Available Online: 14 April 2026 DOI: 10.54254/2977-5701/2026.32761

Measurement of integration between modern service industry and advanced manufacturing industry under the background of digital transformation

Fei Dong

School of Mathematics and Statistics, Xianyang Normal University, Xianyang, China

365889455@qq.com

Abstract. Digital transformation has injected core momentum into industrial integration. Based on four dimensions including digital technology innovation, this paper constructs a comprehensive evaluation index system covering five dimensions, uses the coupling coordination model to measure the integration level of the two industries in 29 provinces in China from 2009 to 2024, and analyzes the heterogeneity from three dimensions: time, space, and industry. The research finds that: the integration of the two industries has steadily climbed, with the coordination level advancing from barely coordinated to moderately coordinated; spatially, it presents a pattern of "southeastern leadership and inland catch-up", forming three radiation centers; industries such as education are leading in integration with advanced manufacturing, while industries such as finance are slower in integration. Based on this, four suggestions are put forward, including optimizing the regional layout and promoting the differentiated development of industries, to provide reference for the in-depth integration of the two industries and empowering high-quality economic development.

Keywords: digital transformation, modern service industry, advanced manufacturing industry, industrial integration, coupling coordination index

1. Introduction

Digital technologies represented by big data, cloud computing and artificial intelligence are deeply penetrating all fields of economy and society, driving the global industrial development into a new stage of digital reconstruction. Industrial integration has become the core path for the optimization and upgrading of industrial structure and the high-quality economic development. The in-depth integration of modern service industry and advanced manufacturing industry has broken the boundary barriers between traditional industries, and formed a new industrial ecology of coordinated development through factor integration, process reengineering and business format innovation, becoming the core driving force for driving the high-quality economic development [1]. As the world's largest developing country and manufacturing power, China has always attached great importance to the integrated development of the two industries. Important policy documents such as the *15th Five-Year Plan* have clearly elevated "promoting the in-depth integration of advanced manufacturing industry and modern service industry" to the national strategic level, pointing out the direction for the integrated development of the two industries.

Driven by digital transformation, China has achieved remarkable results in the integrated development of modern service industry and advanced manufacturing industry, but in practice, it still faces many structural contradictions and development bottlenecks: first, the unbalanced regional integrated development, with a large gap between the eastern region and the central and western regions in terms of integration level, technical support and factor allocation, and the coordinated development mechanism has not yet been improved; second, the insufficient depth of industrial integration, some sub-sectors still stay at the stage of superficial cooperation, and the in-depth coordinated development model empowered by digitalization has not yet formed; third, the imperfect integration support system, such as the uneven regional coverage of digital infrastructure, the unsound market-oriented factor allocation mechanism, and the insufficient cross-industry collaborative innovation capacity, which have severely restricted the quality and efficiency of the integration of the two industries [2]. Against this background, accurately measuring the actual development level of the integration of the two industries under the background of digital transformation, and systematically analyzing its temporal and spatial evolution laws and industrial heterogeneity characteristics, have important theoretical value and practical significance for breaking the bottlenecks of integrated development and formulating targeted policies.

Although existing studies have extensively discussed the connotation, types and measurement methods of industrial integration, with the comprehensive advancement of digital transformation, the limitations of existing studies have gradually become prominent: most studies fail to fully incorporate the dimensions related to digital transformation into the evaluation system, making it difficult to accurately capture the core enabling role of digital technology in the integration of the two industries [3]; at the same time, the analysis of industrial integration heterogeneity lacks systematicness and fails to carry out a comprehensive analysis from the multi-dimensions of time, space and industry. Based on this, this paper constructs a multi-dimensional evaluation index system covering digital foundation, uses the coupling coordination model to dynamically measure the integration level of the two industries in 29 provinces of China from 2009 to 2024, and analyzes the heterogeneity characteristics from the three dimensions of time, space and industry, which makes up for the deficiencies of existing studies in the consideration of digital dimension and heterogeneity analysis, enriches the research framework of industrial integration theory, and provides a new analytical perspective and method support for the research on industrial integration under the background of digital transformation.

The research conclusions of this paper can provide a scientific basis for the government to formulate differentiated policies for the integrated development of the two industries. By clarifying the temporal and spatial evolution laws and industrial differences of the integration of the two industries, it can provide targeted suggestions for the eastern region to build a benchmark for integrated development and the central and western regions to achieve catch-up and surpassing by virtue of the radiation effect; by identifying the advantageous industrial combinations and weak links of integrated development, it can provide practical guidance for different sub-sectors to optimize the integration path; by emphasizing the supporting role of digital foundation, it can provide decision-making reference for improving the construction of digital infrastructure, optimizing the factor allocation mechanism, and building an institutional guarantee system for integrated development, thereby promoting the in-depth integration of the two industries and the high-quality economic development.

The research idea of this paper is as follows: first, sort out the domestic and foreign literatures related to industrial integration, clarify the theoretical connotation, type division and measurement methods of industrial integration, identify the deficiencies of existing studies, and establish the research starting point of this paper; second, based on the core connotation of digital transformation and the dynamic mechanism of industrial integration, construct a comprehensive evaluation index system covering factor supply, industrial benefit, structural characteristics, development potential and digital foundation; third, use the entropy method to determine the index weights, and measure the integration level of the two industries in 29 provinces of China from 2009 to 2024 combined with the coupling coordination model; finally, analyze the heterogeneous characteristics of integration from the three dimensions of time, space and industry, and put forward targeted policy suggestions.

The structure of this paper is arranged as follows: the first part is the introduction, expounding the research background, significance, ideas and structure; the second part is the literature review, sorting out the theoretical development, measurement methods and research deficiencies of industrial integration; the third part is the research design, including the construction of coupling coordination model, the design of index system, and data sources and processing; the fourth part is the empirical analysis, analyzing the heterogeneous characteristics of the integration of the two industries from the dimensions of time, space and industry; the fifth part is the research conclusions and policy suggestions; the sixth part is the research deficiencies and prospects.

2. Literature review

As a core issue of global industrial upgrading and economic transformation, the theoretical connotation and research paradigm of industrial integration have been continuously deepened with technological changes and industrial practices. The academic community's cognition of industrial integration originated from the perspective of technological development. When studying the industrialization process of American machine tools, Rosenberg [4] first defined the phenomenon of diffusion and penetration of the same technology in different industries as technological integration, laying a theoretical foundation for the research of industrial integration. Since then, Sahal [5] and Lind [6] have further expanded the connotation of technological integration, interpreting it as a dynamic process in which advanced technologies are widely applied and promoted in cross-industry scenarios and continuously spawn systematic technological innovations, highlighting the key role of technology as the core driving force of industrial integration.

In terms of the classification of industrial integration types, scholars have formed a diversified research framework based on different analytical dimensions. From the perspective of technical attributes, Greenstein and Khanna [7] divided industrial integration into two types: substitutive technological integration and complementary technological integration. The former emphasizes the substitution effect of a single technology on traditional technologies, while the latter focuses on the superimposed value generated by the collaborative application of multiple technologies. On the basis of technological integration, Stieglitz [8] introduced the product dimension, comprehensively considered the substitution or complementary relationship between technology and products, and constructed a classification system of four types of integration: technological substitution, technological complementarity, product substitution and product complementarity, enriching the analytical dimensions of industrial integration. Pennings and Puranam [9] innovatively incorporated the market supply and demand relationship into the research framework, and proposed a dichotomy of functional integration (demand-side perspective, i.e., consumers believe that products of different industries have substitution or complementarity) and institutional integration (supply-side perspective, i.e., manufacturers produce or sell related products across industries), and further expanded it into four types of integration: demand substitution, demand complementarity, supply substitution and supply complementarity combined with the substitution and complementarity dimensions. Based on the differences in the integration degree of functional integration and institutional integration, Malhotra [10] divided industrial integration into three types: pure integration (high integration of function and institution), demand-driven integration (high function and low institutional integration) and supply-driven integration (low function and high institutional integration), providing a new perspective for analyzing the dynamic mechanism of integration. According to the novelty degree of integrated technologies, Hacklin et al. [11] put forward the classification criteria of application integration, horizontal integration and potential integration, providing theoretical support for predicting the evolution stage and development potential of industrial integration.

The innovation and improvement of industrial integration measurement methods are the key to quantitatively analyzing the integration level and revealing the integration laws. At present, the mainstream measurement methods in academic circles mainly include the following five types: first, the Herfindahl-Hirschman Index method, which is often used to measure the depth of inter-industrial technological integration based on patent data. For example, Gao Mengli [12] measured the integration level of producer services and manufacturing industry in Zhejiang Province from the dual perspectives of industry and space by using this method; Du Jiang [13] analyzed the agglomeration characteristics and industrial integration degree of China's manufacturing industry simultaneously through the Herfindahl-Hirschman Index method. Second, the input-output method, whose core is to use indicators such as direct consumption coefficient and complete consumption coefficient to reflect the intensity of inter-industrial technological correlation, and then calculate the integration level. Wang Fang [14] used this method to quantify the integration degree of 12 sub-sectors of China's manufacturing industry and the information industry, and empirically tested the promoting effect of integration on the performance improvement of manufacturing industry; Hua Guangmin [15] measured the integration depth of high-tech service industry and manufacturing industry by using the input-output method based on the differences in the intermediate input rate of domestic and imported products. Third, the correlation coefficient method (also known as the patent coefficient method), which calculates the integration status by counting the cross-industry distribution characteristics of patent technologies. Fai and Tunzelmann [16] used this method to analyze the patent proportion of four major industries in the United States, including transportation, machinery, chemistry and electronics, and then quantified the inter-industrial integration level; Xu Luyun et al. [17] explored the integration distance and its influencing factors of three major industries including equipment manufacturing, electronic information and automobile by using patent data respectively. Fourth, the coupling index variable method, which measures the industrial integration level by constructing a multi-dimensional comprehensive evaluation system. Gao zhi et al. [18] used this method to measure the integrated development status of equipment manufacturing industry and high-tech service industry; Tao Changqi et al. [19] systematically analyzed the coupling and integration relationship between information industry and manufacturing industry based on this method. Fifth, the entropy method, which is mainly used to reflect the characteristics of regional leading industries and the degree of industrial agglomeration, and then indirectly reflect the integration level. Wang Ling [20] used this method to analyze the integration degree of rural industries in 13 cities and prefectures of Jiangsu Province; Yuan Jun et al. [21] constructed an evaluation system for the integration of tourism industry and cultural industry based on the entropy method, and explored the integration status and development potential of the two industries in the Pearl River Delta region.

Although existing studies have achieved fruitful results in the theoretical connotation, type division and measurement methods of industrial integration, with the comprehensive advancement of digital transformation, the integration of modern service industry and advanced manufacturing industry has presented new characteristics of systematicness, dynamics and cross-domain. The in-depth penetration of digital technologies has broken the boundary barriers of traditional industries, making the integration of the two industries no longer limited to the correlation of a single technology or product, but extending to multiple levels such as factor allocation, process reengineering and business format innovation. However, existing studies still have obvious deficiencies: on the one hand, most measurement index systems fail to fully incorporate the dimensions related to digital transformation, making it difficult to accurately capture the core role of digital technology in factor penetration, structural optimization and efficiency improvement; on the other hand, traditional measurement methods focus more on static cross-sectional analysis, making it difficult to depict the dynamic evolution process and temporal and spatial evolution laws of the integration of the two industries under the digital background. Therefore, constructing a comprehensive evaluation system covering digital foundation and using dynamic measurement methods to systematically analyze the heterogeneous characteristics of the integration of the two industries has become an urgent gap to be filled in the current research on industrial integration.

3. Research design

3.1. Construction of coupling evaluation model

Both the modern service industry and the advanced manufacturing industry are complex systems containing multiple sub-sectors. Under the background of digital transformation, the coupling between the two industries is reflected in the benign interaction and coordinated development of each sub-system on the basis of digitalization. Referring to the research results of Tao Changqi et al. [19], a coupling coordination evaluation model of modern service industry and advanced manufacturing industry is constructed as follows:

Let MS represent the modern service industry sub-system and AM represent the advanced manufacturing industry sub-system. The comprehensive scores of the two systems at time t are given by Formula (1) respectively:

$$MS_t = \sum_{j=1}^{n} \alpha_j x_{jt}, AM_t = \sum_{j=1}^{n} \beta_j y_{jt} \tag{1}$$

where α_j and β_j represent the weights of each indicator in the two sub-systems respectively, x_{jt} and y_{jt} respectively represent the weight of each index and the value of each index in the two sub-systems at time t. The coupling degree between the two systems at time t can be expressed as CP_t (see Formula (2)):

$$CP_t = 2\sqrt{\frac{MS_t AM_t}{(MS_t + AM_t)^2}} \tag{2}$$

To further analyze the coordinated development between the modern service industry and the advanced manufacturing industry, the coordination degree TC and coupling coordination index CR are introduced:

The coordination coefficient of the two industries at time t : $TC_t = \theta_1 MS_t + \theta_2 AM_t$, where θ_1 and θ_2 are the contribution coefficients of the modern service industry and the advanced manufacturing industry. Combined with the actual situation and previous studies, this study assumes that $\theta_1 = 0.4$, $\theta_2 = 0.6$.

The coupling coordination index of the two industries at time t (see Formula (3)):

$$CR_t = \sqrt{CP_t \times TC_t} \tag{3}$$

Referring to relevant studies, this paper divides the coupling coordination index into 10 grades (see Table 1).

Table 1. Classification of coupling coordination index grades

Serial Number	Coupling Coordination Index (CR)	Coupling Coordination Grade
1	(0, 0.1]	Extremely maladjusted
2	(0.1, 0.2]	Seriously maladjusted
3	(0.2, 0.3]	Moderately maladjusted
4	(0.3, 0.4]	Slightly maladjusted
5	(0.4, 0.5]	On the verge of maladjustment
6	(0.5, 0.6]	Barely coordinated
7	(0.6, 0.7]	Primary coordinated
8	(0.7, 0.8]	Moderately coordinated
9	(0.8, 0.9]	Well coordinated
10	(0.9 ,1]	High-quality coordinated

3.2. Data selection and processing

3.2.1. Construction of index system

Drawing on the research frameworks of Tao Changqi et al. [19] and Pan Tao et al. [22], combined with the core connotation of digital transformation and the actual industrial development, and following the principles of objectivity, scientificity, operability and systematicness, a comprehensive evaluation index system for the integrated development of modern service industry and advanced manufacturing industry is constructed from five dimensions: factor supply, industrial benefit, structural characteristics, development potential and digital foundation.

In terms of industrial definition, the modern service industry selects 5 sub-sectors including information transmission, computer services and software industry, leasing and business services, scientific research, technical services and geological prospecting industry, financial industry and education industry; the advanced manufacturing industry selects 5 sub-sectors including pharmaceutical manufacturing industry, special equipment manufacturing industry, transportation equipment manufacturing industry, electrical machinery and equipment manufacturing industry, and communication equipment, computer and other electronic equipment manufacturing industry, covering the core development sectors of the two industries in an all-round way.

In terms of index selection, the factor supply dimension selects two secondary indicators: capital input (fixed asset investment) and labor input (number of employees), reflecting the factor support capacity for the integration of the two industries; the industrial benefit dimension selects two secondary indicators: industrial scale (industrial gross output value/industrial added value) and income level (average wage of employees), reflecting the economic benefits of the integration of the two industries; the structural characteristics dimension selects two secondary indicators: industrial agglomeration (the proportion of the number of legal persons in the sub-system to the total number of legal persons in the region) and industrial proportion (output value proportion), reflecting the optimization degree of industrial structure; the development potential dimension selects two secondary indicators: the growth rate of human input (the growth rate of employees) and the growth rate of capital input (the growth rate of fixed asset investment), reflecting the sustainable development capacity of the integration of the two industries.

At present, the academic community has not formed a unified standard for the statistical caliber of industrial digitalization degree. The core of digital transformation is to rely on digital technologies such as cloud computing and big data to optimize industrial production processes, business models and product services, and informatization is an important foundation of digital transformation. Based on this, this study selects two indicators: the number of enterprise informatization and the number of digital equipment in use, to comprehensively reflect the level of digital infrastructure of the two industries in the region. The specific index system is shown in Table 2.

Table 2. Coupling variables of modern service industry and advanced manufacturing industry

Modern Service Industry			Advanced Manufacturing Industry		
First-level Indicator	Second-level Indicator	Third-level Indicator	First-level Indicator	Second-level Indicator	Third-level Indicator
Factor Supply	Capital Input	Fixed Asset Investment	Factor Supply	Capital Input	Fixed Asset Investment
	Labor Input	Number of Employees		Labor Input	Number of Employees
Industrial Benefit	Industrial Scale	Industrial Gross Output Value	Industrial Benefit	Industrial Scale	Industrial Added Value
	Income Level	Average Wage of Employees		Income Level	Average Wage of Employees
Structural Characteristics	Industrial Agglomeration	Proportion of the Number of Legal Persons in the Sub-system to the Total Number of Legal Persons in the Region	Structural Characteristics	Industrial Agglomeration	Proportion of the Number of Legal Persons in the Sub-system to the Total Number of Legal Persons in the Region
	Industrial Proportion	Output Value Proportion		Industrial Proportion	Output Value Proportion
Development Potential	Growth Rate of Human Input	Growth Rate of Employees	Development Potential	Growth Rate of Human Input	Growth Rate of Employees
	Growth Rate of Capital Input	Growth Rate of Fixed Asset Investment		Growth Rate of Capital Input	Growth Rate of Fixed Asset Investment
Digital Foundation	Informatization Scale	Number of Enterprise Informatization	Digital Foundation	Informatization Scale	Number of Enterprise Informatization
	Equipment Foundation	Number of Digital Equipment in Use		Equipment Foundation	Number of Digital Equipment in Use

3.2.2. Data selection and processing

The research samples of this study are 29 provincial-level administrative regions in China from 2009 to 2024, excluding Xizang Autonomous Region, Hainan Province, Hong Kong, Macao and Taiwan regions. The main reasons are that some core data of the above regions are missing, and their industrial structures have strong particularities, making it difficult to form an effective comparison with other provinces. The original research data are derived from the *China Statistical Yearbook, China Industrial Statistical Yearbook, China Tertiary Industry Statistical Yearbook* and statistical yearbooks of various provinces over the years. The data sources are authoritative and reliable, ensuring the credibility and scientificity of the research conclusions.

In terms of data processing, the linear interpolation method is used to fill in the missing data in some years to ensure the integrity of the panel data; the capital input indicator is measured by the net value of fixed assets, and the perpetual inventory method is used for calculation to eliminate the impact of price fluctuations on data accuracy; to eliminate the impact of index dimension differences on research results, all indicators are standardized, in which positive indicators adopt the maximum standardization method and negative indicators adopt the minimum standardization method.

3.2.3. Determination of index weights

This study uses the entropy method to calculate the weight of each index. This method can objectively assign weights based on the discrete degree of index data, effectively avoid the deviation caused by the subjective weighting method, and meet the analysis needs of panel data (the traditional factor analysis method is not suitable for the weight measurement of panel data). The specific calculation steps are as follows:

Step 1: Standardize the index values. Assume that there are I samples in the modern service industry, J indicators are selected, and the research cycle is T years. Let x_{ijt} be the j-th indicator of the i-th sample of the modern service industry in the t-th year, and the original indicators x_{ijt} can be converted into standardized indicators ${x_{ijt}}^*$.

For positive indicators (see Formula (4)):

$$ {x_{ijt}}^* = \frac{x_{ijt} - x_{minjt}}{x_{maxjt} - x_{minjt}} \tag{4} $$

For negative indicators (see Formula (5)):

$$ {x_{ijt}}^* = \frac{x_{maxjt} - x_{ijt}}{x_{maxjt} - x_{minjt}} \tag{5} $$

Among them, $x_{max\bullet jt}$ and $x_{min\bullet jt}$ respectively represent the maximum and minimum values of the j-th indicator of all samples in the t-th year.

Step 2: Calculate the entropy value of each indicator. Let e_j represent the entropy value of the j-th indicator, then there is (see Formula (6)):

$$ e_j = -k \sum_{t=1}^{T} \sum_{i=1}^{I} p_{ijt} ln p_{ijt} \tag{6} $$

Among them, k is the adjustment coefficient, $k = 1/lnI$. p_{ijt} is the proportion of the j-th indicator of the i-th sample of the modern service industry in the t-th year in the j-th indicator of all samples, $p_{ijt} = {x_{ijt}}^* / \sum_{i=1}^{I} {x_{ijt}}^*$.

Step 3: Calculate the weight of the j-th indicator (see Formula (7)):

$$ \alpha_j = d_j / \sum_{j=1}^{J} d_j \tag{7} $$

Among them, d_j is the redundancy degree of the j-th indicator, $d_j = 1 - e_j$.

Step 4: Calculate the comprehensive evaluation score. The comprehensive evaluation score of the i-th sample of the modern service industry in the t-th year is (see Formula (8)):

$$ x_{it} = \sum_{j=1}^{J} \alpha_j {x_{ijt}}^* \tag{8} $$

Similarly, the comprehensive evaluation score y_{it} of the i-th sample of the advanced manufacturing industry in each province in the t-th year can be calculated. The specific weights of each indicator are shown in Table 3.

Table 3. Comprehensive evaluation index system of modern service industry and advanced manufacturing industry

Modern Service Industry			Advanced Manufacturing Industry		
First-level Indicator	Second-level Indicator	Weight	First-level Indicator	Second-level Indicator	Weight
Factor Supply	Capital Input	0.09	Factor Supply	Capital Input	0.08
	Labor Input	0.08		Labor Input	0.10
Industrial Benefit	Industrial Scale	0.17	Industrial Benefit	Industrial Scale	0.12
	Average Wage	0.12		Average Wage	0.11
Structural Characteristics	Industrial Agglomeration	0.06	Structural Characteristics	Industrial Agglomeration	0.09
	Industrial Proportion	0.10		Industrial Proportion	0.10
Development Potential	Growth Rate of Human Capital Input	0.08	Development Potential	Growth Rate of Human Capital Input	0.09
	Growth Rate of Fixed Capital Investment	0.07		Growth Rate of Fixed Capital Investment	0.08
Digital Foundation	Number of Enterprise Informatization	0.12	Digital Foundation	Number of Enterprise Informatization	0.11
	Digital Equipment	0.11		Digital Equipment	0.12

4. Analysis on the integration measurement of modern service industry and advanced manufacturing industry under the background of digital transformation

To comprehensively and systematically analyze the integrated development characteristics of China's modern service industry and advanced manufacturing industry under the background of digital transformation, this study carries out an empirical analysis from three dimensions: temporal heterogeneity, spatial differentiation and industrial differences. Among them, the time dimension analyzes the evolution trend of integrated development from the two levels of the national whole and regional grouping, the space dimension explores the spatial distribution pattern and evolution characteristics of the integration level, and the industry dimension identifies the integrated development differences of different sub-sectors.

4.1. Integration trend from the perspective of temporal heterogeneity

To clearly present the long-term development trend of the integration of the two industries, this study analyzes the temporal evolution law of the coupling coordination index of the two industries from 2009 to 2024 from the national overall level and the regional grouping level respectively, and interprets the core driving factors of the changes in the integration level combined with the digital transformation process.

4.1.1. Evolution trend of the national overall integration level

From 2009 to 2024, the coupling coordination index of the integration of China's modern service industry and advanced manufacturing industry showed a steady upward trend as a whole, rising from 0.423 in 2009 to 0.687 in 2024, and the integration level crossed from the "on the verge of maladjustment" stage to the "primary coordinated" stage, demonstrating the good resilience and upgrading potential of the integrated development of the two industries. Combined with the time nodes, the overall evolution process can be divided into three stages:

The first stage is 2009-2013, which is a slow improvement period. During this stage, the coupling coordination index increased from 0.423 to 0.489, always staying in the "on the verge of maladjustment" interval. In this period, digital technology had not yet achieved large-scale industrial penetration, the integration of the two industries mainly relied on the complementarity of traditional factors, the modern service industry mainly provided basic services, and the degree of technological coordination and process integration with the advanced manufacturing industry was low, resulting in a relatively insufficient core driving force for integration and upgrading.

The second stage is 2014-2019, which is an accelerated growth period. The coupling coordination index rose rapidly from 0.492 to 0.597, achieving a key leap from "on the verge of maladjustment" to "barely coordinated". In this stage, digital technologies such as big data and cloud computing were gradually promoted and applied in the industrial field, the layout of digital infrastructure was accelerated, and the technical support capacity for the integration of the two industries was significantly enhanced. The demand for intelligent transformation of the advanced manufacturing industry drove the producer services to extend to the high-end, and the modern service industry deeply penetrated into the whole industrial chain of manufacturing R&D and design, production and manufacturing, and after-sales service through digital empowerment, the efficiency of factor integration was greatly improved, becoming the core driving force for the accelerated development of the integration of the two industries.

The third stage is 2020-2024, which is a quality improvement period. The coupling coordination index continued to rise from 0.601 to 0.687, successfully entering the "primary coordinated" stage and steadily approaching the "moderately coordinated" stage. In this stage, digital transformation has entered an in-depth development stage, core digital technologies such as artificial intelligence and industrial internet have been deeply integrated with industrial development, completely breaking the traditional development boundaries of the two industries, and spawning new business formats and models such as service-oriented manufacturing and intelligent manufacturing. At the same time, the inclusive characteristics of digital technology have gradually emerged, effectively alleviating the problem of unbalanced factor allocation between regions, promoting the transformation of the integrated development of the two industries from "scale expansion" to "quality improvement", and the stability and sustainability of integrated development have been significantly enhanced.

4.1.2. Evolution differences of regional grouping integration level

In accordance with the national regional development strategy division standards, the 29 provinces are divided into three major regions: the east, the central and the west, to further analyze the temporal evolution differences of the integration level between regions (see Table 4). Figure 1 shows the evolution trend of the integration level of the two industries in China from 2009 to 2024. From the perspective of the evolution trend, the integration level of the two industries in the three major regions has shown an upward trend, but the gap between regions has always existed, presenting a pattern of "leading in the east, catching up in the central and lagging behind in the west".

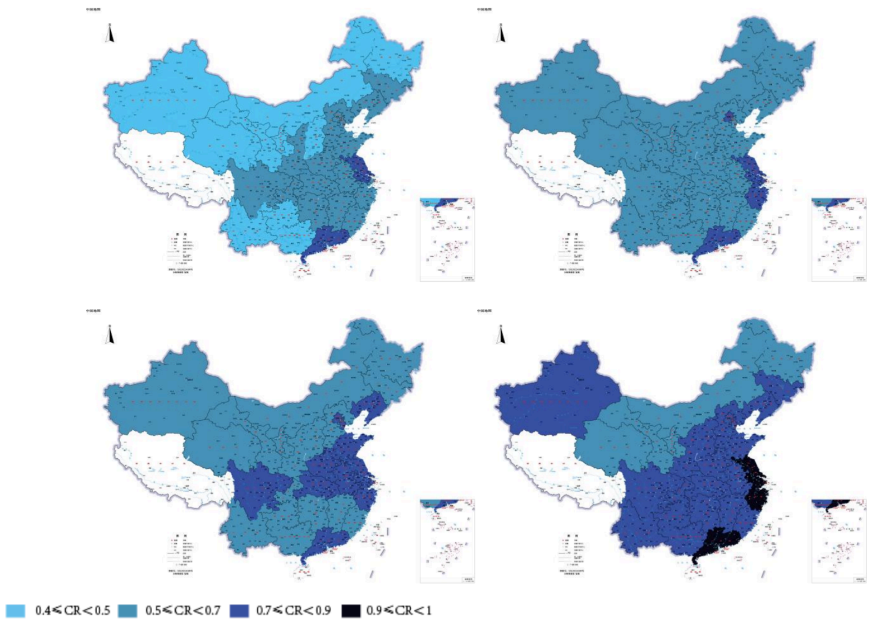

Figure 1. Spatial evolution of the coupling coordination index of the two industries in each province from 2009 to 2024. (a) coupling coordination index of 29 provincial-level administrative regions in 2009; (b) coupling coordination index of 29 provincial-level administrative regions in 2014; (c) coupling coordination index of 29 provincial-level administrative regions in 2019; (d) coupling coordination index of 29 provincial-level administrative regions in 2024

Relying on the advantages of digital infrastructure, industrial agglomeration effect and technological innovation capacity, the eastern region has always led the country in the integration level of the two industries. The coupling coordination index of the eastern region rose from 0.486 in 2009 to 0.762 in 2024, approaching the "moderately coordinated" level, and broke through 0.6 in 2017 to enter the "primary coordinated" stage, 3 years earlier than the national average level. Its core advantage lies in the depth and breadth of the integration of digital technology and industry. For example, the Yangtze River Delta and Pearl River Delta regions have formed a collaborative ecology of "digital services + advanced manufacturing", which has effectively driven the quality upgrading of the integration of the two industries.

The integration level of the two industries in the central region has shown a steady catch-up trend, with the coupling coordination index rising from 0.418 in 2009 to 0.653 in 2024, and entering the "primary coordinated" stage in 2021. In recent years, relying on the advantages of undertaking industrial transfer, the central region has accelerated the construction of digital infrastructure, promoted the transformation and upgrading of traditional manufacturing industry and the expansion and quality improvement of modern service industry, with sufficient late-development driving force for the integration of the two industries. However, there is still a gap of about 0.1 percentage points with the eastern region, mainly due to the shortage of digital talents and the insufficient independent innovation capacity of core technologies.

The integration level of the two industries in the western region has improved relatively slowly, with the coupling coordination index rising from 0.382 in 2009 to 0.579 in 2024, and only entering the "barely coordinated" stage in 2023, always lagging behind the eastern and central regions. Restricted by factors such as economic foundation, location conditions and weak digital infrastructure, the integration of the two industries in the western region still mainly adopts the traditional model, the enabling role of digital technology in factor penetration and business format innovation has not been fully exerted, and there is a large room for improvement in the level and quality of integration.

Table 4. Coupling coordination index and growth rate of the two industries in each province from 2009 to 2024

Coupling Coordination Index CR							
Province	CR 2009	Average Growth Rate 2009~2014 (%)	CR 2014	Average Growth Rate 2015~2019 (%)	CR 2019	Average Growth Rate 2020~2024 (%)	CR 2024
Beijing	0.65	1.86	0.73	1.62	0.81	1.62	0.90
Tianjin	0.55	2.27	0.63	1.67	0.71	1.46	0.78
Hebei	0.52	2.01	0.59	1.89	0.67	1.99	0.76
Shanxi	0.49	2.22	0.56	1.98	0.63	2.56	0.72
Inner Mongolia Autonomous Region	0.47	2.67	0.55	1.82	0.62	1.53	0.68
Liaoning	0.52	3.04	0.62	1.59	0.70	1.57	0.76
Jilin	0.53	2.25	0.60	1.99	0.68	1.90	0.76
Heilongjiang	0.47	2.04	0.53	2.01	0.60	2.32	0.69
Shanghai	0.69	1.47	0.76	1.44	0.83	1.83	0.92
Jiangsu	0.72	1.75	0.80	1.79	0.89	1.24	0.97
Zhejiang	0.68	0.98	0.73	1.67	0.80	1.95	0.90
Anhui	0.57	1.91	0.64	1.59	0.71	1.68	0.79
Fujian	0.53	2.52	0.62	1.67	0.68	1.75	0.76
Jiangxi	0.51	2.74	0.60	1.87	0.67	1.67	0.74
Shandong	0.56	3.63	0.69	2.26	0.78	1.65	0.87
Henan	0.52	2.40	0.60	2.78	0.70	2.21	0.80
Hubei	0.55	2.47	0.63	1.92	0.71	1.69	0.78
Hunan	0.55	2.32	0.63	1.64	0.70	2.52	0.81
Guangdong	0.76	1.23	0.82	1.52	0.89	1.52	0.98
Guangxi Zhuang Autonomous Region	0.50	2.47	0.58	1.84	0.64	2.14	0.74
Chongqing	0.54	2.28	0.62	1.70	0.68	1.94	0.76
Sichuan	0.56	2.20	0.63	1.73	0.70	1.82	0.79
Guizhou	0.46	2.88	0.54	2.67	0.63	2.53	0.74
Yunnan	0.46	2.96	0.54	2.56	0.63	1.72	0.72
Shaanxi	0.51	2.33	0.58	2.33	0.67	2.06	0.76
Gansu	0.46	2.68	0.54	2.03	0.61	1.42	0.67
Qinghai	0.48	2.74	0.56	1.83	0.63	1.47	0.69
Ningxia Hui Autonomous Region	0.45	3.45	0.55	2.16	0.63	1.55	0.69
Xinjiang Uygur Autonomous Region	0.46	2.84	0.55	1.84	0.61	2.51	0.71
National Average	0.55	2.37	0.63	1.91	0.70	1.86	0.79

4.2. Analysis on the spatial differentiation characteristics of the integration level of the two industries

Based on the data of three key time nodes in 2009, 2017 and 2024, the spatial analysis method is used to reveal the spatial distribution pattern and evolution characteristics of the integration level of the two industries, and explore the spatial correlation effect and radiation driving effect of the integration of the two industries under the background of digital transformation.

From the perspective of spatial distribution, the integration level of China's modern service industry and advanced manufacturing industry presents a significant "core-periphery" distribution characteristic. The high integration level regions are mainly concentrated in the core cities and urban agglomerations along the eastern coast, while the low integration level regions are concentrated in the western inland areas. The spatial differentiation pattern is highly consistent with the distribution of digital infrastructure, industrial development foundation and factor agglomeration capacity.

In 2024, there are 5 provinces with the integration level of the two industries at the "high-quality coordinated" and "well coordinated" levels, all of which are in the eastern region, namely Guangdong, Jiangsu, Zhejiang, Shanghai and Beijing, whose coupling coordination indexes all exceed 0.75, forming an agglomeration belt with high integration level along the eastern coast. Relying on the advantages of improved digital infrastructure, sufficient R&D investment, high-end factor agglomeration and mature industrial coordination mechanism, these provinces have realized the in-depth empowerment of digital technology and the integration of the two industries, constructed a diversified and high-level integrated development business format, and become the core benchmark for the integrated development of the two industries in the country.

There are 14 provinces at the "primary coordinated" and "moderately coordinated" levels, mainly including Hubei, Hunan, Henan and Anhui in the central region, Shandong and Fujian in the eastern region, and Chongqing and Sichuan in the western region. Most of these provinces have a certain industrial development foundation and digital development potential. Some provinces have formed local high integration level nodes by virtue of the radiation driving effect of regional central cities, but the balance of the overall integrated development is insufficient, some cities and prefectures are still at a low development level, and the global enabling role of digital technology has not been fully exerted.

There are 10 provinces at the "on the verge of maladjustment" and "barely coordinated" levels, mainly western provinces and some central provinces, such as Guizhou, Yunnan, Gansu and Qinghai, whose coupling coordination indexes are lower than 0.6. Restricted by factors such as the lagging construction of digital infrastructure, single industrial structure, shortage of high-end talents and low efficiency of factor allocation, the integration of the two industries in these provinces is still in the low-level cooperation stage, the enabling effect of digital technology on integrated development has not been effectively released, and the endogenous driving force for integrated development is insufficient.

4.3. Industrial differences in integrated development

From the industrial perspective, there are significant differences in the integrated development level of different sub-sectors of the modern service industry with the advanced manufacturing industry, and the regional differentiation characteristics are prominent. On the whole, the education industry, leasing and business services take the lead in the integration degree with the advanced manufacturing industry. These two industries have a strong industrial correlation with the advanced manufacturing industry, the digital transformation process started early, and the depth and breadth of factor integration and process coordination are relatively high: the education industry provides sufficient human capital support for the development of the advanced manufacturing industry, and the intelligent and high-end development demand of the advanced manufacturing industry also drives the education industry to accelerate the reform of professional setting and talent training mode, forming a two-way enabling integrated development pattern; the leasing and business services have deeply penetrated into the whole process of production, operation and management of the advanced manufacturing industry, and effectively improved the operational efficiency of the advanced manufacturing industry through the innovation of digital service models, realizing the coordinated development between industries.

In contrast, the integration process of industries such as finance, scientific research and technical services with the advanced manufacturing industry is relatively slow, and the regional differentiation characteristics are significant. The main reason for the lagging integrated development of the financial industry is that the digital level of financial services in the central and western regions is low, the innovation capacity of financial products and services is insufficient, which is difficult to meet the diversified financing needs of the intelligent and high-end development of the advanced manufacturing industry, and the allocation efficiency of financial resources between regions and industries is low; the integration bottleneck of the scientific research and technical services is reflected in the insufficient R&D investment in the central and western regions, the imperfect industry-university-research collaborative innovation mechanism, and the low industrialization transformation efficiency of scientific research achievements, which is difficult to effectively connect with the technological innovation needs of the advanced manufacturing industry, leading to the continuous expansion of the integrated development gap between the eastern, central and western regions.

From the perspective of growth trend, all sub-sectors show the characteristic of "late-development growth", and the growth rate of the central and western provinces with a poor foundation for integrated development is generally higher than that of the developed eastern provinces. This characteristic indicates that with the gradual emergence of the inclusiveness of digital technology and the in-depth implementation of the national regional coordinated development strategy, the late-development advantages of the central and western regions have been gradually released, the speed of integrated development of various industries with the advanced manufacturing industry has been accelerated, and the regional gap of industrial integration is gradually narrowing.

5. Conclusion

Based on four dimensions including digital technology innovation, this paper constructs a comprehensive evaluation index system, uses the coupling coordination model to measure the integration level of the two industries in 29 provinces of China from 2009 to 2024, and analyzes the heterogeneity characteristics from the three dimensions of time, space and industry. The core conclusions are as follows: from the time dimension, the integration level of the two industries has risen steadily, the coupling coordination level has advanced from barely coordinated to moderately coordinated, realizing the transformation from scale expansion to quality improvement. The national coupling coordination index rose from 0.423 in 2009 to 0.687 in 2024. Digital technology is the core driving force, and the stability of integration has been continuously enhanced. From the spatial dimension, the integration presents a pattern of "leading in the southeast and catching up in the inland", forming three radiation centers. The spatial spillover effect is significant but the regional gap is obvious. The core cause of the gradient difference between the east, central and west is the gap in digital infrastructure and other aspects. From the industrial dimension, there are significant differences in the integration level of sub-sectors. Education, leasing and business services take the lead in integration degree, while the integration process of finance and other industries is slow. All industries show the characteristic of "late-development growth", with the growth rate in the central and western regions higher than that in the eastern region. The research conclusions have important significance: the constructed index system and analysis framework provide method reference for subsequent research; at the practical level, it can guide all regions to focus on digital empowerment, formulate differentiated strategies, and narrow the regional and industrial integration gaps.

References

[1] Shi, D. (2022). The evolution of industrial development trends under the condition of digital economy. *China Industrial Economics,* (11), 26-42.

[2] Wang, J. Y. (2022). Digital economy enabling the in-depth integrated development of industries: Mechanism, challenges and policy recommendations. *Macroeconomic Research,* (05), 74-81.

[3] Zhang, X., Zhong, J., & Wang, H. F. (2022). Research on the measurement and influencing factors of the integration level of China's advanced manufacturing industry and modern service industry. *Journal of Finance and Economics Theory, 43*(03), 135-141.

[4] Rosenberg, N. (1963). Technological change in the machine tool industry: An econometric history. *The Journal of Economic History, 23*(04), 414-446.

[5] Sahal, D. (1985). Technological guideposts and innovation avenues. *Research Policy, 14*(2), 61-82.

[6] Lind, J. (2004). *Convergence: History of term usage and lessons for firm strategies* (Working Paper). Stockholm School of Economics, Center for Information and Communications Research.

[7] Greenstein, S., & Khanna, T. (1997). What does industry convergence mean? *MIT Sloan Management Review, 38*(04), 20-33.

[8] Stieglitz, N. (2003). Technological and product market convergence: An integrative framework. *Journal of Product Innovation Management, 20*(02), 95-113.

[9] Pennings, J. M., & Puranam, P. (2001). Industry convergence and the evolution of firm scope. *Strategic Management Journal, 22*(06-7), 605-628.

[10] Malhotra, A. (2001). Convergence: Patterns of change in the information industries. *Journal of Management Information Systems, 18*(02), 11-34.

[11] Hacklin, F., Marxt, C., & Fahrni, F. (2005). Convergence of industries: Opportunities and challenges for the future creation of value. *Technology Analysis & Strategic Management, 17*(04), 415-432.

[12] Gao, M. L. (2014). Research on industrial agglomeration degree and development trend of producer services and manufacturing industry in Zhejiang—Based on the perspective of industrial spatial agglomeration. *Science and Technology & Economy, 27*(05), 100-105.

[13] Du, J., & Xia, Y. Y. (2020). Trends and characteristics of manufacturing spatial agglomeration and industrial transfer in China. *Research on Financial and Economic Theory,* (05), 55-65.

[14] Wang, F., & Pan, M. M. (2015). Industrial integration, performance improvement and manufacturing growth—Empirical study based on panel data from 1998 to 2011. *Studies in Science of Science, 33*(04), 530-538, 548.

[15] Hua, G. M., & Huang, W. (2020). Analysis on the integrated development of high-tech service industry and manufacturing industry in China—Based on non-competitive I-O of OECD database in 2015. *Science Research Management, 41*(05), 69-77.

[16] Fai, F. (2001). Industry-specific competencies and converging technological systems: Evidence from patents. *Structural Change and Economic Dynamics, 12*(2), 141-170.

[17] Xu, L. Y., Zeng, D. M., & Zhang, Y. S. (2019). Knowledge aggregation, collaborative R & D model and exploratory innovation performance—Empirical research based on China's automobile industry. *Management Review, 31*(06), 68-76.

[18] Gao, Z., & Lu, Z. G. (2019). The impact of integrated development of equipment manufacturing industry and high-tech service industry on improving total factor productivity. *Commercial Research,* (07), 42-49.

[19] Tao, C. Q., & Zhou, X. (2015). Analysis on the effect of industrial structure optimization and upgrading under industrial integration—Empirical research based on the coupling of information industry and manufacturing industry. *Industrial Economics Research,* (03), 21-31, 110.

[20] Wang, L. (2017). Measurement of rural industrial integration level and regional difference analysis in Jiangsu Province. *Agricultural Economy,* (06), 21-22.

[21] Yuan, J., & Gao, Z. (2018). Measurement of the integrated development level of cultural industry and tourism industry in the Pearl River Delta. *Resource Development & Market, 34*(01), 108-112.

[22] Pan, T., Wang, L. H., & Guo, F. C. (2022). Evaluation of regional innovation capability in China under the background of digital economy—Based on the perspective of collaboration between science and technology service industry and advanced manufacturing industry. *Industrial Technology & Economy, 41*(11), 42-47.