The Impact of New Quality Productivity on Green Logistics Development: A Configurational Analysis Based on fsQCA

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Abstract: Under the dual carbon goals, green logistics serves as a vital pillar for high-quality development. This study adopts a configuration perspective and employs the fsQCA method, centering on new-type productive forces. It selects three primary indicators—new-type laborers, objects of labor, and means of labor—along with nine secondary indicators as antecedent variables to explore their influence mechanisms on green logistics development. The findings reveal that green logistics development lacks a single prerequisite, instead relying on a combination of multiple factors. Nine effective pathways were identified and categorized into three types: innovation-driven industrial leadership, R&D breakthrough compensation, and multi-factor synergy. Results indicate that green logistics development exhibits multi-configuration equivalence characteristics, with innovation-driven development and industrial modernization serving as core supports. These insights provide theoretical and practical references for local governments to formulate tailored policies and promote the deep integration of new productive forces with green logistics.

Keywords: Green Logistics, New Quality Productivity, fsQCA, Configuration Path

1. Introduction

The logistics industry serves as a foundational and strategic pillar supporting national economic development. According to the China Green Logistics Development Report (2023) released by the China Federation of Logistics & Purchasing, China's logistics sector accounts for approximately 9% of the nation's total carbon emissions. Against the backdrop of China's dual carbon goals—achieving carbon peak by 2030 and carbon neutrality by 2060—the green development of the logistics industry is of paramount importance [1]. In recent years, the national government has successively introduced a series of major strategies and policies to support the rapid development of a green logistics system. In 2022, the General Office of the State Council issued the "14th Five-Year Plan for Modern Logistics Development," proposing to promote green logistics development and establish a green and low-carbon logistics innovation project. In 2023, the National Development and Reform Commission and seven other ministries jointly issued the Action Plan for Deepening the Green Transformation of Express Packaging, calling for enhanced green governance of express packaging and the establishment of a comprehensive green packaging standard system for express delivery by the end of 2025. In 2025, the Ministry of Commerce released the Implementation Opinions on Expanding Green Trade, proposing to accelerate the green and low-carbon development of logistics and build a comprehensive framework for green trade development.

The development of green logistics is influenced by multiple factors. Current research on the determinants of green development in the logistics industry primarily analyzes the impact of individual factors on outcome variables or focuses on theoretical explanations, lacking a systematic analysis of the factors affecting green logistics development. Therefore, this paper employs the fuzzy-set qualitative comparative analysis (fsQCA) model, incorporating multiple antecedent variables to investigate the factors influencing green logistics development, thereby providing support for advancing green logistics practices.

2. Theoretical analysis

In existing literature, some scholars have examined the factors influencing green logistics development from single dimensions such as talent, government, enterprises, data, and the environment. For instance, Huang Tao [2] analyzed the impact of scientific and technological innovation talent on the green development of the logistics industry; Gan Junwei et al. [3] conducted a systematic text-quantitative review of national-level green logistics policies, identifying the characteristics and shortcomings of China's green logistics policies; Murphy et al. [4] highlighted the significant impact of mandatory government regulation on green logistics development; Sureeyatanapas et al. [5] examined factors influencing green logistics from a corporate perspective; Han Shuang et al. [6] analyzed the effect of data elements on green logistics efficiency; and Qu et al. [7] investigated environmental factors affecting green logistics development. Additionally, some scholars have conducted theoretical analyses of influencing factors for green logistics development across multiple dimensions. For instance, Dai Dongfang et al. [8] conducted a detailed analysis of key factors affecting green logistics development at the governmental, corporate, and environmental levels; Yang Guochuan [9] explored constraints in green logistics development from the perspectives of ideological concepts, regulatory systems, technological levels, infrastructure, and specialized talent; Xie Sixin et al. [10] proposed development pathways by examining social awareness, policy systems, facility technologies, composite talent, and the current state of reverse logistics within the green logistics system.

In September 2023, the important concept of "new-quality productive forces" was first proposed, emphasizing the need to integrate scientific and technological innovation resources, lead the development of strategic emerging industries and future industries, and accelerate the formation of new-type productive forces. Productivity serves as the fundamental driving force behind human societal development. New-type productive forces inherently represent green productivity, necessitating new productivity theories to guide the green development of the logistics industry. Regarding research analyzing the impact of new-type productive forces on green logistics development: Liu Caixia [11] examined the intrinsic value, practical challenges, and implementation concepts of new-type productive forces empowering green logistics; Wang Lin [12] systematically elaborated the impact mechanism and development strategies of new-quality productive forces on the high-quality development of modern logistics at the theoretical level; Liu Cong et al. [13] analyzed the intrinsic logic, practical challenges, and implementation pathways of new-quality productive forces empowering the green and low-carbon transformation of the logistics industry; He Bo et al. [14] explored multiple pathways for China's green logistics development based on new-quality productive forces. Given the limited existing literature on this topic, this paper examines how new-quality productivity influences green logistics development through specific configuration pathways. It establishes a theoretical framework comprising new-quality laborers, new-quality labor objects, and new-quality labor materials, constructs an evaluation indicator system, and further analyzes the impact of these elements on green logistics development. The theoretical framework for studying the impact of new-type productive forces on green logistics development is illustrated in Figure 1.
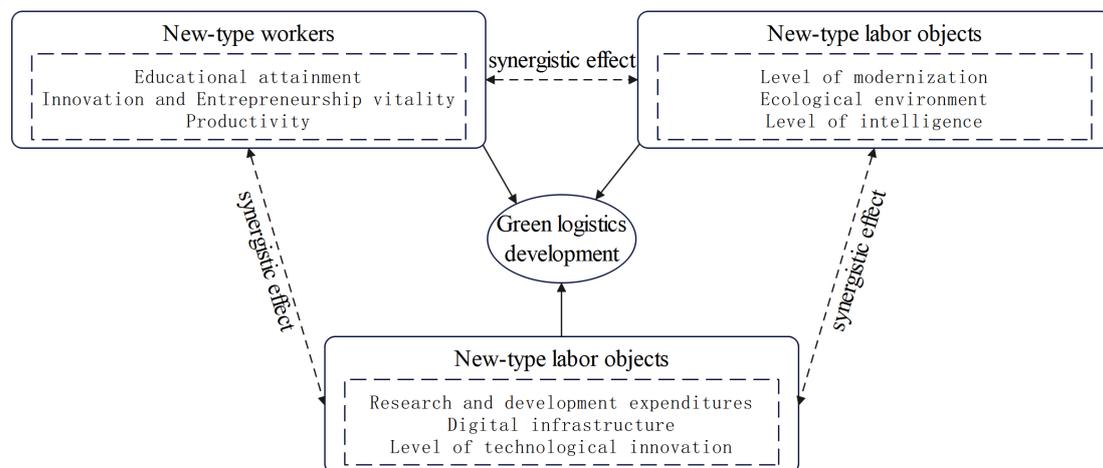

Figure 1. Theoretical framework of the study

3. Research design

3.1 Research methods

Qualitative Comparative Analysis (QCA) is a social science research method grounded in set theory and Boolean algebra logic, proposed by Ragin in 1987. By treating cases as members of condition sets, this approach analyzes the logical relationships between different combinations of conditions and outcomes, thereby revealing multiple concurrent causalities and conditional complementarities. Unlike traditional statistical analysis methods that focus on the linear influence of single variables, QCA emphasizes the combined effects of multiple factor configurations on outcomes, enabling the identification of complex mechanisms where different pathways lead to the same result. QCA encompasses three forms: Clear Set QCA (csQCA), Multi-Valued QCA (mvQCA), and Fuzzy Set QCA (fsQCA). Among these, fsQCA assigns membership degrees between 0 and 1 to variables, better reflecting the ambiguity and gradual nature of conditional relationships in social phenomena. It is particularly suited for studying complex systems that integrate qualitative and quantitative approaches. When analyzing the relationship between new-type productive forces and green logistics, workers, labor objects, and labor tools—the three core elements of new-type productive forces—exhibit significant interactions and systemic coupling effects. Different combinations of these elements may jointly influence green logistics development through multiple pathways. The formation process of green logistics exhibits multidimensional, nonlinear, and context-dependent characteristics. Traditional regression or structural equation models struggle to reveal such complex interactive mechanisms. In contrast, fsQCA can identify the necessity and sufficiency of conditional combinations under limited sample conditions, uncovering multiple potential pathways to achieve high-level green logistics. This approach better aligns with the intricate logical relationship between the internal structural optimization of new-type productive forces and the development of green logistics. Therefore, employing the fsQCA method to analyze synergies among laborers, labor objects, and labor tools from a factor allocation perspective, along with their role in green logistics formation, reveals diverse pathways for green logistics development under different combinations of productive forces.

3.2 Variable definition

(1) Outcome variable

Green Logistics. Based on the evaluation framework proposed by Li Xiangrong, Zhang Lin, and Lü Zhou [15], which constructs an assessment system for green logistics development levels from two dimensions—environmental construction and operational factors—the comprehensive evaluation values for green logistics development across Chinese provinces were calculated using the entropy weight method.

(2) Predictor variable

New Quality Productivity. Marx [16] defined productivity as the objective material force through which people utilize and transform nature in labor production to satisfy human needs. Productivity primarily consists of laborers, objects of labor, and means of production. Guided by principles of scientific rigor, comprehensiveness, and data availability, and drawing upon relevant research by Ding Shichao [17], Yin Chunfeng [18], Wang Jue [19], and others, we constructed a set of antecedent variables comprising three primary indicators—new-quality laborers, new-quality means of labor, and new-quality objects of labor—and nine secondary indicators. The description of these antecedent variables is presented in Table 1.

Table 1. Explanation of antecedent variables

Variable		instruction
New-type workers	Educational attainment	Average years of schooling per capita
	Innovation and Entrepreneurship vitality	China regional per capita Innovation and Entrepreneurship index
	Productivity	GDP per capita
New-type labor objects	Level of modernization	Level of modern industrial system development
	Ecological environment	Forest coverage rate
	Level of intelligence	Industrial Robot Installation Density
New-type means of production	Research and development expenditures	R&D funding
	Digital infrastructure	Internet broadband penetration rate
	Level of technological innovation	Number of patents granted

At the level of new-type workers, three indicators are included: educational attainment, innovation and entrepreneurship vitality, and productivity among workers across China's regions. Educational attainment is measured by average years of schooling, calculated by converting the various educational levels of the population aged 15 and above into equivalent years of schooling. Innovation and entrepreneurship vitality is measured using the China Regional Per Capita Innovation and Entrepreneurship Index, constructed by Dai Ruochun, Zhu Zhongkun, and Zhang Xiaobo [20] using enterprise big data resources from Peking University's Enterprise Big Data Center. Productivity is measured by the ratio of GDP to total population.

At the level of new-type labor objects, three indicators are included: the modernization level, ecological environment, and degree of intelligence across China's regions. The modernization level is measured using the modern industrial system development index for China, as assessed by Zhang Rui and Ma Yunzhi [21] through an entropy-based method across four dimensions. The ecological environment is measured by the proportion of forest area relative to total land area. The degree of intelligence is measured by the ratio of industrial robot installations in the region to the corresponding number of employees in that industry.

At the level of new-type means of production, three indicators are included: R&D investment across China's regions, digital infrastructure, and the level of scientific and technological innovation. R&D investment is measured by the total actual expenditure incurred for implementing R&D activities; digital infrastructure is measured by the ratio of internet broadband access users to the resident population; and the level of scientific and technological innovation is measured by the total number of patents granted in the current year.

3.3 Data sources and calibration

(1) Data Source

This study references the research by He Bo et al. [14], excluding provinces with significant data gaps. It utilizes 2020 data from 30 provinces in China, sourced from the Statistical Yearbooks of China and respective regions, the China Labor Statistical Yearbook, the China Communications Industry Statistical Yearbook, the China Science and Technology Statistical Yearbook, and the National Population Census Bulletin.

(2) Data calibration

Within the fsQCA analytical framework, each variable is treated as a fuzzy set element with varying degrees of membership. Therefore, raw data must be calibrated prior to analysis to convert it into membership values suitable for fuzzy set analysis. Using the calibrate function in the Compute Variable module of fsQCA 4.1 software, both outcome and antecedent variables were processed based on percentiles. Three key anchor points were set using the direct calibration method, incorporating existing literature [22]: 0.95 as the full membership point, 0.5 as the crossover membership point, and 0.05 as the full non-membership point. Following Ragin et al.'s [23] definition of fuzzy set intersections, to prevent values exactly at 0.5 from being excluded from analysis, this threshold was further adjusted downward by 0.001 as a correction. The calibrated anchor points for each variable are shown in Table 2.

Table 2. Variable calibration

Variable	Full membership point	Crossover membership point	Full non-membership point
Green logistics development	0.605	0.457	0.342
Educational attainment	12.142	9.840	7.950
Innovation and Entrepreneurship vitality	99.708	91.780	77.400
Productivity	159325.200	58081.000	40220.600
Level of modernization	0.715	0.358	0.245
Ecological environment	63.416	39.240	5.440
Level of intelligence	129522.173	17475.175	827.744
Research and development expenditures	24289941.800	2974157.000	65797.000
Digital Infrastructure	44.780	34.100	26.240
Level of technological innovation	583390.200	60524.000	3496.600

4. Empirical analysis and discussion

4.1 Necessity analysis

Necessity analysis aims to determine the extent to which individual antecedent conditions or their inverse states can explain the occurrence of an outcome, identifying whether decisive conditions exist. If a variable fails to meet the necessity criterion, it is necessary to further explore pathways formed by combinations of multiple conditions. Typically, when a predictor variable's consistency coefficient reaches 0.9 or higher, it can be considered a necessary condition for the outcome. After conducting necessity condition analysis on the aforementioned predictor variables, as shown in Table 3, none of the variables' consistency values reached the 0.9 threshold. This indicates that no single variable constitutes a necessary condition for the outcome.

Table 3. Necessity analysis of a single independent variable

Predictor variable	Green logistics development		~Green logistics development	
	Consistency	Coverage	Consistency	Coverage
Educational attainment	0.845	0.760	0.653	0.680
~Educational attainment	0.644	0.615	0.770	0.852
Innovation and Entrepreneurship vitality	0.822	0.788	0.519	0.576
~Innovation and Entrepreneurship vitality	0.558	0.500	0.809	0.840
Productivity	0.867	0.846	0.532	0.601
~Productivity	0.591	0.521	0.863	0.883
Level of modernization	0.869	0.926	0.468	0.578
~Level of modernization	0.604	0.495	0.940	0.893
Ecological environment	0.625	0.614	0.645	0.734
~Ecological environment	0.729	0.639	0.660	0.671
Level of intelligence	0.751	0.895	0.480	0.662
~Level of intelligence	0.717	0.543	0.924	0.811
Research and development expenditures	0.806	0.898	0.467	0.603
~Research and development expenditures	0.643	0.510	0.921	0.846
Digital Infrastructure	0.745	0.694	0.635	0.685
~Digital Infrastructure	0.662	0.610	0.717	0.765
Level of technological innovation	0.840	0.918	0.475	0.601
~Level of technological innovation	0.635	0.510	0.935	0.872

Note: ~denotes the absence or opposite state of a variable.

4.2 Configuration analysis

Configuration analysis is a thorough examination of the relationships between various condition variables and the result variable, aiming to explore the pathways through which multiple condition combinations influence the result variable. Construct a truth table with a frequency threshold of 1 and a consistency threshold of 0.80 to obtain the corresponding complex solution, simplified solution, and intermediate solution. Since core conditions are present in both the simplified and intermediate solutions, while peripheral conditions appear only in the intermediate solution, comparing the simplified and intermediate solutions suffices to identify core conditions exerting critical influence on the outcome and peripheral conditions playing auxiliary roles. Finally, the configurations were organized, yielding the results shown in Table 4. The configuration analysis indicates that the consistency levels of the overall solution and each configuration exceed 0.9. Specifically, the overall solution exhibits a consistency level of 0.991 and a coverage rate of 0.723, indicating reliable configuration analysis results. The nine configurations reveal 99.1% of logistics green development cases, with 72.3% of provincial cases demonstrating green logistics development trends. These nine configuration pathways possess high explanatory power for the outcome variable and constitute sufficient conditions for advancing China's logistics green development.

Table 4. Configuration Analysis

	1	2	3	4	5	6	7	8	9
Educational attainment	○	○		○	○	●	·	●	·
Innovation and Entrepreneurship vitality	●	●	●	●	○	○	●	●	●
Productivity	·		·	·	○	●	·	●	·
level of modernization	●	●	●	●	○	●	●	●	●
Ecological environment	○	○	○		○	·	·	○	·
Level of intelligence	·	·	·	·	○	○	○	○	·
Research and development expenditures	·	·	·	·	·	○	○	○	·
Digital Infrastructure		·	·	·	○	●	○	●	○
Level of technological innovation	●	●	●	●	●	○	●	●	●
Consistency	0.998	0.998	0.998	0.989	0.996	0.996	0.996	0.996	0.998
Original coverage	0.382	0.364	0.443	0.458	0.336	0.321	0.327	0.351	0.344
Unique Coverage	0.006	0.002	0.042	0.057	0.050	0.011	0.010	0.013	0.037
Consistency of the overall solution	0.991								
Coverage of the global solution	0.723								

Note: ● or · indicates the condition exists; ○ or ○ indicates the condition does not exist; ● or ○ indicates a core condition; · or ○ indicates a peripheral condition. A blank space indicates the condition may or may not exist.

By systematically analyzing the core and peripheral conditions of the nine obtained configurations, they were categorized into three distinct pathways based on shared characteristics of the core conditions: innovation-driven industrial leadership, R&D breakthrough compensation, and multi-factor synergy.

(1) Innovation-Driven Industrial Pathway. This represents the mainstream development model for green logistics, corresponding to configurations 1-4 and 9. It centers on three core conditions: high innovation and entrepreneurship vitality, high modernization levels, and high technological innovation intensity. This pathway underscores the foundational role of innovation system development and industrial structure modernization in advancing green logistics. By synergizing these core conditions, it builds the fundamental driving force for green logistics development. Simultaneously, it leverages distinct combinations of peripheral conditions to form differentiated implementation mechanisms, adapting to the developmental realities of eastern, central, and select western provinces.

Configuration 1 features low educational attainment, high productivity, low ecological environment, high intelligence level, and high R&D investment as marginal conditions. High productivity provides the economic foundation for green logistics development, reducing carbon emissions intensity per unit of logistics activity through economies of scale. High intelligence level and high R&D investment form technological empowerment, aiding energy conservation, consumption reduction, and efficiency enhancement in logistics operations. Meanwhile, low educational attainment does not act as a constraint, offset by high innovation vitality and technological investment. Low ecological conditions reflect that such regions may leverage industrial agglomeration advantages to develop green logistics, offsetting ecological limitations through intensive logistics operations. Representative regions include Anhui and Shandong, both possessing robust industrial foundations and innovation vitality. Through synergistic productivity growth and technological R&D, they achieve steady progress in green logistics development.

Configuration 2 features low educational attainment, poor ecological environment, high levels of intelligence, substantial R&D investment, and robust digital infrastructure as its boundary conditions. Compared to Configuration 1, this model replaces high productivity with advanced digital infrastructure, highlighting the pivotal role of digital empowerment. A well-developed digital infrastructure underpins the informatization and coordination of the entire logistics chain. Through technologies like IoT and big data, it optimizes route planning, reduces empty-run rates, and facilitates green transformation. The combination of high intelligence levels and high R&D investment further amplifies technology's enabling effect on green logistics. Constraints from low education levels and poor ecological environments are effectively mitigated through the strong driving force of core conditions and the enabling role of digital infrastructure. Representative regions include Sichuan and Anhui. Sichuan, as a major western economic province, is accelerating its digital infrastructure

deployment, while Anhui leverages its technological innovation advantages. Both regions have explored distinctive green logistics development paths by integrating digital empowerment with innovation-driven approaches.

Configuration 3 is defined by the boundary conditions of high productivity, low ecological footprint, high intelligence level, high R&D investment, and high digital infrastructure. Possessing both high productivity and high digital infrastructure as core advantages, it benefits from dual support: efficiency enhancement and digital empowerment. High productivity establishes the economic foundation, while advanced digital infrastructure builds a collaborative platform. Combined with technological support from high levels of intelligence and R&D investment, this creates stronger sustainability for green logistics development. The shortfall in low ecological footprint is effectively mitigated through the synergistic efforts of multiple factors. Representative regions include Jiangsu, Shanghai, and Anhui—areas characterized by economic advancement or concentrated innovation resources, high levels of industrial modernization, and robust digital infrastructure. Through multi-factor coordination, these regions have achieved efficient development in green logistics.

Group 4 features low educational attainment, high productivity, high levels of technological sophistication, substantial R&D investment, and robust digital infrastructure as peripheral conditions. It retains the dual advantages of high productivity and advanced digital infrastructure while maintaining low educational attainment, further validating how core conditions compensate for peripheral weaknesses: the synergy between high productivity and digital infrastructure enables simultaneous improvements in logistics efficiency and green transformation. High levels of technological sophistication and R&D investment provide safeguards for technological innovation, effectively mitigating potential talent constraints arising from lower educational attainment. Representative regions include Fujian, Zhejiang, and Anhui, where vibrant private sectors and robust innovation capabilities foster deep integration between the digital and physical economies. Through synergistic empowerment of industrial efficiency and digital technologies, these regions drive rapid advancement in green logistics.

Configuration 9 features low educational attainment, high productivity, high ecological environment quality, high intelligence level, high R&D investment, and low digital infrastructure as its marginal conditions. Compared to the previous four configurations of the same type, its notable distinction lies in the combination of high ecological environment quality and low digital infrastructure: the high ecological endowment provides a natural foundation for green logistics development, reducing the additional environmental pressure from logistics activities. Despite relatively weak digital infrastructure, synergies among high productivity, high intelligence levels, and high R&D investment ensure effective advancement of green logistics, demonstrating how ecological endowments compensate for digital infrastructure shortcomings. Guangdong serves as a representative region. As an economically strong province, Guangdong possesses high productivity and robust innovation capabilities while achieving significant ecological conservation outcomes. By integrating ecological advantages with innovation-driven development, it has attained high-level green logistics development even without optimal digital infrastructure.

(2) Compensatory Pathway for R&D Breakthroughs. This pathway corresponds to Configuration 5, centered on low ecological environment, low intelligence level, and high technological innovation level as core conditions. With technological innovation as the core breakthrough point, it compensates for multiple peripheral weaknesses through enhanced R&D investment, suitable for regions with relatively weak overall development foundations but possessing certain technological R&D capabilities. Peripheral conditions include low education level, low innovation and entrepreneurship vitality, low productivity, low modernization level, high R&D investment, and low digital infrastructure. This reflects regional shortcomings in talent, innovation ecosystems, economic foundations, industrial capabilities, and digital infrastructure. However, by leveraging high R&D investment as a peripheral condition synergized with the core high technological innovation level, it effectively mitigates constraints from multiple weaknesses. This combination model offers a viable green logistics development path for regions with weak foundations—focusing on the two critical elements of technological innovation and R&D investment to achieve a green transformation driven by key points. Representative region: Hebei. By strengthening technological R&D and innovation applications in logistics, Hebei has achieved steady progress in green logistics despite relatively weaker industrial foundations and digital infrastructure.

(3) Multi-factor Synergistic Pathway. This pathway corresponds to configurations 6-8, featuring a diversified combination of core conditions complemented by peripheral conditions. The balanced allocation of multiple factors drives green logistics development, making it suitable for regions with

solid development foundations and relatively balanced factor allocation.

Configuration 6 centers on core conditions of high educational attainment, high productivity, high modernization levels, low R&D investment, and high digital infrastructure. Its peripheral conditions include low innovation and entrepreneurship vitality, high ecological environment, low intelligentization levels, and low scientific and technological innovation levels. With high educational attainment as the core talent support, high productivity and high modernization levels establish the industrial foundation, while high digital infrastructure provides the technological platform—all three develop synergistically. Despite relatively low innovation and entrepreneurship vitality, intelligence levels, and scientific and technological innovation levels, effective development of green logistics is achieved through the natural advantages of a high ecological environment and the multi-faceted synergy of core conditions. Shaanxi serves as a representative region. Possessing solid educational resources and industrial foundations, with gradually improving digital infrastructure, Shaanxi leverages its talent and industrial strengths while relying on ecological endowments to explore a differentiated path for green logistics.

Configuration 7 centers on high innovation and entrepreneurship vitality, high modernization levels, low R&D investment, and high technological innovation intensity as core conditions. It incorporates high educational attainment, high productivity, high ecological environment quality, low intelligentization levels, and low digital infrastructure as peripheral conditions. High innovation and entrepreneurship vitality combined with high technological innovation levels form the innovation engine, while high modernization levels provide the industrial foundation and high educational attainment supplies talent support for innovation and industrial development. Despite relatively weaker R&D investment, intelligent levels, and digital infrastructure, the synergy of multiple core conditions and the enabling effect of a high ecological environment have established a stable green logistics development mechanism. Beijing serves as a representative region. As the national hub for scientific and technological innovation and a talent powerhouse, Beijing leverages abundant innovation resources, a comprehensive industrial system, and a high-quality talent supply to maintain high-level green logistics development despite relative weaknesses in certain technological applications and infrastructure deployment.

Configuration 8 centers on core conditions of high educational attainment, high innovation and entrepreneurship vitality, high productivity, high modernization level, low ecological environment, low intelligentization level, low R&D investment, high digital infrastructure, and high technological innovation level. It incorporates low ecological environment, low intelligentization level, and low R&D investment as peripheral conditions. The core strength of this configuration lies in the comprehensiveness and synergy of factor allocation: high educational attainment provides talent support; high innovation and entrepreneurship vitality combined with high technological innovation levels stimulate innovation momentum; high productivity and high modernization levels solidify the industrial foundation; and high digital infrastructure enhances technological empowerment. These multiple core conditions work in concert to effectively counteract the constraints of low ecological environment, low intelligentization levels, and low R&D investment, achieving balanced development in green logistics. Tianjin serves as the representative region. As a municipality directly under the central government, Tianjin possesses a complete industrial system, high-quality talent resources, advanced digital infrastructure, and abundant innovation vitality. Through the comprehensive coordination of multiple factors, it has established a comprehensive advantage for green logistics development.

In summary, the development of green logistics does not hinge on a single prerequisite but rather forms differentiated pathways through the diverse configuration of new-quality productive forces. The innovation-driven industrial leadership pathway embodies the core supporting role of innovation and industrial modernization, aligning with most regions possessing a certain industrial foundation and innovation potential. The R&D breakthrough compensation pathway offers a development solution for areas with weaker foundations, leveraging focal points to drive broader progress. while the multi-factor synergy path suits regions with stronger development foundations, achieving stable green logistics growth through balanced allocation of multiple elements. These three pathways demonstrate both the flexibility of new-quality productive forces' elemental combinations and the adaptability of green logistics development to regional resource endowments.

4.3 Robustness test

To enhance the reliability of the research conclusions, robustness testing was conducted on the

configuration analysis results. Since the number of rows included in the truth table analysis varies with the consistency threshold setting, increasing the threshold may affect the final configuration outcome. Therefore, drawing on the methodology of Pappas and Woodside, the original consistency threshold of 0.80 was raised to 0.85. The results indicate that the valid paths obtained at the 0.85 threshold are essentially consistent with the configurations under the 0.80 threshold, showing no substantial differences. This demonstrates that the configuration results in this paper exhibit good robustness.

5. Research findings and implications

5.1 Research findings

Based on data regarding new-type productive forces factors and green logistics development across 30 Chinese provinces, this paper employs the fsQCA method to examine the role of multi-factor combinations within new-type productive forces in driving green logistics development from a configuration perspective. The study concludes that:

First, the development of green logistics does not hinge on any single prerequisite but rather represents a quintessential multi-factor, parallel-driven process. Necessity analysis reveals that none of the independent variables achieved the critical consistency threshold of 0.9, indicating that China's green logistics advancement does not depend on any isolated factor. Traditional single-factor linear logic proves inadequate to fully explain the formation mechanism of green logistics. This underscores that enhancing green logistics necessitates the synergistic interaction of multiple elements within new-quality productive forces.

Second, green logistics exhibits the characteristic of equivalent pathways with coexisting diverse configurations, where different combinations of new-quality productive forces can all generate driving forces. Configuration analysis reveals nine distinct pathways capable of advancing green logistics development, with each exhibiting high levels of overall consistency and coverage. While marginal conditions vary across pathways, high innovation and entrepreneurship vitality, high modernization levels, and high technological innovation intensity emerge as core requirements in most configurations. This indicates that innovation-driven development and industrial modernization have become pivotal elements propelling green logistics.

Third, the three key elements of new-quality productive forces exhibit significant complementarity, enabling different regions to achieve green logistics advancement through factor substitution. Regions with weaker educational attainment, ecological environments, or intelligent infrastructure can enhance green logistics by boosting innovation vitality, increasing R&D investment, or improving digital infrastructure—demonstrating the complementarity and substitutability of these elements within new-quality productive forces. Particularly in areas with relatively weaker resource endowments, technological innovation and R&D investment exert a compensatory effect on green logistics development.

Fourth, the formation of green logistics exhibits distinct regional variations, with different regions displaying unique combinations of key factors. Eastern regions rely more on innovation-driven approaches and digital infrastructure, central regions focus on modernizing industrial structures, while western regions may achieve green logistics development through enhancing human capital or improving ecological foundations. This indicates that China's green logistics development features significant spatial distribution differences, necessitating tailored policy-making that selects appropriate combinations of new productive forces suited to local conditions.

5.2 Research Implications

Based on the above research findings, the following insights are proposed:

First, we should adhere to an innovation-driven strategy to enhance the core momentum of green logistics development.

High levels of innovation and entrepreneurship, along with advanced technological innovation, are central requirements in most configurations, indicating that innovation has become a key driver for green logistics development. Governments should continue to strengthen the innovation ecosystem, promote the application of scientific and technological achievements in the logistics sector, accelerate the development of innovative models such as intelligent supply chains, smart warehousing, and green

transportation, and facilitate the overall upgrading of the green logistics system.

Second, we should advance the coordinated development of green logistics and industrial structure by leveraging the construction of a modern industrial system.

The level of modernization plays a pivotal role across multiple configurations, indicating a highly coupled relationship between green logistics and industrial modernization. Regions should leverage their respective industrial strengths to promote deep integration between the logistics sector and advanced manufacturing as well as the digital economy. This integration should enhance green logistics efficiency through industrial agglomeration effects and supply chain synergies.

Third, select tailored combinations of new productive forces based on regional characteristics to avoid one-size-fits-all policies.

Green logistics development exhibits regional variations, and different areas should select matching paths based on their own conditions: regions rich in innovation resources can pursue the "innovation-digitalization" path; regions with strong manufacturing foundations can pursue the "modern industry-intelligentization" path; regions with good ecological endowments or significant human capital advantages can pursue the "ecology-education-modernization" path; regions with weaker resource endowments can achieve breakthroughs by strengthening scientific and technological innovation and R&D investment. Policies should emphasize local characteristics to achieve differentiated development of green logistics.

Fourth, strengthen digital infrastructure construction to enhance the digitalization and intelligentization of the entire green logistics chain.

Among multiple pathways, digital infrastructure and intelligentization serve as critical boundary conditions providing essential support. Efforts should further advance the deep application of 5G, IoT, and BeiDou navigation systems in logistics operations. Digital means should reduce resource consumption, improve transparency and coordination efficiency in logistics processes, and facilitate green transformation.

Fifth, strengthen government policy guidance and institutional support to foster a favorable external environment for green logistics development.

The green logistics standards system should be refined, incentive mechanisms for green transformation optimized, and the formulation and implementation of standards for green warehousing, green transportation, and green packaging advanced. Concurrently, industry oversight and policy support should be enhanced to encourage corporate participation in green logistics initiatives, thereby achieving a collaborative green development framework involving government, enterprises, and society.

6. Conclusions

In summary, addressing the practical demands for green logistics development under the dual carbon goals, this study employs the fsQCA method with new-quality productive forces as the core entry point. It reveals the intrinsic logic by which combinations of new-quality productive force elements influence green logistics development, clarifies core characteristics such as the absence of a single necessary condition and the equivalence of multiple pathways, and identifies three development paths tailored to different regional resource endowments. This provides a new perspective for unraveling the complex causal mechanisms underlying green logistics development. These findings provide a basis for regions to formulate differentiated policies aligned with their comparative advantages, facilitating the precise integration of new quality productive forces with green logistics. Future research could broaden its scope by employing long-term panel data to explore the dynamic evolution of factor combinations, thereby offering more comprehensive theoretical support and practical guidance for the high-quality development of green logistics.

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