1, H2, H3, H4, and H5). The consistency of five configurations are all higher than 0.8, exceeding an acceptable consistency. The overall solution consistency is 0.894, indicating that these configurations have strong guarantee. The overall solution coverage reaches 0.729, indicating that these configurations are present in nearly 72.9% of samples with high GTI performance.

Meanwhile, the combination of environmental regulation and innovation input as the core conditions in configurations of H1, H2, and H5 indicates that the interaction between environmental regulation and innovation input is particularly important for achieving high GTI performance. Faced with strict environmental regulation, organizations need to increase innovation input to optimize production processes and develop green products, which can facilitate the optimization of resource allocation and achieve a “win-win” situation for the ecological environment and economic growth [30].

Furthermore, the combination of FDI and energy prices as the core conditions in the configurations H3 and H4 show that the interaction between FDI and energy prices is also important for achieving high GTI performance. The increase in energy prices not only enhances the energy-saving awareness, but also increases production costs. In this market environment, enterprises are motivated to obtain advanced technologies and equipment needed in clean production processes through foreign companies to produce clean products to meet the market demand and obtain profits.

Specifically, configuration 1 is high environmental regulation, high innovation input, high foreign direct investment and high market demand, configuration 2 is high environmental regulation, high innovation input, high foreign direct investment and high energy prices, configuration 3 is high environmental regulation, high foreign direct investment, high industrial structure and high energy prices, configuration 4 is high innovation input, high foreign direct investment, high market demand and high energy prices, and configuration 5 is high environmental regulation, high innovation input, non-high foreign direct investment, non-high market demand and non-high energy prices.

In Table 5, there are two configurations for attaining non-high GTI performance (NH1 and NH2). The overall solution consistency is 0.974, indicating that these configurations are likely to consistently produce these results. Moreover, the overall solution coverage reaches 0.650, indicating that these configurations are present in nearly 65.0% of samples with non-high GTI performance. Configuration NH1 is the combination of low level of environmental regulation, innovation input, foreign direct investment, and energy prices, in which the absence of innovation input and energy prices as the core condition. Configuration NH2 combines low level of
TABLE 5. Configurations for GTI performance.

| Variable | High GTI | Non-high GTI |
|----------|----------|--------------|
|          | H1    | H2    | H3    | H4    | H5    | NH1 | NH2 |
| ER       | ●     | ●     | ●     | ●     | ●     | ⊗   | ⊗   |
| II       | ●     | ●     | ●     | ●     | ●     | ⊗   | ●   |
| FDI      | ●     | ●     | ●     | ●     | ●     | ⊗   | ●   |
| MD       | ●     | ●     | ●     | ●     | ●     | ⊗   | ⊗   |
| EP       | ●     | ●     | ●     | ●     | ●     | ⊗   | ⊗   |
| Raw coverage | 0.462 | 0.597 | 0.457 | 0.494 | 0.117 | 0.618 | 0.128 |
| Unique coverage | 0.021 | 0.111 | 0.019 | 0.056 | 0.034 | 0.522 | 0.032 |
| Consistency | 0.989 | 0.919 | 0.976 | 0.971 | 0.893 | 0.982 | 0.923 |
| Overall solution consistency | 0.894 | 0.974 |
| Overall solution coverage | 0.729 | 0.650 |

Notes: ● denotes the presence of a core condition; ● denotes the presence of a peripheral condition; ⊗ denotes the absence of a core condition; ⊗ denotes the absence of a peripheral condition; and blank spaces denote “don’t care”.

Environmental regulation, market demand, energy prices and high level of innovation input, and foreign direct investment, in which the absence of market demand and energy prices as the core condition.

Furthermore, the absence of energy prices as the core condition exists in two configurations, which presents that low energy prices is main reason for non-high GTI performance. Lower energy prices allow organizations to rely on traditional fossil fuels for production activities in the long-term, while lowering enthusiasm for green innovation, thus affecting innovation achievements.

D. FACTORS CONFIGURATION ANALYSIS

From the perspective of environmental regulation, the proportion of samples with high GTI performance caused by high environmental regulation intensity is relatively high (H1, H2, H3, H5), and the coverage is 0.462, 0.597, 0.457, and 0.117, respectively, while the sample proportion of low environmental regulation resulting in non-high performance is 100% (NH1, NH2). This indicates that regions with high performance are more likely have high degree of environmental regulation, while those with low degree of environmental regulation tend to have poor GTI performance. Meanwhile, these regions with high environmental regulation also mostly have high innovation input (H1, H2, and H5), which means that environmental policies reflect the supply and demand of energy resources and pollution control costs through energy prices signals, thus driving enterprises to shift from reliance on energy to advanced factors such as capital and talent [61].

Reasonable environmental regulation can partially off-set or even eliminate compliance costs [29], optimize resource allocation, and achieve green economic development [30]. Meanwhile, innovation funds and innovation personnel are an important guarantee for the development of clean technologies and green products [62]. In conclusion, environmental regulation exerts appropriate incentives and constraints on enterprises, which continues to optimize resource utilization by increasing investment to achieve the advanced, rational, and ecological for industrial structure [63], thus increasing the demand for new technologies, new processes and new methods, and ultimately stimulating GTI performance. Thus, the following proposition is proposed:

**Proposition 1:** Regions with high gti performance tend to be those with high environmental regulation intensity and high innovation input.

In terms of similar configurations, in addition to the same core conditions as in configurations H1 and H2, FDI is present in two configurations. The basic logic is that regions with high degree of environmental regulation and innovation input mostly have good FDI, which can achieve high GTI performance. Previous studies have drawn three conclusions: (1) FDI has a positive impact on innovation performance [64]; (2) FDI negatively affects innovation performance [65]; (3) there is an inverted U-shaped relationship between FDI and innovation performance [66]. This study echoes the third view, that FDI does not exist as a core condition, but as a peripheral condition. Additionally, configuration NH2 supports this view. With low environmental regulation, having an excessively high FDI can have adverse impacts on innovation, even for regions with the support of high innovation input. Therefore, regions should grasp the entry standards for foreign enterprises and give full play to its technology spillover effect to help enterprises update equipment, promote clean technology changes, and improve GTI performance. Therefore, the following proposition is proposed:

**Proposition 2:** When environmental regulation and innovation input intensity are both high, regions should fully consider the effect of foreign direct investment.

The QCA method has advantages in terms of asymmetry. Different from the above proposition, regions can achieve high GTI performance regardless of the existence of environmental regulation and innovation input. For example, configuration H3 and H4 share the same core conditions (the combination of FDI and energy prices), and market demand exists in two configurations. The basic logic is that with high energy prices, FDI and market demand can achieve high GTI performance. Rising energy prices increase production costs, while strong market demand drives enterprises
to use advanced technological resources and capital support brought by foreign investors to promote industrial structure upgrade [67], which can promote regional technological innovation system optimization and ultimately improve GTI performance [68]. Therefore, the following proposition is proposed:

Proposition 3: When energy prices is high, regions should give full play to the technology spillover effect of FDI and the transformation of market demand to reduce the pressure of production costs.

VI. CONCLUSIONS AND IMPLICATIONS

A. MAIN CONCLUSIONS

This paper takes 30 provinces in China as the sample and adopts the entropy weight method to evaluate China’s regional GTI performance, and the fuzzy set qualitative comparative analysis method to analyze the configurations for achieving high (non-high) GTI performance. The findings are as follows:

First, GTI performance shows a decreasing trend from the eastern region to the western region in China. Specifically, at the province level, Ningxia, Qinghai, and Xinjiang have lower performance, while Beijing, Zhejiang, and Shanghai have higher performance. The average GTI performance in the eastern region is 0.5983, significantly higher than the national average of 0.4884; the average in the central region is 0.4843, slightly lower than the national average; and the average in the western region is 0.3585, far lower than the national average.

Second, there are five configurations for achieving high GTI performance and two configurations for achieving non-high GTI performance. The following assumptions are obtained: Regions with high environmental regulation intensity and high innovation input are more likely to achieve good GTI performance. When environmental regulation intensity and innovation input intensity are both high, regions should fully consider the technology spillover effect of FDI to improve GTI performance. When energy prices is high, regions should give full play to the technology spillover effect of FDI and the transformation of market demand to reduce the pressure of production costs to achieve performance improvement.

B. MANAGEMENT RECOMMENDATIONS

Based on the research conclusions, the improvement of China’s GTI performance needs to incorporate the following aspects:

First, managers need to evaluate the level of resource endowment and economic development when formulating strategies for the configurations of GTI performance. In particular, the prominent role of environmental regulation and innovation input need to be addressed. Regions can establish reasonable innovation plans and realize resource complementarity by formulating environmental regulation policies. Meanwhile, regions should strengthen innovation resource investment and green technology applications to accelerate industrial structure transformation and promote the output of innovation achievement.

Second, managers should change their conception of policy implementation and explore diversified and complementary green innovation policies. The role of the combination of energy prices and FDI in GTI performance should be emphasized. Regions can regulate energy prices according to environmental changes to encourage market players to adjust factor structures, upgrade industrial structures and improve green technology capabilities. Simultaneously, managers should set reasonable entry standards for foreign enterprises and realize knowledge sharing through reasonable technology transfer and foreign technology import to strengthen technical foundations.

Third, managers should optimize regional technology innovation systems and adjust green innovation strategies. The gap between current and future innovation strategies should be assessed, and regions should adjust their innovation development path to constantly improve innovation capacity. Furthermore, regions should take a rational approach to green innovation instead of simply relying on experience to summarize the causes of low GTI performance and retrospectively deducing the possible paths to high GTI performance. In summary, regions should consider how to harmonize different elements according to their own strengths and weaknesses, ultimately selecting a properly configure path.

C. THEORETICAL CONTRIBUTIONS

This research has certain theoretical and practical significance. First, this study confirms and expands the research on the Porter hypothesis, which provides new evidence for inconsistent conclusions. High environmental regulation can lead to high GTI performance, but regions should have strong innovation input and FDI simultaneously to enhance their response to the change in regulatory requirements and the increase of pollution control costs. Second, this paper provides a new perspective for GTI performance evaluation research by comprehensively measuring GTI performance from four perspectives: economic performance, innovation performance, environmental performance, and social performance. Third, the contribution of this paper is to extend the influence mechanism of GTI performance from single factor to combination of multiple factors. Furthermore, the fsQCA method is used to explore the factor configurations for GTI performance, which enriches the methodological toolbox and determines which combinations of factors can achieve high (non-high) GTI performance.

D. LIMITATIONS AND FUTURE RESEARCH

Even though this paper contributes to the field, it also has certain limitations, which may provide some insight for future research in this field. First, this study selected Chinese provinces as samples, the sample diversity was insufficient. In future research, other emerging economies can be selected as research samples. Second, this study could not include all the factors that might affect GTI performance. In the
follow-up study, qualitative comparative analysis or other methods can be used to further explore this issue from additional perspectives.

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