Coupling and Coordination Analysis of Digital Economy and High-Quality Development of Manufacturing Industry: An Empirical Study Based on Shaanxi Province, China

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Abstract: A strong manufacturing base is crucial for achieving high-quality economic growth, and the digital economy is increasingly recognized as a vital catalyst for its progress. This study analyzes the relationship between these two sectors in Shaanxi Province, China, using data from 2010 to 2021. Employing the entropy weight method, I developed indices to assess the development of both the digital economy and high-quality manufacturing, then used a coupling coordination model to examine their interaction. My findings show a clear positive trend in the coupling and coordination between the digital economy and manufacturing in Shaanxi, which has recently reached a state of good coordination. However, achieving a sustained and stable level of high-quality coordination remains a key objective. We conclude by recommending interventions aimed at strengthening this synergistic relationship.

Keywords: Digital Economy; High-Quality Development; Entropy Weight Method; Coupling Coordination

1. Introduction

National strategy prioritizes accelerating the digital economy and its integration with the real economy. Given that manufacturing is the foundation of the real economy, a core focus is on leveraging digital productivity to enhance its development. A crucial research area, therefore, is how to utilize digital advancements to transform and upgrade traditional manufacturing.

Situated in western China, Shaanxi Province serves as a vital manufacturing hub, encompassing 31 major industry categories and significantly impacting the region's economic growth. Recent years have seen active reforms and innovation in sectors such as aerospace, new energy vehicles, transportation equipment, energy and chemicals, assembly manufacturing, and electrical machinery and equipment. Integrating the digital economy with these traditional manufacturing sectors promises to accelerate industrial transformation and upgrading, unlocking new economic opportunities for Shaanxi.

2. Literature Review

2.1 Integration of Digital Economy and Real Industry

Digital technology is permeating every facet of manufacturing, making digital transformation an unavoidable path for the industry's future. The progressive integration of the digital and real economies, facilitated by advancements in information and communication technology, is poised to become the primary driver of high-quality economic development in China.[1] The integration of the digital economy can revolutionize manufacturing, yielding higher quality products, streamlined operations, and a more dynamic, responsive production model.[2] Quantitative analysis reveals a coupling and coordination relationship between the digital economy and high-quality development across cities in Zhejiang Province, China, though with uneven progress and room for improvement.[3] Quantitative analysis reveals that in Chengdu, China, the digital economy and high-quality manufacturing development have achieved an intermediate level of coordination.[4] The digital economy fosters industrial upgrading by driving innovation in technology, products, business models, and demand structures. This mechanism is analyzed using empirical methods.[5] Given data's ascendance to a factor of production on par with labor and capital, the profound integration of the digital and real economies, enabled by technology platforms, is an inherent necessity for constructing a modern industrial system.[6]

2.2 The Impact of Digital Economy on High-Quality Development

From the perspective of social welfare, digital technology has promoted the upgrading of consumption patterns, reduced information search costs and communication costs, and both consumer demands and corporate profits have been met. Digital technology promotes economic growth and changes people's lifestyles. [7] Digital economy promotes the overall improvement of social benefits, achieves the sharing of development results and maximizes social welfare.[8] Digital technology has played an important role during the COVID-19 epidemic. Big data collection, online learning and work platforms, unmanned food delivery robots and other digital technology innovations that "do good with technology" have changed people's lifestyles.[9] Through data analysis that the integration of digital technology and physical industries will create new jobs and provide new employment opportunities.

From the perspective of economic production, it is generally believed that the development of Internet technology can improve the innovation performance and resource allocation efficiency of enterprises. Traditional enterprises are undergoing digital transformation,[10] and technological innovation is driving business model innovation.[11] Data technology has subverted the traditional business model of enterprises and expanded the production boundaries of enterprises. Technological progress has prompted enterprises to speed up their response to the market and decision-making speed.[12] Through technological advancements, the manufacturing industry achieves greater efficiency in resource allocation and labor productivity.[13] Empirical analysis demonstrates that the digital economy significantly mitigates resource misallocation, fosters the concentration of scientific and technological talent, and is pivotal to upgrading the manufacturing industry's industrial chain, scientific and technological resource allocation, and production factors.[14] Research has shown that the digital economy facilitates high-quality manufacturing development by bolstering information flows, enriching value creation, and fostering innovation.[15] Analysis of coupling coordination indicates a general upward trend in China's digital economy and high-quality development, despite noticeable regional imbalances. [16] The degree of coupling coordination has evolved from a state of imbalance towards gradual coordination across China. In this progression, the eastern region maintains a leading position, while the northeastern region remains behind other areas.

2.3 Assessment of High-Quality Development in Manufacturing

A multifaceted strategy, encompassing seven key dimensions, is essential for promoting high-quality manufacturing development: foundation, development motivation, production methods, product models, supporting industries, and development goals.[11] Research on manufacturing transformation and upgrading, viewed through the lens of industrial structure adjustment, suggests that industrial structure should evolve towards a more advanced, rational, and coordinated state. This dynamic process of industrial upgrading entails a shift from low-tech to high-tech, from small to large scale, and from capital-intensive to technology-intensive operations.[17] The manufacturing industry should use technological updates, equipment upgrades, etc. to improve production efficiency and resource utilization, and gradually transform into a high-efficiency, high-yield and high-quality industrial development model.[18] Manufacturing enterprises must use information technology to carry out independent innovation, thereby transforming to the sustainable development path of innovation-driven and endogenous growth.[19] Research has been conducted to analyze the impediments to the transformation and upgrading of the equipment manufacturing industry in Liaoning Province, China, employing a global value chain perspective. This analysis has informed the development of a targeted strategy to facilitate the industry's transformation and upgrading.[20] Defining high-quality development in manufacturing across three dimensions—resource allocation efficiency, innovation and upgrading capabilities, and inclusive development — scholars have empirically illuminated the role of the digital economy in achieving this progress.[16]

2.4 Literature Evaluation

Existing research extensively explores the digital economy's influence on high-quality development, generally agreeing that it drives innovation and upgrades in real industries. The fusion of manufacturing with the digital economy, a key part of the real sector, provides a crucial avenue for advancing industrial chains, technology, equipment, and resource allocation. Recognizing the significant regional economic diversity across China, some scholars have focused their analyses on specific areas to examine how the digital economy and high-quality manufacturing development interact. The main research regions include: the Pearl River Delta, the Yangtze River Delta, Zhejiang Province, Foshan City, Chengdu City, etc. From the literature review, we found that almost all existing research focuses on the economically developed eastern regions, and there are almost no relevant studies on the western region, and there are even fewer studies on Shaanxi Province. Shaanxi Province, a key province in western China, is experiencing rapid transformation in its traditional manufacturing sectors, including new energy vehicles, machinery, and energy and chemicals. Examining the interplay between the digital economy and high-quality manufacturing development in Shaanxi will inform strategic layout adjustments for future industrial growth. Moreover, these findings can serve as a valuable model for other western provinces, contributing to the broader economic transformation of the region.

3. Indicator Framework and Data Description

3.1 Indicator System Design

3.1.1 Indicators for the digital economy

Regarding specific indicators, empirical evidence from 36 countries confirms that Internet-related infrastructure development significantly enhances the technological sophistication of the digital industry. [16] An empirical investigation of the digital economy in Zhejiang Province was undertaken, employing a framework that utilizes digital infrastructure, core industries, and integrated applications as primary indicators for the purpose of calculating the aggregate development level of the digital economy.[20] Following a current situation analysis, the scholar selected digital infrastructure, digital application core industries and digital technology innovation level as the first-level indicator dimensions to construct a digital economy indicator system. Therefore, this article constructs the following first-level indicators in three dimensions and sets up 8 related second-level indicators.[21] Details of the indicator system are shown in Table 1.

Table 1. Digital Economy Indicator System of Shaanxi Province

First level indicators	Secondary indicators	Indicator properties
Digital infrastructure	Total telecommunications business volume (100 million yuan)	+
	Internet users (10,000 households)	+
	Optical cable line length (km)	+
Digital economy application degree	Number of websites (10,000)	+
	Mobile phone penetration rate (units/100 people)	+
Digital technology innovation level	R&D expenses (10,000 yuan)	+
	Total number of talents with bachelor degree or above (10,000 people)	+
	Software product revenue (10,000 yuan)	+

3.1.2 Indicators for high-quality manufacturing development

Regarding indicator selection, an empirical study of 30 Chinese provinces from 2002 to 2016 showed that technological innovation significantly upgrades the manufacturing industry. Further empirical research highlights how information technology has modernized traditional manufacturing, enabling intelligence, collaboration, and customization.

In assessing manufacturing upgrading, one scholar evaluated it across three dimensions: economic benefits, innovation capabilities, and structural advancement.[22] Among them, economic benefits are mainly reflected by numerical values such as output value and profit; innovation capabilities are mainly reflected by indicators related to R&D investment; structural height is mainly reflected by the scale of main business income. Therefore, this article establishes the following two first-level indicators and sets up seven related second-level indicators. Details of the indicator system are shown in Table 2.

Table 2. Indicator System for High-quality Development of Manufacturing Industry in Shaanxi Province

First level indicators	Secondary indicators	Indicator properties
Economic benefits	Total output value of mid-to-high-end manufacturing industry (100 million yuan)	+
	Gross regional product (100 million yuan)	+
	Total Import-Export Turnover (billion yuan)	+
	Number of employees in the manufacturing industry (10,000 people)	+
technological innovation	Technical transformation expenditure (10,000 yuan)	+
	R&D funds (10,000 yuan)	+
	Number of R&D project patents (items)	+

3.2 Data Sources and Descriptive Analysis

This article takes Shaanxi Province as the research object, and the research time range is from 2010 to 2021. The original data for each indicator in this article come from CSMAR database, White Paper on the Development of China's Digital Economy, China Statistical Yearbook, China Industrial Statistical Yearbook, Shaanxi Province Statistical Yearbook, individual missing values are imputed by means method filling. The descriptive statistical characteristics of each indicator are shown in Table 3.

Table 3. Descriptive Statistical Values of Various Indicators in Shaanxi Province

Indicator name	Years	Minimum	Maximum	Mean	Standard Deviation
Total telecommunications business volume (100 million yuan)	12	319.66	4148.73	1219.24	1299.86
Internet users (10,000 households)	12	332.82	1642.80	821.99	421.72
Optical cable line length (km)	12	296044.29	1795700.00	919505.01	540453.62
Number of websites (10,000)	12	41175.10	186033.74	118937.54	49472.33
Mobile phone penetration rate (units/100 people)	12	66.67	121.33	100.22	17.85
R&D expenses (10,000 yuan)	12	966768.00	3542906.40	2060253.95	787507.76
Total number of talents with bachelor degree or above (10,000 people)	12	59.52	83.41	69.74	5.83
Software product revenue (10,000 yuan)	12	1189424.77	6879782.80	3916689.51	1818149.40
Total output value of mid-to-high-end manufacturing industry (100 million yuan)	12	8575.60	18979.02	14492.48	3526.27
Gross regional product (100 million yuan)	12	10957.60	27314.81	19338.76	5574.65
Total import and export volume (billion yuan)	12	902.20	4363.40	2290.89	1248.26
Number of employees in the manufacturing industry (10,000 people)	12	75.66	107.91	91.47	12.09
Technical transformation expenditure (10,000 yuan)	12	456105.10	827212.30	577777.63	126005.52
R&D funds (10,000 yuan)	12	710176.00	3196866.60	1822196.66	720556.36
Number of R&D project patents (items)	12	2506.00	16285.00	8860.33	4172.75

4. Model Construction

4.1 Entropy Method Model

The entropy method needs to go through the following steps when calculating the weight of indicators:

Step1: Data standardization processing

When the indicator is a positive:

$$Y_{ij} = \frac{X_{ij} - min(X_{ij})}{max(X_{ij}) - min(X_{ij})} \quad (1)$$

When the indicator is negative:

$$Y_{ij} = \frac{max(X_{ij}) - X_{ij}}{max(X_{ij}) - min(X_{ij})} \quad (2)$$

The above two formulas represent the range standardization of positive indicators and negative indicators respectively; X_{ij} is original data, reflects the original value of the j-th plan for the i-th indicator; Y_{ij} is standardized indicator statistics, reflects the standardized value of the j-th solution for the i-th indicator; $max(X_{ij})$ and $min(X_{ij})$ shows the maximum and minimum of the i-th indicator for each; i is the indicator; j is the indicator plan.

Step2: Dimensionless data

$$P_{ij} = \frac{Y_{ij}}{\sum Y_{ij}} \quad (3)$$

In particular, P_{ij} represents the proportion of the j-th plan in the indicator, and $\sum Y_{ij}$ represents the sum of the statistical values of all indicators after standardization.

Step3: Calculate the information entropy of each indicator

$$E_i = -\sum P_{ij} log(P_{ij}) \quad (4)$$

Specifically, E_i represents the entropy value of the i-th indicator.

Step4: Weight each indicator

$$W_i = \frac{(1-E_i)}{\sum(1-E_i)} \quad (5)$$

Specifically, W_i represents the weight of the i-th indicator.

Step5: Normalized weight

$$W_i = \frac{(1-E_i)}{\sum(1-E_i)} \quad (6)$$

After the above steps, we can get the following calculation outcomes, as shown in Table 4 and Table 5

Table 4. Weight of Various Indicators of Digital Economy in Shaanxi Province

First level indicators	Secondary indicators	Indicator properties	Indicator Weight
Digital infrastructure	Total telecommunications business volume (100 million yuan)	+	0.4294
	Internet users (10,000 households)	+	0.1205
	Optical cable line length (km)	+	0.1636
Digital economy application degree	Number of websites (10,000)	+	0.0895
	Mobile phone penetration rate (units/100 people)	+	0.0153
Digital technology innovation level	R&D expenses (10,000 yuan)	+	0.0673
	Total number of talents with bachelor degree or above (10,000 people)	+	0.0032
	Software product revenue (10,000 yuan)	+	0.1111

Table 5. Weights of Various Indicators for High-Quality Development of Manufacturing Industry in Shaanxi Province

First level indicators	Secondary indicators	Indicator properties	Indicator Weight
Economic benefits	Total output value of mid-to-high-end manufacturing industry(100 million yuan)	+	0.0697
	Gross regional product (100 million yuan)	+	0.0950
	Total Import-Export Turnover (billion yuan)	+	0.3350
	Number of employees in the manufacturing industry(10,000 people)	+	0.0195
technological innovation	Technical transformation expenditure (10,000 yuan)	+	0.0503
	R&D funds (10,000 yuan)	+	0.1786
	Number of R&D project patents (items)	+	0.2518

4.2 Comprehensive Index

According to the weight and normalized value of each secondary indicator, the first-level indicator index of each dimension can be obtained through weighted sum calculation, and then the comprehensive index can be obtained. Presented below are comprehensive indices on the digital economy and manufacturing development. (Table 6, Table 7).

Table 6. Indices and Composite Indices of Digital Economy in Shaanxi Province from 2010 To 2021

Year	Digital Infrastructure Index	Digital Economy Application Index	Digital Technology Innovation Index	Composite Index
2010	0.0561	0.0167	0.0000	0.0728
2011	0.0070	0.0246	0.0103	0.0419

2012	0.0222	0.0532	0.0278	0.1031
2013	0.0536	0.0075	0.0479	0.1089
2014	0.0749	0.0134	0.0598	0.1481
2015	0.1204	0.0568	0.0829	0.2601
2016	0.1250	0.0988	0.1027	0.3265
2017	0.1966	0.0856	0.1001	0.3824
2018	0.3796	0.0879	0.1501	0.6176
2019	0.5561	0.0655	0.1164	0.7380
2020	0.6774	0.0861	0.1403	0.9037
2021	0.2979	0.0931	0.1599	0.5510

Table 7. Indices and Composite Indices of High-Quality Development of Manufacturing Industry in Shaanxi Province from 2010 To 2021

Year	Economic efficiency index	Technological Innovation Index	Composite Index
2010	0.0032	0.0503	0.0535
2011	0.0238	0.0996	0.1234
2012	0.0421	0.1175	0.1596
2013	0.1063	0.1527	0.2590
2014	0.1671	0.1641	0.3312
2015	0.1904	0.1799	0.3703
2016	0.2167	0.2007	0.4174
2017	0.3089	0.2129	0.5218
2018	0.3899	0.2493	0.6393
2019	0.4117	0.3141	0.7258
2020	0.4342	0.3748	0.8090
2021	0.4932	0.4337	0.9270

4.3 Coupling Coordination Model

4.3.1 Coupling Degree Model

In order to study the coupling relationship between the digital economy and the high-quality development of the manufacturing industry, this paper establishes a coupling degree model.

$$C = \sqrt{\frac{u_1+u_2}{\left(\frac{u_1+u_2}{2}\right)^2}} \quad (7)$$

Among them, u_1 represents the comprehensive evaluation index of the digital economy, u_2 represents the comprehensive index of high-quality development of the manufacturing industry, C represents the coupling degree of the high-quality development of the digital economy and the manufacturing industry. The value of C is between [0,1], and the higher the value, the greater the correlation between the two systems. The coupling coordination degree is calculated to measure the system's level of coordinated development.

$$D = \sqrt{C \times T} \quad (8)$$

$$T = \alpha \times u_1 + \beta \times u_2 \quad (9)$$

In this context, D represents the coupling coordination degree, ranging from 0 to 1. Higher D values indicate greater coordination between the digital economy and manufacturing development. The contribution coefficients, α and β, represent the respective weights of the digital economy and manufacturing development, where α + β = 1. Assuming equal importance, this study sets α = β = 0.5. Table 8 outlines the evaluation criteria for coupling coordination.

Table 8. Standards for Grading Coupling Coordination

D-value Range for Coupling Coordination	Coordination level	The degree of coupling coordination
(0.0，0.1)	1	Significant disorder
[0.1，0.2)	2	Severe disorder
[0.2，0.3)	3	Slight disorder
[0.3，0.4)	4	Mild disorder
[0.4，0.5)	5	Nearing disorder

[0.5，0.6)	6	Scarcely coordinated
[0.6，0.7)	7	Primary coordination
[0.7，0.8)	8	Mid-level coordination
[0.8，0.9)	9	Strong coordination
[0.9，1.0)	10	High-quality coordination

Table 9. The Extent of Coupling and Coordination Between the Digital Economy and High-Quality Manufacturing Development in Shaanxi Province, 2010-2021

Year	C Value (Coupling Degree)	D value (Coupling Degree)	Coordination level	Coupling Coordination Degree
2010	0.770	0.146	2	Severe disorder
2011	0.604	0.172	2	Severe disorder
2012	0.972	0.318	4	Mild disorder
2013	0.881	0.379	4	Mild disorder
2014	0.907	0.453	5	Nearing disorder r
2015	0.985	0.554	6	Scarcely coordinated
2016	0.994	0.611	7	Primary coordination
2017	0.989	0.679	7	Primary coordination
2018	1.000	0.816	9	Strong coordination
2019	1.000	0.885	9	Strong coordination
2020	0.997	0.960	10	High-quality coordination
2021	0.967	0.874	9	Strong coordination

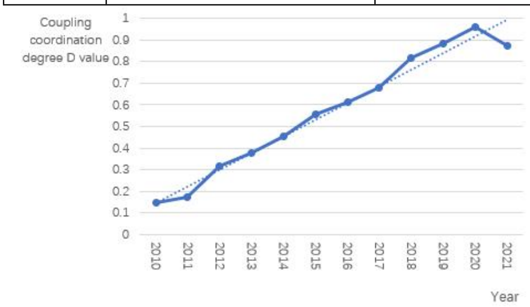

Figure1. Coupling Coordination Trend: Shaanxi's Digital Economy and High-Quality Manufacturing Development (2010-2021)

Table 9 and Figure 1 illustrate a steady improvement in the integrated development of Shaanxi's digital economy and manufacturing industry. This progression can be categorized into three stages: imbalance (2010-2013), primary coordination (2014-2017), and Strong coordination (2018-2021), achieving high-quality coordination in 2020.

5. Findings and Countermeasures

5.1 Findings

This study analyzes 2010-2021 data from Shaanxi Province to determine the coupling coordination degree between the digital economy and high-quality manufacturing development. The analysis produces the following conclusions:

First, from 2010 to 2021, the comprehensive index for Shaanxi Province's digital economy exhibited a general upward trend. In terms of its constituent dimensions, the index for digital economy infrastructure generally followed an upward trajectory, although it experienced a marked decline in 2021, primarily attributable to the deceleration in economic infrastructure construction resulting from the coronavirus pandemic. The index for digital economy application, however, demonstrated consistent growth, signifying the progressive integration of the digital economy into various aspects of the real economy and a deepening relationship between the two. The index for digital technology innovation, meanwhile, increased annually, rising from 0.0728 in 2010 to 0.5510 in 2021, indicating the ongoing development and expansion of the digital industry within Shaanxi Province, while simultaneously suggesting that considerable scope for further advancement remains.

Second, Shaanxi Province's manufacturing development index demonstrated a generally upward trajectory from 2010 to 2021. Notably, the sector's economic benefits grew consistently, underscoring its vital role in economic progress, as reflected in improved GDP, trade, and employment figures. Concurrently, a steady rise in the technological innovation index highlights the significant impact of technological transformation and R&D investment in driving the industry's upgrading and pursuit of high-quality development.

Third, the coupling and coordination analysis indicates that the alignment between Shaanxi's digital economy and high-quality manufacturing development progressively improved from a severe imbalance in 2010 to a state of good coordination by 2021. However, future studies should prioritize achieving even higher levels of coordination, particularly in light of the continued growth of the digital sector and the changing demands of manufacturing transformation.

5.2 Countermeasures

First, increase the construction of digital industry infrastructure and improve the level of basic hardware facilities. For example: renovating industrial broadband networks, expanding optical cable lines, etc. At the same time, we will actively explore new models of cross-regional co-construction and sharing.

Second, it is essential to strategically develop future-oriented industries and advance new digital sectors. By fostering the growth of cutting-edge technologies like the Internet, IoT, blockchain, cloud computing, and big data, we can secure a competitive advantage through technological leadership and early adoption. Furthermore, promoting deep integration of digital technologies with the manufacturing value chain, encompassing areas such as smart factories, networked equipment management, and collaborative platforms, will enable the formation of a robust digital ecosystem within the manufacturing industry.

Third, the government should enhance its support for technological investments aimed at transforming the manufacturing sector. This involves addressing key shared challenges in the modernization of traditional enterprises through strategic investments, while simultaneously establishing innovation platforms. Fostering collaboration between renowned universities and leading enterprises, potentially through the integration of high-tech firms and research institutions, can create an ecosystem that supports technological innovation, its commercialization, and practical application.

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