Review of Economic Assessment 2024 3 (1) 46-66

Review of Economic Assessment

Homepage: https://www.anserpress.org/journal/rea

Influencing Factors as well as Implementation Path of Synergistic Development of Digitalization and Greening in Manufacturing Industry: Analysis from a Configuration Perspective

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ABSTRACT

The manufacturing sector must incorporate digitalization and greening as crucial strategies to attain high level of development in the context of the digital economy, given its significant role in quality of environment. Most of existing studies explore net effect of a single or several factors on the digitalization or greening in the manufacturing industry. Limited investigation has been done to integrate various factors impacting the connection and synchronized advancement of digitalization and greening within the manufacturing. Factors affecting the synergy of digitalization and green change within manufacturing are recognized in this article, and a theoretical framework is established to analyze. FsQCA tool is also put into use to survey configurational cases, which contains synergy degree of green digitalization from 30 provinces' manufacturing in China. Results show that: (1) Between 2007 and 2020, the development level of digital-green integration in the manufacturing industry shows an upward trend. There are three types of collaborative modes, namely, "industrial robot driven" "market development driven" and "market development driven - industrial robot driven", with each mode consisting of at least one to four equivalent pathways. (2) The marketization level and application of industrial robots are the important external and internal pulling forces that drive the synergy degree of digitalization and green change within manufacturing industry, respectively.(3) The influencing factors of the collaborative mode choice of digital-green development within manufacturing industry are complementary, among which, the degree of marketization is similar to the role of industrial robots in the configuration, which are capable to weaken the negative impact from insufficient government R&D investment support under specific conditions; (4) The non-high collaborative state of digital green in manufacturing industry is mainly due to the low level of marketization, openness, and economic development, as well as the low application rate of industrial robots and software products. This study enriches the theoretical understanding on digitalization and green change of manufacturing industry. Meanwhile, it also provides insights to advance the integrated and synergistic advancement of digital green transformation in manufacturing practice.

KEYWORDS

Manufacturing industry; Digital transformation; Green transformation; Coupling coordination path; FsQCA

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ISSN 2972-3515
doi: 10.58567/rea03010004

Received 10 November 2023; Accepted 04 March 2024; Available online 11 March 2024

1. Introduction

Guided by the concept of sustainable development and the digital technology revolution, the manufacturing industry has begun to carry out extensive change towards digitalization and environment-friendly direction. The 14th Five-Year National Informatics Plan calls for promoting the integration of digital transformation and green improvement. To achieve first-class development of manufacturing industry, digital empowerment needs to be coordinated with low energy consumption and low pollution. It is important to improve the green innovation's efficiency to drive the shift towards sustainability in the manufacturing sector. According to Lin and Xie (2023), leveraging digital technology for digital transformation can enhance management efficiency and drive green innovation within the manufacturing industry through research and development subsidies, ultimately fostering a green transformation. Nevertheless, the use of digital technology requires a significant amount of energy resources, leading to electronic pollution, which contradicts the principles of high-quality ecological environment (Loeser et al.,2017). Fostering the integrated and harmonized growth of digital green initiatives in the manufacturing industry is conducive to achieving sustainable development. In particular, digital technologies that support environmentally-friendly practices and digital strategies oriented towards green development are identified as the two principal mechanisms for achieving these goals (Ye et al.,2024). No matter the level of coordination between digital economy and industrial green development, or the level of coordination between data elements and green change, multi-index construction, entropy weight method and synergy degree are commonly used methods (Liu et al., 2022; Tao et al.,2023).

Factors at the economic, technological and government levels need to be taken into account when realizing digital green integration of manufacturing. The existing results mainly present the impact of these factors above on digital development or green transformation (Wang & Su, 2021a; Chen et al., 2021). Digitalization selection can optimize production efficiency and strongly support green and sustainable development, and manufacturing enterprises that introduce and utilize foreign capital have more opportunities to embrace the advantage of digital technology (Yang et al.,2024). High-quality urbanization development is crucial for the establishment of low-carbon and digital smart cities. Research has shown that low-carbon city initiatives can facilitate the digital transformation of manufacturing by alleviating financial barriers and enhancing investments in financial technology (Zhao et al.,2023). By studying the process of digital technology application reshapes the profit model in manufacturing, Zhang et al.(2023c) find that policy support can optimize manufacturing profit model by adopting digital technology to provide strategic flexibility, while regulation turbulence is counterproductive. While there exists a substantial body of research on the digitalization and green change, the great mass of studies often focus on analyzing the impact of only one or two factors from s singular viewpoint. Few studies have examined the dynamic links between influencing factors at different levels and their possible synergistic effects on the synergy development of digital-green change in the manufacturing. Generally speaking, the digital-green synergy is a development mode choice made by the manufacturing industry focusing on the driving of technology application and the integration of the economic environment and the supporting factors provided by the government. Thus, from a configurational standpoint, this paper explores whether the synergy of various factors enhances the synergy advancement of digital-green transformation at the manufacturing industry level. Specifically, the manufacturing industry panel data from 30 provinces in China are used as the research target, and the FsQCA tool is applied to study the configuration configuration of digital green deep collaborative development at this level. The content of this study is to address the following questions: (1) What is the current status of digital green integration in manufacturing sector, and what are the factors affecting the process of integration? (2) What are the key factors for high or non-high synergy degree configuration of digital-green within manufacturing industry? (3) In the process of promoting the integrated development of digital green change, is the relationship between multiple factors of different dimensions collaborative or conflicting? The solutions to these questions are crucial to promote the coupled and coordinated development of digital green change within manufacturing industry. The main contributions made by this study include conducting a theoretical analysis on the interaction of various factors influencing the integration and synergy of digital-green change within the manufacturing, as well as proposing an analytical framework; creating a linkage at both macro and meso levels to examine the relationship between government behavior, industry action, and manufacturing companies change. FsQCA tool with configuration thinking has been adopted to transform single-dimensional view into the overall perspective.

The research content structure is arranged as follows. On the basis of reviewing the existing research results, Section 2 integrates and put forward the theoretical analysis framework. The methodology used, the selected model, the data sources used and the results of data calibration are presented in the third section. Section 4 shows the development status of the digital and green integration of manufacturing industry, the test of the necessary conditions for the integration development, and the conditional configuration of the results of the deep integration development and the non-deep integration development, so as to summarize the main collaborative integration modes and test the stability of the results. Finally, section 5 summarizes the findings and policy measures.

2. Review and analysis framework

2.1. Review of existing academic achievements

Different provinces in China have shaped distinct economic environment. For example, the three provinces contained in the Yangtze River Delta region, as the most advanced urbanized region in China, have a highly open economy and a comprehensive industrial support system, and are the most competitive area, leading in manufacturing digitization and green practices. From an industrial green development perspective, the use of resources and energy, the application and progress of technology, and the supervision of environmental quality vary in different regions of China. This has resulted in different modes of green change across these regions' industry. The eastern area is mainly distinguished by its approach to development, which involves expanding investment scales while also implementing environmental regulations and fostering the capacity for creativity. The provinces in central China mainly undertake the technology transfer from the east and improve the efficiency of resource allocation through the technology catch-up transformation mode. In contrast, under the background of relaxed environmental quality regulation, western provinces introduce and apply external capital in the form of introducing technology to promote industrial green improvement (Mao et al., 2019). Moreover, regional economic strength impact the industrial green transformation. Eco-industrial parks in provincial capitals generally demonstrate superior construction effects(Song & Zhou， 2021), and larger cities exhibit a positive correlation with green development efficiency， typically achieving higher efficiency levels(Zhou et al., 2020). There exists a symbiotic relationship between urbanization and industrialization. Some scholars have combined urbanization,industrialization, and carbon emissions to explore the interactive relationship among these three factors (Meng et al., 2021). In practice, green urbanization necessitates green improvement and upgrading of industries. From an industrial digital development standpoint, when FsQCA tools are used to investigate the influencing factors, the fundamental driving force for digital transformation is investment in digital equipment and innovation activities (Llopis-Albert et al.,2021). Furthermore, from an internal and external perspective, the influencing factors can be classified as technical aspects such as digital infrastructure construction and security risks; organizational aspects including corporate culture and financial resources; as well as environmental aspects like market demand and competition (Wang & Su, 2021a). In addition, the ratio of service industry to industrial output increase is used to measure the progress of industrial structure, with higher levels indicating enhanced service capabilities that provide opportunities for integrating industry with service sectors. Digital transformation within manufacturing industries has revolutionized traditional business models by leveraging digital technologies resulting in continuous improvements in service quality while simultaneously facilitating savings energy and emission reduction through enhanced green technology innovation efforts and optimized element structure (Wang et al., 2023). Apart from these aforementioned factors, government behavior also plays a non-negligible impact on the digitalization and green improvement of manufacturing industry. Governmental intervention in the form of appropriate environmental regulations can help drive the green change within manufacturing by impacting their access to finance and technological advancements, as noted by Zhai and An (2020). Simultaneously, augmenting government financial support for the digitalization within manufacturing serves as one avenue to promote their digital transformation (Luo et al., 2023). For manufacturing enterprises with insufficient scale and strength, the problems caused by the lack of technical resources, capital constraints and talent scarcity all need the support of the government to solve (Chen et al., 2021).

Existing academic achievements have explored various factors and pathways influencing the digitalization or green change within the manufacturing, which can be categorized into the following aspects: urbanization level, marketization level, opening up level, economic development level, industrial structure upgrading, technology level, and government support. However, there remains opportunity for deeper exploration in two areas: (1) while many studies have investigated the factors influencing digitalization or green change within the manufacturing, few have delved into the interaction and synchronized advancement of these two types of transformation. This lack of comprehensive analysis hinders providing theoretical support for selecting multiple paths to achieve a deeper synergy degree of digital-green transformation. (2) Achieving the integrated and synergistic development of digital-green transformation within manufacturing industry requires the interdependent relationship between the antecedent condition variables rather than the independent existence of them. Existing literature primarily focuses on discussing individual influencing factors without adequately addressing complex causal relationships that impact the synergy of green-digital transformation.

2.2. Analytical framework

Referring to the existing academic results, the factors affecting the digital green integration and synergy of the manufacturing industry are classified as economic environment, government support, and technology application. Among these factors, the secondary conditions of economic environment include urbanization level, marketization level, openness to international trade level, economic strength, and advanced industry structure. Government support is governmental assistance for industrial research and development innovation. The secondary conditions of technology application encompass industrial robot utilization and software product implementation. In the analysis part, the FsQCA tool is used to study the linkage effect of economic environment, government support and technology application on the collaborative and integrated development of digital green within manufacturing, and at the same time, the potential complex causal relationship in different condition variables is revealed.

2.2.1. Complementation of economic environment and government support

The economic environment has varying degrees of influence on a given economy, including urban development, liberalization, degree of marketization, modernization of industry, and overall economic strength. Process of digitalization and green change taking place simultaneously and synchronously requires careful consideration of the economic context. From an urban development perspective, increasing level of urbanization imply a continuous increase in urban population size and ongoing improvement in rural-urban integration. Andersson (2018) examined the relationship between democratization, urbanization, and government tax revenues and found that the more democratic the country with a higher level of urbanization development, the more its tax revenue increases due to the reduction in the costs associated with collecting taxes from a concentrated urban population. This rise in government income tax revenue can provide an economic foundation for supporting manufacturing industry transformation efforts. In terms of openness to foreign markets, this is often reflected by import-export trade levels. Some studies have found that in countries with developed foreign trade, their tax system reform can positively affect the government's tax performance (Gnangnon & Brun, 2019). In addition, government investment in R&D innovation and regional creativity play an intermediary role in the relationship between self-employment and the marketization level. Additionally, when government R&D investment surpasses a certain threshold level, regional creativity is negatively correlated with marketization level; thus promoting administrative streamlining and power delegation by the government becomes crucial (Zhang et al.,2023a). From the viewpoint of advancing industrial structure, the synergy between government spending and low-carbon policies across different levels of government has notably boosted local industrial structure development, supported the growth of the service sector, and continuously driven industrial upgrade (Pan et al., 2023; Wang and Wang, 2021b). Similarly, industrial upgrading will augment government revenue through taxation, thereby fortifying the economic foundation for supportive governmental actions. With the ongoing improvement in local economic development, the government's increasing fiscal revenue can increase financial assistance for digital green manufacturing to promote its synergistic growth.

2.2.2. Complementation of economic environment and technological application

Digital technology is the core of digital green integrated development of manufacturing industry. On one hand, it possesses a clean property that enables significant reduction in resource and energy consumption, thereby facilitating the green manufacturing (Ran et al., 2023). Alternatively, digital technology can promote the optimization of production factor structure, stimulate the research and development and application of green-oriented technology, so as to promote the development of manufacturing industry towards the direction of improving environmental quality (Zhang et al.,2023b). For instance, by leveraging an optimized algorithm system, industrial robots can enhance productivity while simultaneously reducing resource and energy consumption as well as pollution emissions levels; thus propelling forward the environment-friendly development of this sector (Rubio et al., 2021). In consideration of data availability, this paper selects industrial robot application and digital software product application as indicators to characterize the level of technology implementation. The application level of manufacturing technology is closely intertwined with the local economic environment. Specifically, digital technology not only facilitates low-carbon urbanization by enabling citizen participation in government decision-making, creating more job opportunities, and promoting digital financial inclusion but also responds to the growing demand for sustainable urbanization by continuously updating and upgrading technological capabilities (Goel and Vishnoi, 2022). To improve technological proficiency, continuous research and development efforts are essential in manufacturing companies. With China's market-oriented reform process underway, high-tech industries have witnessed a significant improvement in their research and development efficiency (Zeng et al., 2021). Achieving digitization and green change integration within manufacturing industry relies heavily on rapid advancements in the digital economy. Technological advances brought about by the digital economy can drive urban export growth (Zhang et al., 2022). Meanwhile, the sound and rapid development of foreign trade will also facilitate manufacturing enterprises' access to cutting-edge digital technologies from abroad and promote the application of these technologies. At present, China is actively carrying out the intelligent and service-oriented development of industries, leading the upgrading of traditional industries, and promoting the complementarity of economy, ecology and environment (Tang et al., 2020). On one hand, transition from traditional agriculture to industry has resulted in resource waste, energy consumption, and pollution that hinder green development. In addition, green technologies aimed at utilizing renewable energy can improve the energy structure and achieve coordination between industrial development and ecological environment (Cheng et al., 2018). Recognizing upgrading industrial structure involves both streamlining and progress is vital. Research indicates that as rationalization requires an increasing proportion of GDP contributed by tertiary industries, whereas green technologies like new energy focus on secondary industry development; technological innovation aimed at developing and utilizing clean energy conflicts with the rationalization of the industrial structure. Regions with advanced industrial structures tend to adopt more green technologies such as new energy applications, breaking inter-regional barriers for sustainable development (Su & Fan, 2022). Furthermore, regions with stronger economic strength attract more talent, technology transfer opportunities capital inflows among other elements conducive to technological advancements thereby continuously promoting coupling effects for coordinated regional developments.

2.2.3. Complementation of government support and technology application

In China, governmental support is a crucial and strategic resource that guides and facilitates the transformation and advancement of enterprises through policies, financial subsidies, and other means. It offers a crucial economic assurance for aligning and coordinating digital-green manufacturing. Furthermore, taking into account market failures and externalities in economics, enterprise investments in research and development activities may not reach socially optimal levels due to knowledge spillover effects. This predicament poses challenges for many manufacturing enterprises when undertaking digital or green transformations. Hence, government intervention becomes imperative. Governments can alleviate economic burdens on industrial enterprises and expedite industrial transformation by offering subsidies, tax incentives, loans, and other forms of support to promote the advanced technology application (Wang et al., 2022; Radas et al., 2015). Meanwhile, government will also regulate various business activities of manufacturing enterprises, such as implementing environmental policies that promote the urgent need for digital technology to enable green development and leveraging sustainable development goals to guide and promote the digitization of manufacturing industry (Khaddage-Soboh et al., 2023). This has led to a faster uptake of digital technologies in the manufacturing sector. Moreover, scholars have emphasized that due to variations in industry maturity, sectors can be categorized as emerging or mature, each requiring distinct styles of exploratory innovation and exploitation innovation. Consequently, government subsidy plans should also differ accordingly, with a particular focus on strengthening research and development support for startups in emerging sectors (Lee et al., 2022a). Based on the aforementioned theoretical analysis, this paper ultimately selected eight antecedents including marketization level, openness to international markets, economic development, urbanization level, industrial structure upgrading, industrial robot application, software product application and government support. These factors were then divided into three dimensions: economic environment; technology application; and government support. A theoretical analysis framework was constructed as illustrated in Figure 1.

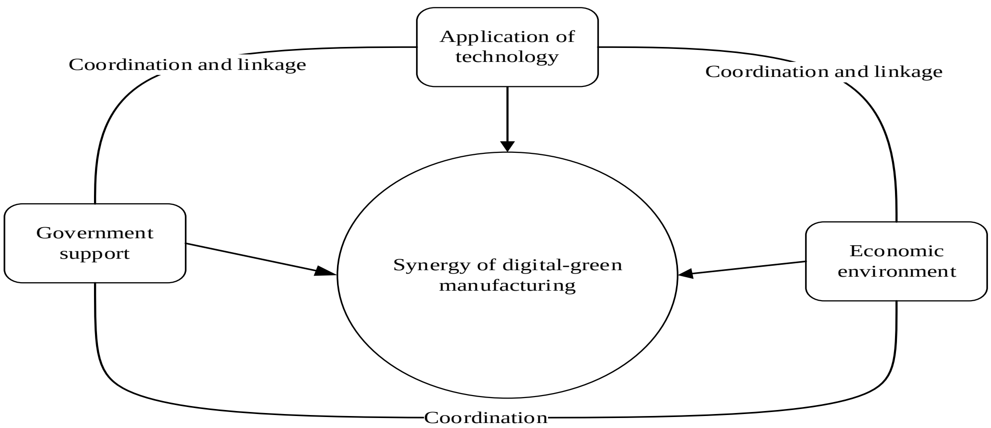

Figure 1. Theoretical analytical framework for enhancing the integration and synchronization of digital-green manufacturing.

3. Empirical test design

3.1. Econometric Tool

3.1.1. Coupling coordination degree model

The coordination level determined according to the coupling coordination model usually reflects the coordination status between systems. This article uses the above tools to evaluate the level of digital green integration and coordination in the manufacturing industry. Among them, coupling degree indicates the extent of mutual influence among two or more systems, including two kinds of influence: complementary and mutual restriction. The coordination degree primarily signifies the degree of positive coordination between systems. Entropy weight tool is employed to calculate the index of digital manufacturing and green manufacturing, and the coupling coordination degree model is further used to calculate the coordination degree of digital manufacturing and green manufacturing. With reference to the introduction to the theory of Liu et al. (2022), a coupling coordination degree model is established as follows.

Coupling degree model:

$$C = \frac{2\sqrt{Y_1 + Y_2}}{Y_1 + Y_2} \tag{1}$$

Coordination degree model:

$$Q = \alpha_1 \times U_1 + \alpha_2 \times U_2 \tag{2}$$

Synergy degree model:

$$D = \sqrt{C \times Q} \tag{3}$$

In the formula, Y_1 and Y_2 are respectively manufacturing digital transformation index and manufacturing green transformation index. C and Q are the degree of coupling and coordination, respectively, α_1 as well as α_2 indicate the undetermined parameters, digital manufacturing and green manufacturing are equally important to the first-class development of the manufacturing industry, take $\alpha_1=\alpha_2=0.5$. D represents the degree of collaboration between digitalization and greening of manufacturing industry, and its value ranges from 0 to 1. As the value of D increases, the level of collaboration also increases.

3.1.2. Fuzzy set qualitative comparison method

The Qualitative comparison method (QCA), proposed by Charles Larkin, can systematically and effectively process the data of multi-case comparisons and analyze the combinations of multiple anthems that lead to complex events. Qualitative comparison of Fuzzy Sets, based on set theory and configuration, effectively combines qualitative research methods with quantitative research methods. FsQCA uses both architectural theory and Boolean algebra to analyze the relationships between antecedents and their combinations, as well as the outcomes, viewed through the lens of sets. This approach helps to uncover the intricate causal relationships underpinning a specific phenomenon. Compared with traditional regression analysis, FsQCA is suitable for small and medium-sized data. Moreover, by introducing the concept of membership degree and calibration, the changes in the degree and level of the influencing factors are investigated, and all the data are between 0 and 1, so as to calculate. The factors influencing the integration and synergy of digital-green manufacturing are fuzzy and uncertain due to the lack of unified standards. The sample of this study uses provincial panel data of the manufacturing industry, and the data scale is medium, which is in line with the scope of application of the above method, so that they can be used for analysis.

3.2. Variable data measurement

3.2.1. Calculation of synergy degree

In this paper, the outcome variable is the degree of synergy between digital manufacturing and green manufacturing calculated in the previous section. Firstly, based on scientific accuracy and data availability, the comprehensive index system of digital manufacturing and manufacturing green improvement is designed respectively. The degree of digital development in the manufacturing industry involves indicators such as the capacity of mobile switches in China, long-distance optical cable lines length, the proportion of the total number of Internet and mobile fixed telephone users in the total number of users, industrial robots installation density, and the proportion of the main business income of various basic software and electronic information manufacturing industries in the total industrial income. The evaluation of the green degree of manufacturing industry mainly involves industrial energy and water consumption, industrial solid waste disposal, and industrial nitrogen oxide emissions. Secondly, based on the above index system, the degree of digitalization Y1 and the green degree Y2 are calculated by using entropy weight TOPSIS.

3.2.2. Selection of antecedent conditioning variables

The level of marketization in the economic environment is primarily assessed through various dimensions of the institutional framework, such as the interaction between government and market, private enterprises growth, mature product and factor markets, developed intermediary organizations, and effective legal institution. The proportion of the total amount of foreign trade import and export in the GDP of different provinces determines the degree of opening-up. The proportion of the urban population in the total population at the end of the year reflects urbanization degree. It is reasonable to use GDP per capita to evaluate economic development. The level of modernization of industrial development is determined by the ratio of increased output of services to industry.

The application of hardware technology is reflected by the number of robots installed per capita in the industrial sector. The per capita number of robots in the industrial field in different provinces = the installed number of robots in the industry×the proportion of the number of manufacturing employees in the total number of employees. In addition, the proportion of the revenue of various software products in the industrial main revenue is calculated to reflect the degree of software application.

Government support is important for transforming the manufacturing industry. Its initiatives like tax reduction, increased subsidies, technical protection, and environmental regulations. However, the most significant impact on industry transformation comes from financial support. Furthermore, at the heart of connecting and aligning digital-green manufacturing is to utilize technological advancements, with an emphasis on investing in R&D funds as primary assurance to enable such technological innovation endeavors. Therefore, the proportion of government investment in the R&D expenditure of industrial companies reflects the level of government support.

3.2.3. Data sample selection description

Related data of manufacturing industry in different provinces are sourced from a variety of publications including the China Statistical Yearbook, China Industrial Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, China Electronic Information Industry Statistical Yearbook, International Federation of Robotics Report, China Science and Technology Statistical Yearbook, and others. There are different influencing factors on the synergy degree between digital manufacturing and green manufacturing, which has time lag problem, so a solution is proposed to address the issue of individual data problems. This involves selecting the 2020 result variable to align with the average value of the preceding condition variables from 2019 and 2020.

3.2.4. Data calibration results

Prior to the QCA analysis, the original case data should be calibrated with the ensemble member score for further necessity and adequacy analysis. FsQCA allows case data to be calibrated to an adherence score between 0.0 and 1.0. The direct calibration method was used to calculate the 75%, 50% and 25% quantiles of all conditions and outcome variables, which were set to three thresholds of full membership, crossing point and full non-membership, respectively, so as to transform the original variable data into a score between 0-1. In addition, after calibration, the sample data in this paper had a value of 0.5 after calibration at the crossover point. In order to avoid such data being invalid and affecting the accuracy of the final result, the value of 0.5 was manually changed to 0.5001. The Table 1 displays the calibration anchor points for specific variables.

Table 1. Calibration of result variable and condition variables.

Variable Type	Index Name	Full Membership Threshold	Intermediate-Set Membership	Full Non-Membership Threshold
Outcome Variable	The synergy degree of digital- green manufacturing	0.695	0.618	0.541
Antecedent Condition	Marketization level	9.615	8.817	7.087
	Opening-up degree	0.290	0.137	0.106
	Urbanization level	0.680	0.610	0.573
	Economic development level	11.248	10.959	10.818
	Industrial structure advanced degree	1.512	1.359	1.255
	Industrial robot application	24336.806	17056.693	3749.621
	Software product application	0.024	0.009	0.002
	Government support	0.063	0.036	0.024

4. Empirical Analysis

4.1. Coupling coordination development status

The national results average of the synergy degree of digital-green manufacturing calculated by entropy weight tool and coupled coordination degree tool is shown in Figure 2. The results show that the synergy level of digital-green integration in China's manufacturing industry shows a steady upward trend. Figure 3 shows the growth rate of the synergy degree of digital-green manufacturing. The curve shows that the growth rate of the synergy degree of the digital green transformation of the manufacturing industry is less than 10% in the sample period, and the numerical fluctuation is small, indicating that the synergy degree is on the rise.

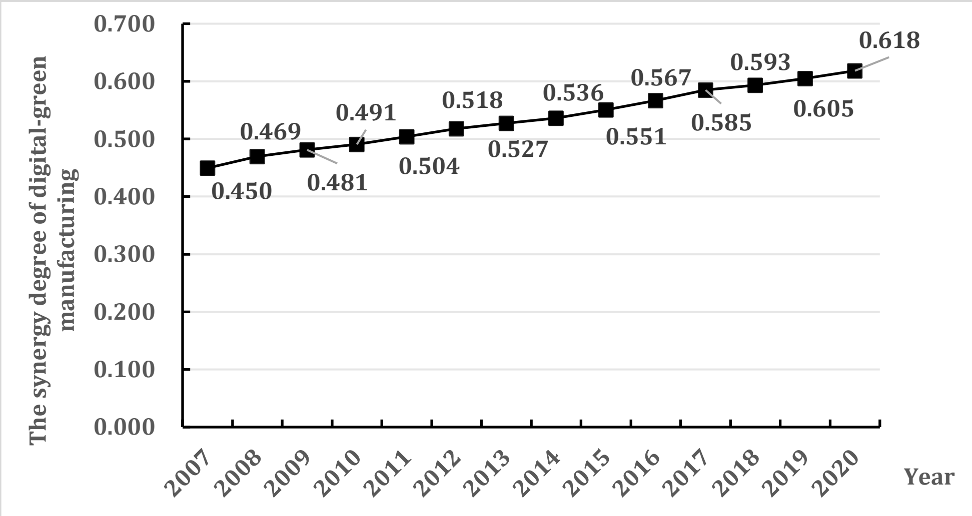

Figure 2. Development status of synergy between digital-green manufacturing.

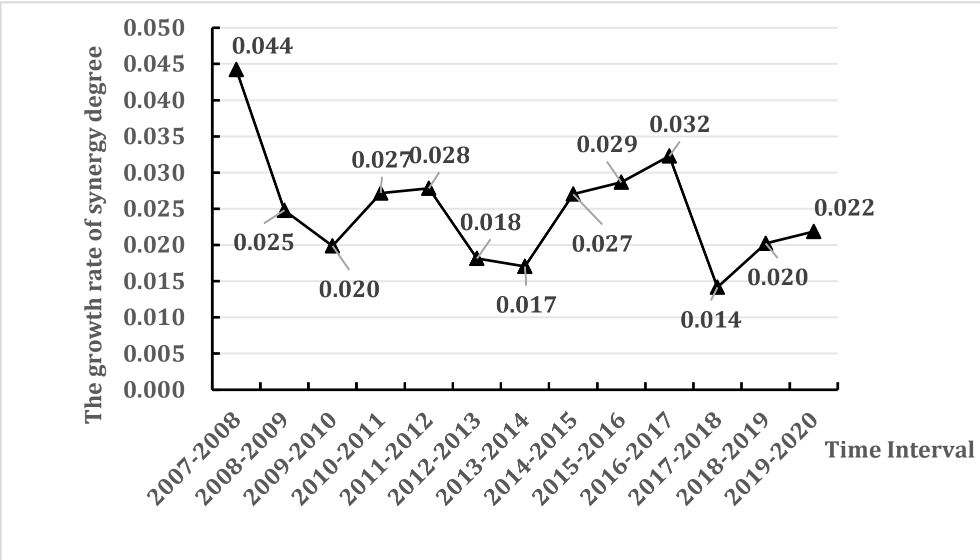

Figure 3. Growth rate of synergy degree between digital-green manufacturing.

4.2. Necessity analysis

In order to find out whether the appearance of the outcome variable is caused by a single condition, necessity analysis is needed. This study mainly uses Fs-QCA3.0 software to verify whether a single factor (including its non-set) is necessary for high (or non-high) synergy degree of digital-green within manufacturing. See Table 2 for specific results. Consistency is frequently utilized as a criterion for evaluating if a factor is necessary. The definitive decision is that if the consistency degree exceeds 0.9, the factor will be deemed necessary for the result variable. In Table 2, when result variable is high or non-high coupling coordination degree, the all consistency levels are lower than 0.9, which reflects that a single antecedent factor variable cannot explain high (or non-high) coupling coordination degree of digital-green manufacturing.

Table 2. Necessity conditions analysis.

Antecedent Condition	High synergy degree		Antecedent Condition	Non-high synergy degree	
	Consistency	Coverage		Consistency	Coverage
Marketization level	0.897	0.871	Marketization level	0.391	0.326
~Marketization level	0.306	0.368	~Marketization level	0.845	0.876
Degree of Opening-Up	0.817	0.818	Degree of Opening-Up	0.474	0.408
~Degree of Opening-Up	0.409	0.475	~Degree of Opening-Up	0.788	0.787
Urbanization level	0.735	0.729	Urbanization level	0.560	0.477
~Urbanization level	0.472	0.555	~Urbanization level	0.681	0.689
Economic development level	0.832	0.796	Economic development level	0.481	0.396
~Economic development level	0.369	0.452	~Economic development level	0.753	0.794
Industrial structure advanced degree	0.602	0.570	Industrial structure advanced degree	0.716	0.583
~Industrial structure advanced degree	0.559	0.696	~Industrial structure advanced degree	0.472	0.505
Industrial robot application	0.851	0.881	Industrial robot application	0.399	0.355
~Industrial robot application	0.377	0.422	~Industrial robot application	0.867	0.834
Software product application	0.772	0.812	Software product application	0.369	0.334
~Software product application	0.366	0.403	~Software product application	0.792	0.749
Government support	0.559	0.578	Government support	0.669	0.595
~Government support	0.608	0.681	~Government support	0.525	0.506

4.3. Conditional configuration analysis

Conditional configuration analysis reflects the adequacy impact of differentiated configuration composed of multiple antecedent conditioning variables on outcome variables. The level of agreement regarding the adequacy of the configuration is generally required to be greater than 0.75, but is specific depending on the differences in the study sample. The number of samples determines the frequency threshold. In general, the threshold is generally set to 1 for a small sample size, and greater than 1 for a large sample size. The study defined the consistency threshold as 0.8. Secondly, the sample size of this study is 30 cases, which belongs to the medium sample size. Hence, it is more suitable to choose a case frequency threshold of 1. In addition, the minimum acceptable standard for the PRI conformance threshold is defined as 0.75 to eliminate the contradictory configurations. The configuration results are presented in Table 3 and Table 4.

(1) Configuration analysis of the high synergy degree of digital-green manufacturing

The results in Table 3 reflect that the consistency degree contains the overall solution and the individual configurations both exceeds 0.8. Specifically, the overall solution consistency is 0.971, while the overall solution coverage is 0.751. There are seven configurations, which are sufficient conditions for the formation of highly coupled and coordinated development of digital-green manufacturing. In configuration H1, industrial robots application plays a core role, and the consistency level is 0.991, the original coverage is 0.146, and the unique coverage is 0.024. Results show that the extensive application of industrial robots in the manufacturing industry can make up for the lack of government R&D support, thus driving their high-coupling and coordinated development of digitalization and green, represented by Henan and Hebei. In configuration H2, the marketization level plays a core role, and the consistency level is 1.000, the original coverage degree is 0.152, and the unique coverage degree is 0.019. A high level of marketization can weaken the impact of insufficient government support and drive the manufacturing industry to realize digital-green coordination, representing Anhui and Hunan provinces. In configuration H3, the marketization level and the application of industrial robots play a core role, and the consistency level is 0.969, the original coverage degree is 0.368, and the unique coverage degree is 0.213. The widespread use of industrial robots is a crucial factor in advancing the integrated development of digital-green manufacturing in regions with more advanced market development, filling the void left by insufficient government backing, represented by Jiangsu, Zhejiang, Fujian, Tianjin, Shandong, Guangdong, and Chongqing. In configuration H4, marketization level plays a core role. Its consistency level is 0.968, the original coverage degree is 0.320, and the unique coverage degree is 0.138. The degree of marketization plays a decisive role in the economic environment,

Table 3. Configuration analysis of high synergy degree of digital-green manufacturing.

Conditional configuration		H1	H2	H3	H4	H5	H6	H7
Economic Environment	Marketization level	⊗	⬤	⬤	⬤	⬤	⬤	⬤
	Degree of opening-up	⊗	⊗	●	●	●	⊗	●
	Urbanization level	⊗	⊗	●	●	⊗	●	⊗
	Economic development level	⊗	●	●	●	⊗	●	⊗
	Industrial structure advanced degree		⊗		●	⊗	⊗	●
Technology Application	Industrial robot application	⬤		⬤		⬤	⬤	⬤
	Software product application	⊗	⊗	●	●	⊗	●	●
Government Support	Government investment in R&D	Ⓧ	Ⓧ	Ⓧ	●	Ⓧ	●	●
Consistency		0.991	1.000	0.969	0.968	1.000	0.996	0.991
Original coverage		0.146	0.152	0.368	0.320	0.139	0.152	0.143
Unique coverage		0.024	0.019	0.213	0.138	0.009	0.046	0.034
Typical cases		Henan、Hebei	Anhui、Hunan	Jiangsu、Zhejiang、Fujian、Shandong、Guangdong、Tianjin、Chongqing	Shanghai、Beijing、Liaoning	Jiangxi	Hubei	Sichuan
Overall solution consistency					0.971			
Overall solution coverage					0.751			

Notes: ● or ⬤ said the condition exists; Ⓧ or ⊗ said the lack of conditions; ⬤or Ⓧ said core conditions; ● or ⊗ said non-core conditions; A blank signifies the condition's potential presence or absence.

driving economic development, opening up, industrial service upgrading, urbanization development, and driving the digital-green upgrading of manufacturing industry under the background of industrial software application and government research and development help, represented by Shanghai, Beijing, and Liaoning. In configuration H5 to H7, marketization level and industrial robots play a core role. Their consistency levels both exceeds 0.99. In provinces with a high degree of marketization, expanding the application scenarios of robots in the manufacturing industry can make up for the shortcomings of insufficient government R&D subsidies and the disadvantages of economic resources, represented by Jiangxi, Hubei, and Sichuan.

(2) Configuration analysis of non-high synergy degree of digital-green manufacturing

There are six configurations in Table 4 of non-high synergy degree between digital-green manufacturing, namely, configuration L1-L6. The consistency level between the overall solution and each group of states is greater than 0.8, the overall solution consistency is 0.979, and its coverage is 0.645. The six paths listed above are sufficient for achieving a low synergy degree of digital-green manufacturing. Non-high configuration means that there are blocked points and blind spots when promoting the integrated and synergistic development of digital-green manufacturing. In configuration L1, government R&D investment plays a core role. Its consistency is 0.995, original coverage is 0.420, and unique coverage is 0.088, showing that in the case of poor economic environment and insufficient technology application, the higher the proportion of government investment in enterprise R&D investment, it can not bring about the improvement of the innovation level, but may protect some manufacturing enterprises with weak competitiveness and low productivity through "deepening subsidies", conflicting with the law of "survival of the fittest" in the market. Thus, the synergy progress of digital-green manufacturing are impeded, particularly concerning the provinces of Gansu, Guizhou, Ningxia, Heilongjiang, Yunnan, and Qinghai. Configuration L2 indicates that when marketization level and economic development is low, the industrial robots application is insufficient, even if the degree of openness is high, industrial upgrading cannot promote the synergy development of digital-green manufacturing. Its consistency level is 0.968, original coverage is 0.199, and unique coverage is 0.031, representing Guangxi and Hainan. In configuration L3, when marketization level, openness and economic development is low, and software products application is insufficient, the government's support for enterprise R&D investment will not bring about the synergy development of digital-green manufacturing. Its consistency is 0.980, original coverage is 0.357, and unique coverage is 0.036. Its representative provinces are Gansu, Guizhou, Yunnan, and Jilin. The consistency level of configuration L4 is 1.000, original coverage is 0.141, and unique coverage is 0.046. In this configuration, when marketization level and openness is low, and industrial robots application and software products application is insufficient, even if the economic development and urbanization is fast, it is also difficult to promote the synergy development of digital-green manufacturin, representing Inner Mongolia. The consistency level of configuration L5 is 0.982, original coverage is 0.239, and unique coverage is 0.010. In this configuration, when marketization level and economic development are absent, and industrial robots application and software products application are insufficient, it is difficult to promote the digital-green integration within manufacturing even if the industrial structure is advanced. The representative provinces are Xinjiang and Guangxi. In configuration L6, when marketization level, openness and economic development are absent, and the application of industrial robots and software products is insufficient, the high degree of industrial structure upgrading will only lead to the formation of non-high synergy degree of digital-green manufacturing. Its consistency level is 0.995, original coverage is 0.405, and unique coverage is 0.002, which represents Gansu, Guizhou, Yunnan, and Xinjiang. In general, marketization, openness as well as the low economic development, lacking industrial robots application and software products application are the blocking points of the synergy development of digital-green manufacturing. Paying attention to the government's research and development investment support for enterprises can not work alone, and need to cooperate with other factors.

Table 4. Configuration analysis of non-high synergy degree of digital-green transformation manufacturing.

Conditional configuration		L1	L2	L3	L4	L5	L6
Economic Environment	Marketization level	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ
	Degree of opening-up	Ⓧ	●	Ⓧ	Ⓧ		Ⓧ
	Urbanization level		ⓧ	ⓧ	●	ⓧ	ⓧ
	Economic development level	Ⓧ	Ⓧ	Ⓧ	●	Ⓧ	Ⓧ
	Industrial structure advanced degree		●	●	ⓧ	●	●
Technology Application	Industrial robot application	Ⓧ	Ⓧ		Ⓧ	Ⓧ	Ⓧ
	Software product application	Ⓧ		Ⓧ	Ⓧ	Ⓧ	Ⓧ
Government Support	Government investment in R&D	●	ⓧ	●	ⓧ	ⓧ	
Consistency		0.995	0.968	0.980	1.000	0.982	0.995
Original coverage		0.420	0.199	0.357	0.141	0.239	0.405
Unique coverage		0.088	0.031	0.036	0.046	0.010	0.002
Typical cases		Gansu、Guizhou、Yunnan、Ningxia、Heilongjiang、Qinghai	Guangxi、Hainan	Gansu、Guizhou、Yunnan、Jilin	Inner Mongolia	Xinjiang、Guangxi	Gansu、Guizhou、Yunnan、Xinjiang
Overall solution consistency		0.979					
Overall solution coverage		0.645					

Notes: ●or ● said that the condition exists; Ⓧ or ⓧ said the lack of conditions; ●or Ⓧ said core conditions; ● or ⓧ said non-core conditions; A blank signifies the condition's potential presence or absence.

4.4. Synergy path mode summary and analysis

By comprehensively comparing the configuration results of high (or non-high) coupling coordination degree promoted by the condition variables of economic environment, technology application and government support, it can be found that non-high configuration is not the opposite of high configuration, and the antecedent conditions promoting the synergy development of digital-green manufacturing are asymmetrical. By further integrating the above seven high configurations, three coupling coordination mode paths can be obtained.

(1) Industrial robot driven

The configuration H1 belongs to this mode, and the provinces represented are Henan and Hebei. The industrial robot driving mode configuration results indicate low levels of marketization, openness, urbanization, and economic development, as well as insufficient utilization of software products and government support for research and development. The core missing element is government investment in R&D. The deployment of robots in industry can empower manufacturing industry to make up for the deficiency of government financial assistance in R&D activities, promote technological upgrading and green creativity within manufacturing (Lee et al.,2022b). Specifically, as a symbol of intelligent manufacturing, industrial robot refers to the multi-joint manipulator applied in the industrial field, which has the advantages of ease of use, high level of intelligence, high production efficiency, high safety and high economic benefits, and has a rich application scenarios. China's development of robot industry calls for accelerating application of robots, carrying out "Robot +" application actions, developing intelligent manufacturing systems based on industrial robots, and achieving the synergy of digital-green manufacturing upgrading. Industrial robots are primarily used in electronic information, automotive, and metal processing industries for terminal applications. Henan has identified the industrial robot and CNC machine tool industry chain as a critical industry chain, aiming to leverage the "robot+" strategy to spur technological advancements, fully harness the transformative power of robots machine, and enhance the effectiveness of manufacturing. Hebei Province has taken a series of measures to boost the growth of the robot industry, with a key focus on broadening application scenarios, fostering associated industries, advancing innovation, nurturing talent, as well as championing the widespread application of robots in the manufacturing sector. These efforts are aimed at catalyzing the shift towards enhanced productivity and innovation within the manufacturing industry.

(2) Market development driven

In this model, there are two possible paths to realize the synergy development of digital manufacturing and green manufacturing. One path is to promote the economic development by promoting the continuous improvement of marketization level, reduce the negative effect of insufficient government support in enterprise R&D investment, and promote the synergy of digital-green manufacturing. Highly marketized Provinces exhibit superior management at the government-market relationship level, robust growth in the non-state-owned economy, high-quality development in product and factor markets, rapid expansion of market intermediary organizations, and a relatively well-established legal framework. These factors facilitate the flow of technology and resources, lower transaction costs, enhance resource allocation efficiency, deepen the division of labor, and stimulate economic growth, to provide the required elements and economic basis for the synergy development of digital-green manufacturing. The Anhui Provincial government has released official documents, including the Opinions on Establishing a Top-notch Business Environment and the Opinions on Enhancing Market Players to Enhance quality, Expand Quantity, and Boost Efficiency. These documents aim to advance the reform of delegating power, delegating regulation, and offering services, stimulate market players' dynamism, enhance marketization, and expedite the transformation of traditional industries towards digitization, smart technologies, and sustainability. In 2020, Hunan puts forward initiatives to enhance marketization, bolster the manufacturing sector through industrial transfer, strengthen traditional industries, reform the service sector under the RCEP agreement, and nurture new competitive industries. These efforts included deepening market-oriented land factor allocation, directing the rational movement of labor factors, promoting market-oriented capital allocation, accelerating technical factor market growth, developing the data factor market, and advancing market-oriented factor price reform. The other path is to promote the synergy of digital-green manufactuing by promoting the in-depth development of marketization, supplemented by promoting opening-up, urbanization,economic development and industrial structure, strengthening the application of software products and the government's R&D investment support, namely, H4, which represents Shanghai, Beijing and Liaoning. Beijing, Shanghai and Liaoning are eastern provinces with high levels of marketization and opening-up, rapid economic development, rapid urbanization, high talent attraction and fast industrial upgrading. The digitalization and green change within manufacturing mainly rely on the above economic environment's advantages. One the one hand, it can rapidly acquire the capital, technology, talent, and other essential elements for transitioning, thereby fostering the integration and harmonious growth of the digitalization and green manufacturing sectors. In addition, urbanization level high will increase the digital and green products demand, forcing the manufacturing to continuously upgrade technology. While vigorously promoting digital development, it will give consideration to green development, and provide consumers with more clean and intelligent products.

(3) Market development driven - industrial robot driven

This mode indicates that marketization degree and industrial robots adoption are crucial factors for the integration and synchronized advancement of digital-green manufacturing. In this mode, there are four potential pathways for the integration of digital and green initiatives. Path 1 is driven by the improvement of industrial robots installation, the highly marketization level in the provinces where the manufacturing industry is located, supplemented by the rapid development of opening up, urbanization and economic development, can reduce insufficient government investment support's impact, promote the manufacturing to acquire technology, experience, talent and other factors, and realize the synergy of digital-green manufacturing, that is, configuration H3, the representative provinces are Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Tianjin, as well as Chongqing. Jiangsu, Zhejiang, Fujian, Shandong, Guangdong as well as Tianjin are categorized as eastern coastal regions with high urbanization rates, extensive market development, robust economic prowess, heightened openness to international trade, booming tertiary sector growth, and rapid industrial structural optimization. Its independent innovation and technology application ability is strong, industrial robot application scenarios are rich. Although situated in the western region, Chongqing belongs to the Yangtze River Economic Belt. Its urbanization development and economic development are accelerating, and marketization degree and openness level are constantly improving. Path 2 driven by industrial robots, enables the manufacturing sector in highly marketized and open provinces to circumvent the negative effects of inadequate government R&D support. This facilitates the achievement of digitalization and green coordination, known as configuration H5, exemplified by Jiangxi. In 2020, Jiangxi, an inland province in central China, was designated as one of the open economy pilot zones, further enhancing its marketization and opening-up levels. Industrial robots are extensively employed in conventional manufacturing sectors. Through human-machine collaboration, problems such as difficult operation, high risk and rising labor costs are solved, and the digital-green synergy of manufacturing is promoted. Path 3 is driven by industrial robots, provinces with high marketization level, supplemented by rapid urbanization and economic development, rich application scenarios of software products, and increased government R&D investment support can make up for the disadvantages of low level of opening-up and low level of optimization of industrial structure, so that the manufacturing industry in this environment is more likely to realize the synergy of digital-green manufacturing. Configuration H6 represents Hubei province, this province emphasizes the need to enhance the green manufacturing system and make manufacturing sector environment-friendly. In addition, Wuhan, Hubei Province, has the only national industrial Internet identification and analysis top node in central China. In 2020, the number of cloud industrial enterprises in Hubei Province reached 32,000, and the digital economy is developing rapidly. Hubei province is situated in the central section of the Yangtze River, with Wuhan earning the nickname "the thoroughfare of nine provinces". Its development of land, water and air transport ranks among the best in China, and the economy develops rapidly. Path 4, characterized by the use of industrial robots, a high degree of marketization in the manufacturing industry' s province, accelerated opening up, optimized industrial structure, software product applications, and increased government support for R&D investment, can mitigate the negative effects of urbanization and economic slowdown. Additionally, it can foster the blending of digitalization with green manufacturing, known as Configuration H7. The representative province is Sichuan. Sichuan is located in the western region of China. In recent years, guided by the "Chengdu-Chongqing Economic Circle", Sichuan has made great efforts to build a scientific and technological innovation center with national influence. At the same time, it has expedited the growth of the modern service industry, advanced the green improvement of digital economy and manufacturing, progressively enhanced openness, and deepened marketization.

4.5. Robustness test

Two approaches are employed in this paper to assess robustness. First, change the consistency threshold of 0.8 to 0.85, and consider that the PRI consistency is greater than 0.7, and the configuration results after calculation are consistent with the above. Second, the PRI consistency threshold of 0.7 was adjusted to 0.85 for QCA configuration analysis. Table 5 shows the specific results. The overall solution consistency of 0.971 remains unchanged, the coverage of the overall solution decreases from 0.751 to 0.746, and there are still 3 high configuration paths after the PRI consistency threshold is increased. It is consistent with the above results.

Table 5. Robustness test.

Conditional configuration		H1	H2	H3	H4	H5	H6	H7
Economic Environment	Marketization level	●	●	●	⊗	●	●	●
	Degree of opening-up	⊗	•	•	⊗	•	⊗	•
	Urbanization level	⊗	•	•	⊗	⊗	•	⊗
	Economic Development level	•	•	•	⊗	⊗	•	⊗
	Industrial structure advanced degree	⊗		•	⊗	⊗	⊗	•
Technology Application	Industrial robot application		●		●	●	●	●
	Software product application	⊗	•	•	⊗	⊗	•	•
Government Support	Government investment in R&D	Ⓧ	Ⓧ	•	Ⓧ	Ⓧ	•	•
Consistency		1.000	0.969	0.968	1.000	1.000	0.996	0.991
Original coverage		0.152	0.368	0.320	0.131	0.139	0.152	0.143
Unique coverage		0.019	0.213	0.138	0.019	0.009	0.046	0.038
Typical cases		Anhui、Hunan	Jiangsu、Zhejiang、Fujian、Shandong、Guangdong、Tianjin、Chongqing	Shanghai、Beijing、Liaoning	Henan、Hebei	Jiangxi	Hubei	Sichuan
Overall solution consistency		0.971						
Overall solution coverage		0.746						

Notes: •or ● said that the condition exists; Ⓧ or ⊗ said the lack of conditions; ●or Ⓧ said core conditions; • or ⊗ said non-core conditions; A blank signifies the condition's potential presence or absence.

5. Conclusion and countermeasures

5.1. Conclusion

This paper develops a theoretical analytical framework that influences the integration and synchronized development of digital-green manufacturing. By using relevant data from 30 provinces in China, the synergy degree of digital-green manufacturing is measured. Furthermore, the FsQCA method was creatively employed to investigate the combined effects of 8 antecedents, including marketization level, openness, urbanization, economic development, industrial upgrading, industrial robot application, software product application and government support, on the integrated development of digitalization and green manufacturing industry through a configurational lens. The conclusions are generally as follows: (1) On the whole, the synergy degree of China's digital-green manufacturing has been increasing steadily from 2007 to 2020. At the driving force level, various and simultaneous conditions in the economic environment, technology adoption, and government backing converge to create diverse patterns of collaborative development in digital and green transformation within manufacturing. These configurations exhibit distinct pathways leading to a common destination. The synergy of digital-green manufacturing is affected by the economic environment, technology application and government support conditions. The coupling and coordination configuration results indicate three collaborative modes "industrial robot-driven", "market development-driven", and"market development driven-industrial robot driven", with each mode consisting of at least one to four equivalent pathways. (2) Through the comparison of the core antecedence conditions of the three modes, it is found that the marketization level and industrial robots installation are the vital external and internal traction forces driving the collaborative development of manufacturing digitalization and greening respectively. As auxiliary forces, opening-up, economic development and other factors are linked with the core forces, and finally achieve the synergistic effect of digital-green manufacturing. (3) Factors affecting the choice of digital-green manufacturing collaborative mode are complementary. The similarity between marketization function and industrial robots function can weaken the negative impact of insufficient government R&D investment support under specific conditions. (4) The main reasons for the non-high synergy degree results of digital-green manufacturing are marketization degree, economic environment, and openness are absent, as well as the insufficient industrial robots application and software products application.

5.2. Countermeasures

The above conclusions are of great significance for the mode selection of the synergy development of digital-green manufacturing. Technology and innovation should guide the change of manufacturing industry. In light of the deepening market-oriented reform, the accelerated and high-degree urbanization, the enhanced openness's quality, as well as the industrial structure upgrade, there is a need to proactively pursue technological transformation, secure government financial support for R&D investments, and drive continual enhancement in the linked development level of digitalization and green initiatives. Specifically, it should be promoted jointly from three levels: manufacturing enterprises, producer services, and government.

Initially, manufacturing companies must select diverse collaboration methods based on the economic landscape of their respective regions to prevent getting stuck in the low collaboration trap. In lowly marketized provinces, openness, urbanization rate, economic development, and insufficient government support for R&D investment, high application of industrial robots can drive innovative R&D activities in the manufacturing industry and weaken the external adverse effects brought by the economic environment. The degree of marketization not only addresses issues like limited openness, slow industrial structure upgrading, and delayed urbanization, but also facilitates the coordinated growth of manufacturing and industrialization through the deployment of robots in industry. To clarify, manufacturing companies should start by shifting their mindset, acknowledging the inevitability of machine replacement, managing the transition of employees displaced by machines effectively, enhancing the digital skills and knowledge of their workforce, and establishing appropriate training programs and initiatives. Secondly, it is necessary to do a good job in the prediction of industrial robot application scenarios, predict the possible problems, communicate with production service providers, and reduce the loss caused by operation technology, parameter matching and other problems.

Furthermore, it is essential to ensure the top-class development of producer services. Producer services, which cover R&D and design, information, logistics, finance and other services, are the key to promoting technological progress, improvement and upgrading of manufacturing. Therefore, producer services should take the lead in advancing the manufacturing industry's top-class development. In particular, science and technology service sector must consistently engage with the global technological forefront, actively advance fundamental research and critical technology exploration, continually achieve the fusion of technology and practical application, science and technology with manufacturing industry, enhance the standards of research and development as well as design, technical advisory, testing, and certification services, persist in delving into green technology innovation in digital infrastructure, and encourage the establishment of data centers in close proximity to energy-abundant zones. Explore the development and utilization of new energy, and constantly explore the application scenarios of digital technology supporting green technology; Software and information service industry should accelerate efforts in basic software, security software and other aspects on the basis of mining the transformation needs of manufacturing industry, and explore the security technology of data transmission. The modern logistics service industry should keep advancing the development of "logistics+advanced manufacturing", enhancing the digitalization and sustainability of logistics services. Simultaneously, the financial industry must actively venture into diversified service products like green finance, digital finance, and science technology innovation finance to enhance funding support for the integrated and harmonized progression of manufacturing digitalization and sustainability.

Thirdly, at the government level, it is important for the government to uphold the principle of an "efficient market and effective government". This involves leveraging the market's decisive role in resource allocation, enhancing the government's effectiveness, and improving its support for manufacturing sector. It is necessary to continue to optimize the property rights policy, improve the marketization level of production factors, promote the rapid expansion of market intermediary organizations, smooth the great domestic circulation, promote the vigorous development of private enterprises, improve the laws and regulations of market governance, constantly deepen the marketization process, and build a high-quality unified domestic market. Additionally, the government should integrate urbanization development with industry modernization adjustment to achieve a harmonious relationship and synergy between the two variables above, thereby steadily advancing the comprehensive development of urbanization. Furthermore, the government has consistently upheld the fundamental state policy of opening up, enacted advanced trade and investment liberalization measures, enhanced the development of pilot free trade zones, boosted provincial openness except the eastern region, solidified coastal areas' leading status in openness, promoted the inflow of talents and technology, and achieved broader and more advanced levels of openness. Ultimately, the government should consistently encourage economic growth, shifting the focus from quantity to quantity and quality, and proactively enhance the quality of economic development.

Although this study explains the selection of collaborative mode between digital-green manufacturing from a multi-dimensional view of configuration, there are still shortcomings. This paper focuses on China's manufacturing industry development at the provincial level, which may neglect the micro explanation at the enterprise level. In addition, there are various forms of government support, and this study only selects the proportion of government investment in industrial companies R&D expenditure, which may ignore other factors.

Funding Statement

This research was funded by Guilin University of Technology Research Initial Fund "Research on the Long-term Mechanism of Ecological Industrialization in Guangxi Ethnic Poor Areas", grant number GUTQDJJ2018120.

Acknowledgments

Acknowledgments to anonymous referees' comments and editor's effort.

Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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