World Scientific Research Journal Volume 10 Issue 9, 2024
ISSN: 2472-3703 DOI: 10.6911/WSRJ.202409_10(9).0001

Research on the High-Quality Development Path of Science and Technology Dual-Cycle-Driven Regions Based on the DEA-Malmquist Index Model

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Abstract

In the context of the economic "dual circulation," technological means driving regional sustainable development face challenges. However, there have been few studies systematically elucidating the underlying mechanisms of the technological "dual circulation" and regional sustainable development. This article constructs a green total factor productivity calculation model, using 19 provinces in China as an example, and employs the FsQCA method to explore the impact mechanisms of technology self-innovation and technological openness on green total factor productivity. The results show that the core variables that enhance green total factor productivity include the conversion of self-developed research outcomes, direct foreign technological investment, key technology imports, and high-tech exports. The analysis of three typical paths of technological "dual circulation" driving sustainable development indicates that external technology utilization, internal and external dual circulation coordination, and self-innovation circulation utilization have a positive impact on optimizing regional sustainable development. The article diagnoses the constraints on regional sustainable development and proposes policy recommendations to strengthen the synergy of technological "dual circulation."

Keywords

Economic "Dual Circulation"; High-Quality Development; Green Total Factor Productivity; Independent Technological Innovation; Technological Openness to the Outside World.

1. INTRODUCTION

This article, based on the Green Total Factor Productivity calculation model, delves into the mechanisms through which the technological "dual circulation" plays a role in promoting regional sustainable development [1]. In the context of the global economy facing a new era of "dual circulation," the use of technological means to promote regional sustainable development is particularly crucial. This study constructs a Green Total Factor Productivity index system and takes 19 provinces in China as examples. It employs the FsQCA method to thoroughly analyze how the two key subsystems of regional technological self-innovation and technological openness can enhance green total factor productivity, leading to specific pathways for achieving regional sustainable development. The research identifies three distinct mechanisms through which technological "dual circulation" drives sustainable development and, based on these findings, proposes a series of quantitative policy recommendations to optimize regional sustainable development. These recommendations not only enrich the theory of technological

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development and economic growth but also provide empirical support for constructing a new development pattern, demonstrating significant practical value [2].

2. TECHNOLOGY DUAL CIRCULATION THEORY AND EVALUATION SYSTEM FOR REGIONAL HIGH-QUALITY DEVELOPMENT

2.1. Interpretation of Technology Dual Circulation Theory

Technology dual circulation theory is proposed under the guidance of economic dual circulation theory. It refers to a dual-directional circulation system of technology innovation elements within and outside the region in an open and shared environment, aimed at promoting high-quality economic development [3]. The technology dual circulation system consists of two subsystems: the internal autonomous research and development circulation system and the technological openness to the outside world circulation system. The internal autonomous research and development circulation system emphasizes harnessing endogenous growth dynamics within the region, investing in research and development funds and personnel, conducting independent core technology research, achieving independent research and development outcomes such as patents, and enhancing the region's overall technological strength. The technological openness to the outside world circulation system, on the other hand, involves foreign direct investment in research and development, technology trade such as technology imports and exports, and engagement with advanced technology elements from abroad, facilitating international technology flow [4-5]. These two subsystems complement each other and jointly drive regional technological advancement. Technology dual circulation can enhance regional productivity levels, strengthen regional core competitiveness, and drive high-quality regional development by improving the efficiency of technology element allocation and transforming economic growth patterns. It is a key support for constructing a new development pattern.

2.2. Green Total Factor Productivity Evaluation System

Green total factor productivity is a key indicator for measuring regional high-quality development. It incorporates environmental constraints on the basis of traditional total factor productivity, balancing both economic growth and ecological environment dimensions [6]. As shown in Figure 1, when constructing this evaluation system, input indicators involve regional GDP, employment, and fixed asset investment, among others. These quantitative indicators reflect the level of economic development input in a region accurately. At the same time, output indicators include emissions of pollutants like wastewater, sulfur dioxide, and solid waste, quantifying the impact of economic activities on the environment. To assess changes in regional green total factor productivity, the DEA-Malmquist index model is widely used. This model can effectively analyze input-output data over multiple periods. Such calculations of green total factor productivity not only evaluate a region's economic and environmental performance during a specific period but also track development trends and environmental improvements over different time frames [7]. Therefore, it becomes a crucial tool for assessing regional high-quality development, emphasizing both the speed and scale of economic growth and the sustainability and ecological efficiency during the growth process.

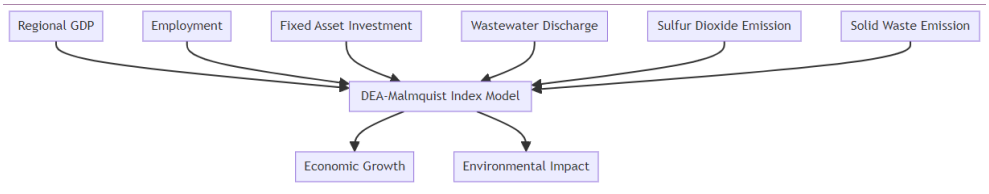


Figure 1. Green Total Factor Productivity Evaluation System

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202409_10(9).0001

2.3. Analysis Framework for Technology Dual Circulation Driving High-Quality Development

The technology dual circulation system can promote high-quality regional development through various mechanisms and pathways. To construct an analysis framework for technology dual circulation driving high-quality development, it is essential to clarify the connection between the technology dual circulation system and regional high-quality development, as shown in Figure 2. The internal autonomous research and development subsystem within the technology dual circulation system, through inputs such as research and development funds and personnel, engages in independent core technological innovation and obtains research and development outcomes such as patents [8]. The application of these outcomes can enhance resource utilization efficiency, optimize industrial structure, and reduce environmental costs, thereby increasing green total factor productivity. The technological openness to the outside world subsystem, through means such as foreign research and development investment and technology trade, acquires technology spillovers, bringing innovation vitality and also promoting the improvement of green total factor productivity [9]. Therefore, the analysis framework for technology dual circulation driving high-quality development revolves around using green total factor productivity as the outcome variable, representing the level of regional high-quality development. It incorporates relevant indicators for internal autonomous research and development and technological openness to the outside world as the predictor variables. The framework explores how these two subsystems, through different configurations and intensities, influence the outcome variable, investigates the relationship between technology dual circulation and regional high-quality development, and identifies paths driving high-quality development [10].

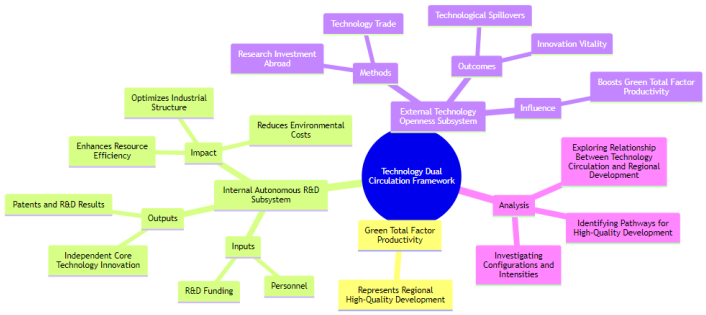


Figure 2. Analysis Framework for Technology Dual Circulation Driving High-Quality Development

3. TECHNOLOGY DUAL CIRCULATION DRIVING HIGH-QUALITY DEVELOPMENT PATH MODEL

3.1. Path Evaluation Model Based on Green Total Factor Productivity

To evaluate the path of technology dual circulation driving high-quality development, it is necessary to establish an evaluation model. The evaluation model constructed in this paper is as follows: Green total factor productivity is taken as the outcome variable, representing the level of regional high-quality development. The two subsystems of the technology dual circulation system are taken as predictor variables, reflecting the level of regional technological development. The calculation method for the outcome variable, green total factor productivity, utilizes the DEA-Malmquist index model. Input indicators for the years 2018 and 2019 in 19 provinces, such as GDP, social employment, and fixed asset investment, are selected, along with environmental constraint indicators like wastewater emissions, sulfur dioxide emissions, and

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industrial solid waste emissions. Based on multi-indicator data from two years, green total factor productivity is calculated using the DEA method.

GTFPit represents the green total factor productivity of the i-th province in the t-th year, and its calculation formula can be expressed as:

$$GTFP_{it} = f(X_{it}, Y_{it}, EX_{it}) \quad (1)$$

Where f represents the functional form of the DEA-Malmquist model, Xit represents economic input indicators (such as GDP, employment, fixed asset investment), Yit represents economic output indicators, and Eit represents environmental constraint indicators (such as wastewater emissions, sulfur dioxide emissions, industrial solid waste emissions).

The internal autonomous research and development subsystem (IS) and the technological openness to the outside world subsystem (OS) as predictor variables can be represented as:

$$IS_{it} = g(RD_{it}, RP_{it}, RC_{it}) \quad (2)$$

$$OS_{it} = h(FDI_{it}, TI_{it}, TE_{it}) \quad (3)$$

Where g and h respectively represent the functional forms of the internal autonomous research and development subsystem and the technological openness to the outside world subsystem. RDit represents research and development expenditure, RPit represents research and development personnel input, RCit represents research and development outcomes, FDIit represents foreign direct investment in research and technology, TIit represents technology imports, and TEit represents technology exports.

Finally, a regression model can be constructed to assess the impact of the technology dual circulation system on green total factor productivity:

$$GTFP_{it} = \alpha + \beta_1 IS_{it} + \beta_2 OS_{it} + \varepsilon_{it} \quad (4)$$

Where α is the constant term, $\beta 1$ and $\beta 2$ are regression coefficients representing the degree of influence of the internal autonomous research and development subsystem and the technological openness to the outside world subsystem on green total factor productivity, and ε it is the error term.

For some provinces with missing data on environmental constraint indicators, this paper calculates growth rates based on historical annual data to predict and complete the data. After calculations, the green total factor productivity data for each province in 2018 and 2019 are shown in Figure 3.

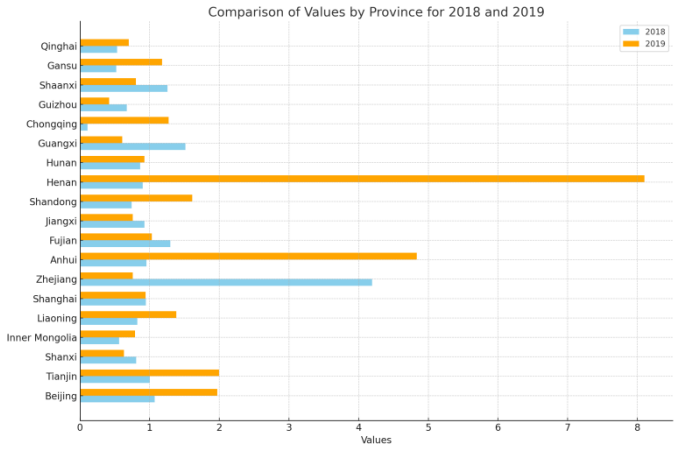


Figure 3. Green Total Factor Productivity for Provinces in 2018 and 2019

As for the predictor variables, this paper constructs the two subsystems of the technology dual circulation system: the internal autonomous research and development subsystem, consisting of three indicators: regional internal research and development expenditure input,

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internal research and development personnel input, and internal research and development outcomes; and the technological openness to the outside world subsystem, composed of three indicators: regional foreign direct investment in research and technology, technology imports, and technology exports. Data for each indicator is obtained from relevant yearbooks and statistical reports.

3.2. Data Preprocessing for Model Variables

The data for the variables involved in the model were subjected to preprocessing. Descriptive statistical analysis was conducted on the sample data for each variable. The results indicate that there is a significant variation in the data ranges of different variables, and their degrees of variation vary. This suggests that there is a significant disparity in the levels of technological development and high-quality development among regions, with noticeable regional differences. To use the FsQCA method for variable calibration, it is necessary to first determine the anchor points for the membership functions of the variables based on the upper and lower quartiles. Subsequently, each variable is quantitatively transformed into a set of values within the 0-1 interval, laying the foundation for subsequent analysis. The results of variable calibration are shown in Table 1.

Table 1. Variable Calibration Results

Variable	Full Membership Value	Crossover Value	No Membership Value
Green Total Factor Productivity	1888.911	500.43	20.4065
Internal Research and Development Expenditure	461872.3	99685	5417.25
Internal Research and Development Personnel Input	28.4065	5.085	0.2985
Research and Development Outcomes	204678.55	19922.5	278.35
Foreign Direct Investment in Research and Technology	2053.7915	518.465	3.053
Technology Imports	5657.461	723.61	0.3855
Technology Exports	4.9964	0.924	0.4025

4. MEASURING AND EVALUATING THE IMPACT OF TECHNOLOGY DUAL CIRCULATION EFFECTS ON THE PATH OF REGIONAL HIGH-QUALITY DEVELOPMENT

4.1. Validation of the Regional High-Quality Development Path Evaluation Model

The effectiveness of the regional high-quality development path evaluation model based on green total factor productivity can be verified using the FsQCA method. It involves the necessary analysis of the variables in the model. The results indicate that the presence or absence of any single variable is not a necessary condition for the outcome variable, and the consistency does not exceed the critical value of 0.9. This implies that an analysis of variable combinations is required to identify effective paths for driving high-quality development. Consistency thresholds of 0.80 and 0.85 are set for the path model, and two rounds of variable configuration analysis are conducted. As shown in Figure 4, the number of driving path combinations, consistency, and coverage are identical for both rounds of analysis. The overall consistency is 0.828, and the overall coverage is nearly 80%, indicating that the three identified driving paths

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effectively cover the sample. They represent valid combinations of conditions. The importance of the variables can be determined based on whether they exist as core conditions in different paths. Variables that exist only in the parsimonious solution are considered key driving conditions, those in the intermediate solution are secondary, and those in the complex solution are auxiliary conditions. For instance, technology exports appear only as marginal conditions, while foreign direct investment in research and technology and technology imports are core conditions in most paths.

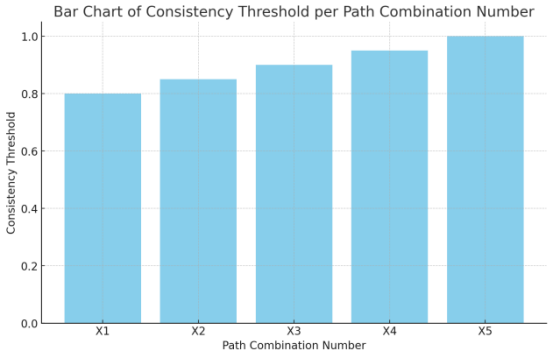


Figure 4. Bar Chart of Consistency Threshold per Path Combination Number

4.2. Measurement of the Impact of Technology Dual Circulation Effects on the Regional High-Quality Development Path

Configuration analysis can quantify the driving effect of the technology dual circulation system on the path of regional high-quality development. As shown in Figure 5, the three indicators of the technological openness to the outside world subsystem, namely foreign direct investment in research and technology, technology imports, and technology exports, play a central role in all three high-quality development paths, with foreign direct investment in research and technology and technology imports participating in all three paths. This indicates that the international flow and spillover of technology are key mechanisms driving regional high-quality development and represent relatively universal and significant driving forces. On the other hand, the role of the three indicators in the internal autonomous research and development subsystem, namely internal research and development expenditure, internal research and development personnel input, and research and development outcomes, is more conditional. They play a critical driving role in paths where domestic technology circulation is predominant, but their effect is minimal in paths where external circulation is dominant. This variation is related to differences in the regions' own innovation capabilities. The impact of the technological openness to the outside world subsystem on the regional high-quality development path is more widespread and pronounced, while the role of the internal autonomous research and development subsystem depends on the region's own technological strength and is more conditional. Therefore, promoting regional high-quality development requires balancing the development of internal and external technology circulation based on regional characteristics.



Figure 5. Measurement of the Impact of Technology Dual Circulation Effects on the Regional High-Quality Development Path

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5. OPTIMIZING THE DUAL CIRCULATION OF TECHNOLOGY TO DRIVE REGIONAL HIGH-QUALITY DEVELOPMENT

5.1. Diagnosis of Key Factors Constraining Regional High-Quality Development

The constraints on achieving high-quality regional development are primarily rooted in deficiencies within the technology dual circulation system. These constraints can be diagnosed from several key perspectives: Firstly, there is an insufficient internal autonomous research and development capability, particularly in western and other low-income regions. The scarcity of universities and research institutions, coupled with a shortage of talent and funding, obstructs the establishment of an effective autonomous innovation system. Consequently, these regions struggle to generate core proprietary knowledge. Secondly, there is a high dependence on technology in central and western regions. Economic growth heavily relies on external circulation, primarily driven by the importation of technology. However, this overreliance on external sources cannot sustain long-term development. Furthermore, there is a limited capacity for digesting and absorbing technology, leading to insufficient innovation. Thirdly, there is an inefficient allocation of technology resources in certain areas. The research environment lacks vitality, resulting in a low conversion rate of R&D funds and personnel. This inefficiency extends to the utilization and output efficiency of innovation resources, which fall short of their potential. Lastly, there is inadequate international technology cooperation, with most areas, except for the eastern regions, displaying limited involvement and openness in this regard. This lack of engagement translates to insufficient technology exchange between regions and with foreign countries. Additionally, access to cutting-edge technology information is constrained. These factors collectively pose significant challenges to the achievement of high-quality regional development.

5.2. Policy Recommendations to Strengthen the Effectiveness of Technology Dual Circulation

To enhance the technology dual circulation system's role in driving regional high-quality development, various strategies can be implemented: Efforts should be made to increase investments in research and development (R&D). This includes allocating more funding for education and research, expediting the training of high-level talent across diverse fields, and creating a supportive environment that encourages innovation among researchers. Key core technology breakthroughs should be actively promoted. This can be achieved through the organization of major research projects and the establishment of platforms that facilitate collaboration between academia, industry, and research institutions. The focus should be on overcoming critical technological barriers, with a particular emphasis on securing intellectual property rights for technological achievements. International technology cooperation should be expanded. Deeper partnerships with leading technological nations should be cultivated to facilitate the rapid absorption of advanced foreign technologies. Additionally, regional technology initiatives should be encouraged to "go global," opening up greater opportunities for international technology exchange and collaboration. Efforts should be directed toward transforming the allocation of technology resources. Establishing a more efficient mechanism for managing and distributing these resources can significantly enhance their overall utilization efficiency. This realignment of resource allocation should be tailored to better serve the specific requirements of regional high-quality development. These strategic measures collectively aim to address the existing challenges within the technology dual circulation system, ultimately strengthening its capacity to drive high-quality development in regional areas.

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6. CONCLUSION

This paper, based on the perspective of green total factor productivity, constructed a theoretical model of the technology dual circulation system and its relationship with regional high-quality development. Using fuzzy set qualitative comparative analysis, it examined cases from different provinces to explore the connection between technology dual circulation and high-quality development. The research identified three effective configurations of technology dual circulation paths that drive regional high-quality development: paths primarily focused on external technology circulation, paths with a balanced combination of internal and external circulation, and paths predominantly emphasizing domestic circulation. Among these, the role of the technological openness to the outside world subsystem is more universal, while the impact of the internal autonomous innovation subsystem depends on the region's own technological capabilities. Finally, the article diagnosed the current shortcomings in technological development that hinder regional high-quality development. It provided recommendations from the perspective of strengthening the construction of the technology dual circulation system, including increasing R&D investment, breaking through core technologies, expanding international cooperation, and reforming the allocation of technology resources. These suggestions aim to provide guidance for promoting regional high-quality development.

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