Can digital transformation become a new engine for the development of the textile industry? Evidence from China

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ABSTRACT – REZUMAT

Can digital transformation become a new engine for the development of the textile industry? Evidence from China

At present, China is undergoing a major transition from an industrial economy to a digital economy, particularly as enterprises that demonstrated resilience during the pandemic were predominantly those at the forefront of comprehensive digital transformation and online-offline integration. Recently, Shandong Municipality placed significant emphasis on the transformation and upgrading of its textile industry, which played a crucial role in the digital economy. Based on the contemporary implications of the digital economy and high-quality development, this study selected relevant indicator data from Shandong Province for the period 2014–2023 and constructed a coupling coordination model to measure the coupling coordination level between the two systems. The findings indicated that the coupling coordination development demonstrated a favourable trend, which was conducive to the healthy development of the textile industry. This research aimed to promote the deep integration of the textile industry with the digital economy and create a "strong engine" for high-quality development in the face of new historical opportunities.

Keywords: *coupling coordination model, digital economy, entropy method, green development*

Transformarea digitală poate deveni un nou motor al dezvoltării industriei textile? Date din China

În prezent, China se află în plin proces de tranziție de la o economie industrială la o economie digitală, în special datorită faptului că întreprinderile care au dat dovadă de reziliență în timpul pandemiei au fost, în mare parte, cele aflate în avangarda transformării digitale cuprinzătoare și a integrării dintre mediul online și cel offline. Recent, municipalitatea Shandong a acordat o importanță deosebită transformării și modernizării industriei textile, care a jucat un rol crucial în economia digitală. Pe baza implicațiilor contemporane ale economiei digitale și ale dezvoltării de înaltă calitate, acest studiu a selectat date privind indicatorii relevanți din provincia Shandong pentru perioada 2014–2023 și a construit un model de coordonare a cuplării pentru a măsura nivelul de coordonare a cuplării dintre cele două sisteme. Rezultatele au indicat că evoluția coordonării de cuplare a demonstrat o tendință favorabilă, care a contribuit la dezvoltarea sănătoasă a industriei textile. Acest studiu a avut ca scop promovarea integrării profunde a industriei textile cu economia digitală și crearea unui „motor puternic" pentru dezvoltarea de înaltă calitate în contextul noilor oportunități istorice.

Cuvinte-cheie: *model de coordonare a cuplării, economia digitală, metoda entropiei, dezvoltarea ecologică*

INTRODUCTION

China's textile industry has a long history, from hemp and silk weaving in the Neolithic Age to modern high-tech fibres and functional fabrics; it has always been an important pillar of China's economy [1]. As the world's largest textile producer and exporter, China possesses a complete industrial chain, covering multiple stages such as cotton cultivation, fibre processing, fabric weaving, and garment manufacturing [2, 3]. In recent years, China's textile industry has made significant progress in technological innovation, sustainable development, and international cooperation, driving industrial upgrading and green transformation [4, 5]. In the future, China's textile industry will continue to develop toward high-end, intelligent, and green directions, strengthen international cooperation, meet the upgrading of domestic consumption and diverse market demands, and contribute more to the prosperity of the global textile industry [6].

By 2024, China's digital economy had continued to grow and had become a key force driving economic progress [7]. According to the latest data from the "Research Report on China's Digital Economy Development (2024)", China's digital economy reached 53.9 trillion yuan in 2023, accounting for 42.8% of GDP, representing an increase of 1.3 percentage points from the previous year, with the digital economy's contribution to GDP growth reaching 66.45% [8].

The digital economy's resilient growth during challenging circumstances further highlighted its important position in the national economy, effectively supporting pandemic prevention and control as well as economic and social development [9, 10]. Scholars Si et al. found that the deep integration of the digital economy with manufacturing could drive manufacturing to achieve quality transformation, efficiency transformation, and dynamic transformation [11]. Scholars

Heping and Fuxiang employed a “micro-meso-macro” analytical framework to investigate the intrinsic mechanisms by which the digital economy drove high-quality economic development [12]. Scholars Fromhold-Eisebith et al. contended that it was essential to vigorously enhance the deep integration of informatisation and industrialisation, advance the widespread application of digital technology in various textile processes, and construct new manufacturing models such as intelligent production and digital management [13].

Under the influence of the digitalised economy, the textile industry was progressing towards intelligent production, management, and operations [14]. However, few scholars had analysed the coordinated development level and mutual interaction effects between the digitalised economy and the textile industry. Against this broader backdrop, this study was dedicated to exploring the coupling coordination relationship between the digitalised economy and the progress of the textile industry, to identify opportunities for the progress of Shandong Province’s textile industry.

The innovations could be summarised as follows: First, by selecting textile industry and digital economy indicators from Shandong Province for the period 2014–2023, this study filled the gap in previous research that predominantly focused on national-level or earlier data, whilst considering both the latest development trends and regional characteristics. Second, beyond traditional economic growth and scale effects, this research incorporated “green” elements into the high-quality development evaluation indicator system, systematically examining for the first time the synergistic improvement of resource utilisation efficiency and environmental friendliness in the textile industry’s digital transformation. Third, based on entropy method-weighted dual system evaluation indicators, this study employed a coupling coordination model to quantify the interaction and coordination level between the two systems, filling the research gap in the application of such models in the textile industry field. Fourth, beyond empirical calculations, this study drew upon the “micro-meso-macro” analytical framework to deeply analyse how technological innovation, industrial integration, and policy guidance at different levels promoted the evolutionary path of coupling coordination. Fifth, combining Shandong Province’s transformation and upgrading experience, this study proposed precise policy recommendations and pathway designs targeting the “lag” and “imbalance” issues in coupling coordination, demonstrating strong operability and promotional value. Sixth, this study proposed a “digital economy-textile industry green high-quality development” mutually reinforcing and complementary “strong engine” model, enriching the theoretical system of industrial transformation and upgrading and regional economic growth.

LITERATURE REVIEW

The connotation of digital economy

The digital economy has emerged as a transformative force in the modern world, reshaping industries and driving economic growth on a global scale [15, 16]. On one hand, the rapid development of the digitalised economy has been marked by the vigorous promotion of digital infrastructure construction, which includes critical components such as information and communication technology (ICT) and the industrial internet [17]. These advancements have not only generated new business models but also brought unprecedented opportunities to various industries, propelling the rapid progress of related sectors [18, 19]. For instance, the integration of advanced ICT solutions has enabled businesses to streamline their operations, enhance customer engagement, and develop innovative products and services that were previously unimaginable [20]. Similarly, the industrial internet has facilitated the interconnectivity of industrial systems, allowing for real-time data exchange and collaborative production processes that boost efficiency and productivity [21, 22].

On the other hand, the digital economy is inextricably linked to the quality of digital applications, which is prominently demonstrated in the breakthrough and integrated development of cutting-edge technologies such as blockchain, big data, and AI. These technologies have revolutionised the way data is managed, analysed, and utilised, thereby accelerating equipment access and system deployment [23]. Blockchain technology, with its decentralised and secure nature, has the potential to transform supply chain management, financial transactions, and digital identity verification, among other applications [24, 25]. Big data analytics enables organisations to extract valuable insights from vast amounts of information, informing decision-making processes and driving strategic business initiatives [26]. AI, with its ability to learn and adapt, has become an integral part of numerous sectors, from healthcare diagnostics to autonomous vehicles, significantly enhancing efficiency and effectiveness [27, 28].

Moreover, government investment in digital research and experimental funding has emerged as a key factor in bolstering the digital economy’s research and development capabilities [29]. This support has been instrumental in facilitating the continuous release of the digital economy’s potential, fostering innovation and driving technological advancements. For example, government-backed research initiatives have led to breakthroughs in quantum computing, which promises to revolutionise data processing and encryption [30, 31]. Additionally, funding for experimental projects has enabled startups and established companies alike to explore new digital frontiers, such as the development of smart cities and the Internet of Things (IoT), which have the potential to transform urban living and industrial operations [32–34].

This study delves into the connotation of the digital economy from an economic perspective, interpreting it as an economic form that achieves progress through the digitalisation of knowledge and information. By leveraging digital technologies, the digital economy guides the optimal allocation and regeneration of resources, ensuring that they are utilised as efficiently and productively as possible. This not only drives economic growth but also fosters social development by creating new job opportunities, enhancing educational outcomes, and improving public services. As the digital economy continues to evolve, it is poised to play an even more significant role in shaping the future of our global society, offering endless possibilities for innovation and progress.

The connotation of green advancement in the textile industry

Rapid development of the textile industry was conducive to enhancing the transformation of economic development patterns and establishing a modern economic system [35, 36]. At the macroscopic level, this referred to stable economic growth, balanced urban-rural development, green, coordinated sustainable development, and the sharing of development outcomes by the people. Therefore, the textile industry needed to implement the understanding of healthy, green, and sustainable development [37]. From an industrial perspective, development of the textile industry referred to a reasonable industrial structure, continuously optimised industrial layout, achievement of transformation and upgrading, and enhancement of sustainable development capabilities [38]. From the perspective of textile enterprises, high-quality development was influenced by factors such as first-class competitiveness, reliable quality, and brand influence [39]. Development of the textile industry needed to focus on intelligent manufacturing, accelerate the deep integration of the digital economy with the textile industry, promote the digitalisation and intelligentisation of textile industry development, and advance towards high-quality development [40].

The coupling relationship between digital economy and green development of textile industry

In recent years, international and domestic market layouts, commodity structures, and trade patterns have undergone profound adjustments, and these changes provided a window of opportunity for the formation of a new pattern characterised by domestic circulation as the main section and mutual improvement of domestic and international dual circulation [41]. As a pillar industry of the national economy, the textile industry had witnessed digital transformation become the core driving force for high-quality development within this developmental context, with the digital economy becoming a key element in technological innovation and transformation of the textile industry [42]. The higher the degree of digitalisation in the textile industry, the deeper the integration with the digital economy, and consequently, the stronger the coupling relationship between the two systems. Against the backdrop of the digital economy driving industrial transformation and upgrading, big data and cloud computing technologies highly integrated supply-side and demand-side data, reduced production energy consumption, and achieved efficient digital management of textile production, resulting in breakthroughs across three dimensions: cost, quality, and profit. The textile industry transformed from “manufacturing” to “intelligent manufacturing”, with enhanced automation levels, further promoting digital transformation and technological innovation in the textile industry whilst improving competitive advantages [43]. This provided a platform for the development of four indicators: economic development, technological resources, green development, and innovation performance in the new era, consolidating the rapid development of the textile industry and thereby supporting the advancement of digital economy industrialisation processes, as illustrated in figure 1.

Analysis of digital economy application scenarios in Shandong textile enterprises

The year 2024 represented a year of particular significance in China’s modernisation construction process,

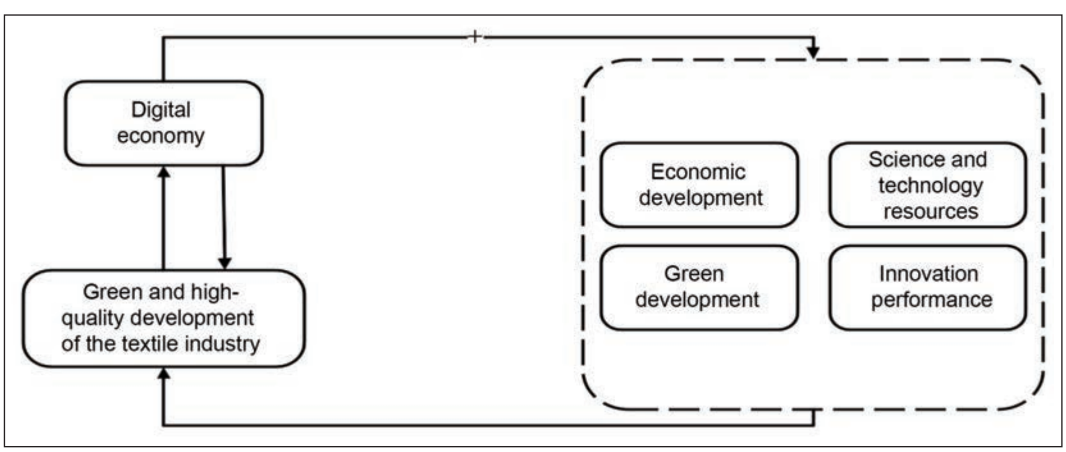

Fig. 1. The coupling relationship between digital economy and green high-quality development of textile industry

where “pandemic prevention and control” and “economic recovery”, “global cooperation” and “strategic competition”, and “human survival” and “sustainable development” were interwoven and overlapping, creating a complex environment. As an important light industry sector, the textile industry was not only closely related to people’s daily lives but also had extensive applications in industry, national defence, and medical and health sectors. The textile industry represented a labour-intensive industry, where a series of processes including textile design and development, production, and sales constituted factors that influenced the transformation and upgrading of textile enterprises. This study selected textile enterprises in Shandong Province with high levels of digitalisation and representativeness as examples to analyse the digital application scenarios in their design and development, production, and sales processes, as detailed in table 1.

In addition, we used the texts of the Shandong Provincial Government work reports from 2014 to 2023, employing word cloud diagrams to depict the development of the digital economy in Shandong Province (as shown in figure 2) and the development of the textile industry in Shandong Province (as shown in figure 3).

Figure 2 displayed the keywords “Economy”, “Blockchain”, “Infrastructure”, and “Digital data”, which signalled Shandong Province’s focus on digital infrastructure, blockchain technology, and big data as foundational pillars of its digital-economy agenda.

During the past five years the province accelerated investment in fifth-generation (5G) mobile networks, industrial internet, and data centres, thereby creating a robust underpinning for digital growth. National-level internet backbone nodes were commissioned in Jinan and Qingdao, markedly improving inter-provincial data-transfer speeds. Blockchain was designated a strategic priority: the Shandong Blockchain Research Institute initiated multiple technology-development projects and industry partnerships, fostering a trusted digital ecosystem across supply-chain management, government services, and finance.

Shandong also expanded access to public-sector data, established a provincial data-trading platform, and trialled data-asset valuation mechanisms, which deepened the use of digital information in agriculture, manufacturing, and services. As China’s largest industrial province, Shandong promoted widespread “cloud adoption, data activation, and intelligentisation” among factories, generating benchmark demonstrations in smart manufacturing, intelligent mining, and precision agriculture and enhancing the competitiveness of traditional sectors.

These initiatives raised total-factor productivity by integrating technological innovation with data-driven decision-making, facilitating a shift from resource-intensive to technology-intensive development. Digital technologies upgraded legacy industries and spawned new business formats: platform economy, shared manufacturing, and digital trade, thereby diversifying and upgrading the industrial structure.

By building advanced digital infrastructure and strengthening innovation capacity, Shandong assumed a leading role in the ecological protection and development of the Yellow River Basin and elevated its strategic position within China’s digital-economy landscape. Data, treated as a new factor of production, improved efficiency in finance, logistics, health care, and education through circulation and exchange, creating additional sources of economic growth.

Overall, the province used digital infrastructure as its foundation and blockchain, big-data analytics, and other emerging technologies as engines to achieve deep integration between the digital and physical economies. This process injected new momentum into Shandong’s economy and provided a replicable “Shandong model” for China’s wider digital transformation. Looking forward, further marketisation of data elements and refinement of digital governance systems are likely to establish Shandong as a major growth pole for high-quality national digital development.

Fig. 2. Digital economy word cloud

Figure 1 contained a set of fragmented terms implying flame-retardant cotton, Cocoon, Bast, Syntehti Fibre and Tenac, which collectively signalled Shandong Province’s move toward a broad-spectrum fibre portfolio spanning natural sericulture, bast fibres, high-tenacity synthetics and functionalised cellulosics.

Over the past decade Shandong consolidated its position as China’s largest bast-fibre processing base, utilising locally grown hemp and ramie to manufacture high-count yarns for technical textiles. The province simultaneously rejuvenated its centuries-old sericulture belt in the Yimeng mountainous region; annual cocoon output rose to 18,000 tonnes, thereby securing a domestic feedstock for premium silk apparel and medical sutures.

On the synthetic side, Sinopec Yanshan and Luxi Chemical commissioned polyester and nylon 6 chips plants with a combined capacity exceeding 1.5 Mt yr^{-1}. Drawing on these chips, downstream filament-spinners in Qingdao and Weifang introduced ultra-high-tenacity (≥8.0 cN $dtex^{-1}$) industrial yarns now embedded in tyre cord, soft-body armour and geogrids.

To satisfy stringent fire-safety standards, Shandong researchers developed flame-retardant cotton (FRC) using a phosphorus-nitrogen synergetic finish that withstands 50 wash cycles while maintaining limiting-oxygen index ≥ 28%. Pilot mills in Zibo produced 30 million metres of FRC sheeting in 2022, chiefly exported to European work-wear brands.

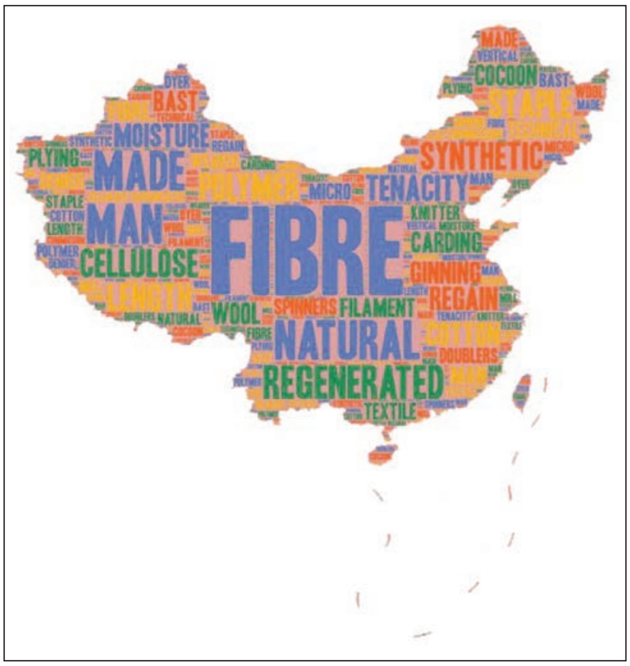

Fig. 3. Textile industry word cloud

Economic significance emerged on three fronts. First, value-added per tonne of fibre climbed from RMB 6 300 to RMB 11 800 between 2015 and 2023 as the share of technical and functional textiles rose above 42 % of provincial output. Second, the integrated bast-fibre → yarn → fabric chain created 47,000 rural jobs and lifted hemp growers' income by 18 % relative to cereal cropping. Third, substitution of imported aramid with locally engineered high-tenacity nylon and FRC saved an estimated USD 240 million in foreign-exchange outflows and strengthened Shandong's resilience against volatile commodity prices.

In sum, Shandong leveraged both its agricultural bast-fibre heritage and its petrochemical backbone to build a diversified, innovation-driven textile ecosystem. This trajectory not only raised regional value capture but also offered a replicable model for upgrading traditional fibre provinces into high-margin technical-textile hubs within China's broader supply-chain security strategy.

CONSTRUCTION OF EVALUATION INDICATOR SYSTEM FOR DIGITAL ECONOMY AND DEVELOPMENT OF TEXTILE INDUSTRY

Shandong digital economy evaluation indicator system

This study adhered to the principles of objectivity, operability, systematicity, and scientific rigour, and combined with the exposition of the connotation of digital economy, constructed a digital economy development evaluation indicator system for Shandong Province [44]. Three dimensions were selected to assess the quality of Shandong's digital economy advancement: digital infrastructure, digital network penetration, and digital research and development capabilities, as presented in table 1.

Table 1

SHANDONG DIGITAL ECONOMY DEVELOPMENT EVALUATION INDICATOR SYSTEM

Primary indicators	Secondary indicators	Weights
Digital infrastructure	ICT development index	0.1132
	Total post and telecommunications business	0.0348
	Fibre optic line long way	0.1178
	Percentage of informatized employees	0.0155
	Number of internet broadband access subscribers	0.1299
Quality of digital applications	Average e-commerce turnover of enterprises	0.0365
	Digital TV coverage rate	0.1333
	Internet penetration rate	0.0461
	Mobile phone subscribers at the end of the year	0.1454
Digital R&D capabilities	Contribution rate of scientific and technological progress	0.1155
	Transformation of scientific and technological achievements	0.1120
	Investment in scientific research and experimental funding	0.0554

Shandong textile industry development evaluation index system

Combined with the above analysis, four first-level indicators of scientific and technological resources, innovation performance, economic progress, and green development, a total of 14 second-level indicators, were used to build a Shandong textile industry development evaluation index system [45]. In addition to the annual emissions of sewage as a reverse indicator of the green development of the textile industry, the rest are positive indicators. Table 2 presents the detailed evaluation index system.

Data sources

This study selected data from Shandong Province covering 10 years from 2014 to 2023 as the foundational data for the research. The original data were sourced from the Statistical Yearbook of Shandong Province, Shandong Provincial Bureau of Statistics, Shandong Provincial People's Government, and the National Bureau of Statistics. To address missing indicator data for certain years, mean replacement interpolation methods were employed to complete the dataset.

Standardisation Processing

Due to the different dimensions and orders of magnitude among the selected indicator data, this study first conducted standardisation processing on the original indicator data before data analysis to eliminate the influences these differences might cause [46].

The standardisation processing formula for positive indicators was:

$$X'_{ij} = \frac{X_{ij} - m_j}{M_{ij} - m_j} \tag{1}$$

The formula for normalising the reverse indicator is:

$$X'_{ij} = \frac{M_{ij} - X_{ij}}{M_j - m_j} \tag{2}$$

In equation 1 and equation 2, i denotes the year, j denotes the indicator, and X_{ij} is the original data, which denotes the original value of the j^{th} indicator in the i^{th} year. X_{ij} is the standardised statistical value of the indicator, which denotes the standardised value of the j^{th} indicator in year i. M is the maximum value of X_{ij} and m is the minimum value of X_{ij}.

To make the data analysis more meaningful, this paper eliminates the zero and negative values, so that the standardised data are shifted as a whole, that is:

$$\chi'_{ij} = X'_{ij} + \alpha \tag{3}$$

To maximise the preservation of the original data by following the intrinsic laws of the original data, α is any real number, and to make α the smallest value closest to χ'_{ij}, $\alpha = 0.0001$ is taken.

Entropy value method to calculate weights

The entropy value method is one of the commonly used objective assignment methods to determine the level of dispersion of an indicator. To obtain accurate and objective evaluation results, this article adopts the entropy value method as the assignment method for evaluating the performance of digital economy development and the green development of the textile industry.

(1) Compute the proportionate part of the j^{th} indicator to the indicator in the i^{th} year, i.e. P_{ij}:

$$P_{ij} = \frac{\chi'_{ij}}{\sum_{i=1}^{n} \chi'_{ij}} \tag{4}$$

$\sum_{i=1}^{n} \chi'_{ij}$ denotes the sum of statistical values of all years of the j^{th} indicator after standardisation.

(2) Entropy value calculation: compute the entropy value e_j of the j^{th} indicator, that is:

$$e_j = -\frac{1}{Inn} \sum_{i=1} P_{ij}\, In(P_{ij}),\ 0 \le e_j \le 1 \tag{5}$$

Table 2

SHANDONG TEXTILE INDUSTRY GREEN HIGH-QUALITY DEVELOPMENT EVALUATION INDEX SYSTEM

Primary indicators	Secondary indicators	Attributes	Weights
Science and technology resources	Textile engineers and technicians	+	0.0856
	Personnel with intermediate titles or above	+	0.0467
	Independent scientific research institutions	+	0.0555
	Land for public facilities	+	0.0389
	Private technology-based textile enterprises	+	0.0476
Innovation performance	Achievements through appraisal	+	0.0865
	Patent applications received	+	0.1111
Economic development	Capital return rate	+	0.0532
	Cloth production	+	0.0844
	Yarn production	+	0.0666
Green development	Green space	+	0.0567
	Total water supply	+	0.0162
	Water penetration rate	+	0.0878
	Sewage annual emissions	-	0.1632

(3) Compute the parameter of variation of the indicator g_i. The value of the coefficient of variation is directly proportional to the degree of the indicator in the comprehensive evaluation system, ie:

$$g_i = 1 - e_j \tag{6}$$

(4) Compute the weight of each indicator W_j , i.e:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j},\ j = 1,2,3,\ldots,m \tag{7}$$

The results of the weight calculation are shown in table 1 and table 2.

(5) Calculate the comprehensive score of Shandong's digital economy and development of the textile industry, U_1 is the digital economy development index, and U_2 is the development index of the textile industry, that is:

$$U_n = \sum_{j=1}^{m} W_j P_{ij},\ (n = 1, 2) \tag{8}$$

The results of the index calculation are shown in table 4.

Third, the digital economy and the textile industry green development coupling and coordination degree analysis

CONSTRUCTING THE COUPLING AND COORDINATION DEGREE MODEL

Combined with the relevant research, to determine the coupling degree of the digital economy and the textile industry green development, the formula, that is:

$$C = \sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \tag{9}$$

The larger the value of C, the stronger the coupling effect between the two systems and $0 \leq C \leq 1$.

The coupling degree model can only reflect the degree of mutual influence between the two systems of the digital economy and the high-quality development of the textile industry, and cannot reflect the level of the two systems. To accurately and objectively measure the level of coordinated development between the two systems, drawing on relevant research, the coupling coordination degree D of the digital economy and the development of the textile industry is calculated, that is:

$$D = \sqrt{C \times T} \tag{10}$$

$$T = \alpha U_1 + \beta U_2,\ \alpha + \beta = 1 \tag{11}$$

D is the coupling coordination level of the digital economy and the development of the textile industry, and T is the extensive coordinated development index of the two systems of the digital economy and the development of the textile industry, reflecting the value of the contribution of the overall development level of the two to the degree of their coupling coordination, respectively. Both α and β are coefficients to be determined, according to the description of the coupling relationship between digital economy and textile industry in this paper, it is believed that the digital economy can promote the development of the textile industry, and the high-quality development of the textile industry will also promote the progress of the digital economy to a certain degree, and the importance of the two systems is equal, so it is given to $\alpha = \beta = 0.5$, and the results of the calculation are shown in table 5.

In order to objectively and effectively study the coupling development status between the digital economy and the development of the textile industry, with reference to the grades of the coupling coordination degree division in related literature, the coupling coordination degree judgment standard of this paper is presented in table 3.

COUPLING COORDINATION FINDINGS

Using the coupling degree coordination model, the results are calculated according to the formula and table 4 is obtained.

Figure 4 shows the coordinated relationship between the advancement of the digital economy and the green development of the textile industry. Table 4 clearly reflects the coupling degree, coupling coordination degree, and coordination levels between digital economy development and green development of the textile industry. Overall, from 2014 to 2023, the

Table 3

CRITERIA FOR JUDGING THE DEGREE OF COUPLING COORDINATION

Coupling harmonization	Coupling development stage	Coupling harmonisation level	Classification
0.00≤D≤0.10	Minimum coupling	Extreme dissonance	Type of dysregulation decline (Unacceptable interval)
0.10≤D≤0.20	Low level coupling	Severe dissonance	
0.20≤D≤0.30	Low level coupling	Moderate dissonance	
0.30≤D≤0.40	Antagonistic coupling	Mild dissonance	
0.40≤D≤0.50	Antagonistic coupling	Threatened dissonance	Intermediate transition type (Antagonistic interval)
0.50≤D≤0.60	Antagonistic coupling grinding phase	Barely coordinated	
0.60≤D≤0.70	Grinding coupling	Primary coordination	Coordination elevation type (Acceptable interval)
0.70≤D≤0.80	Grinding coupling	Intermediate coordination	
0.80≤D≤0.90	High level coupling	Good coordination	
0.90≤D≤1.00	Maximum coupling	Quality coordination	

Table 4

COUPLING COORDINATION LEVEL OF GREEN AND DEVELOPMENT OF DIGITAL ECONOMY AND TEXTILE INDUSTRY, 2014–2023

Year	Digital economy development index U1	Textile industry green quality development index U2	Coupling C	Degree of coupling coordination D	Harmonization level	Classification
2014	0.123	0.078	0.067	0.076	Extreme coordination	Type of dysregulation decline (Unacceptable interval)
2015	0.119	0.122	0.111	0.145	Severe dissonance	
2016	0.368	0.248	0.321	0.205	Moderate dissonance	
2017	0.389	0.299	0.444	0.467	Endangered coordination	Intermediate transition type (Antagonistic interval)
2018	0.412	0.367	0.489	0.567	Barely coordinated	
2019	0.544	0.443	0.522	0.666	Primary coordination	Coordination elevation type (Acceptable interval)
2020	0.667	0.566	0.603	0.723	Intermediate coordination	
2021	0.778	0.670	0.777	0.799	Intermediate coordination	
2022	0.880	0.783	0.815	0.812	Good coordination	
2023	0.965	0.888	0.899	0.900	Quality coordination	

coupling degree between Shandong's digital economy and green development of the textile industry increased from 0.076 to 0.900, whilst the coupling coordination degree rose from 0.067 to 0.899, with both demonstrating upward trends. The coordination level evolved from extreme disorder to high-quality coordination, and the coupling development type transformed from a disordered decline type to a coordinated improvement type. During this period, Shandong's digital economy and development of the textile industry demonstrated rapid evolution towards a coordinated relationship with high growth potential, establishing a solid foundation for the high-quality development of Shandong's textile industry.

PATHWAYS FOR GREEN DEVELOPMENT OF SHANDONG TEXTILE INDUSTRY

Looking towards the future, a new positioning for the textile industry has emerged: a pillar industry for national economic development, a fundamental industry for addressing livelihood issues and beautifying life, and an advantageous industry for international cooperation. To enable Xuzhou's textile industry to seize new opportunities, pursue digital transformation, and achieve high-quality development, this study proposed the following development pathways.

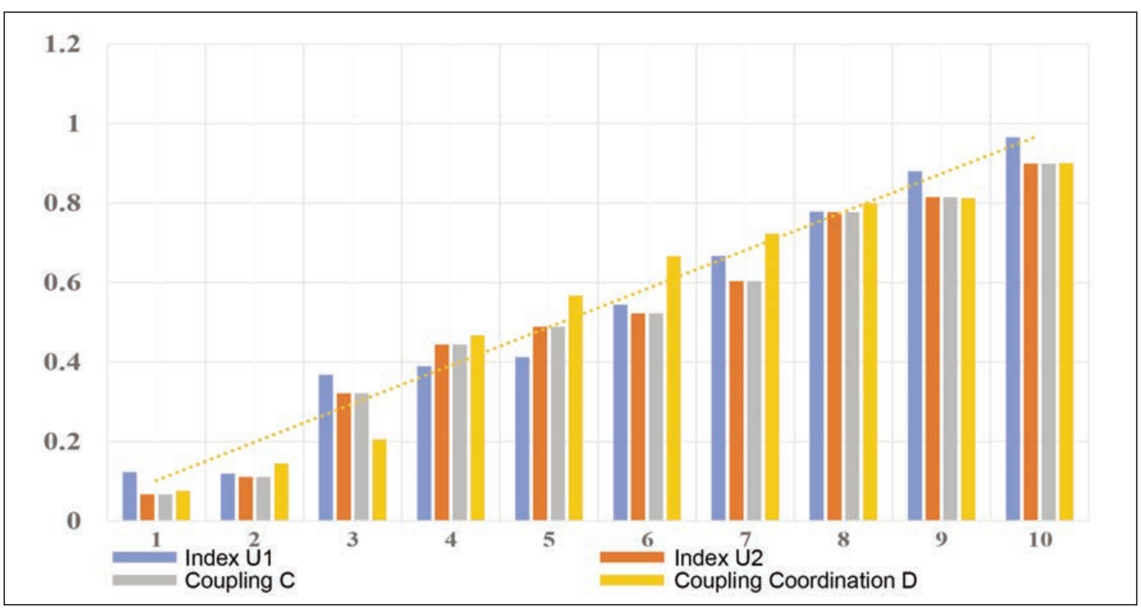

Fig. 4. The coupling degree coordination

Maintaining digital economy leadership and exploring new models for high-quality development

Through coupling coordination model analysis, it was evident that the coupling coordination level between the digital economy and textile industry had gradually improved from 2014 to 2023, reaching high-quality coordination. This demonstrated the important role of the digital economy in the development process of textile enterprises, suggesting that the leading position of the digital economy should be consistently maintained. Although the coordination degree between the digital economy and textile industry development had been high in recent years, with the digital economy demonstrating favourable development trends, compared to developed countries, there remained shortcomings in new materials, software, high-end equipment, and chips, which represented the key to promoting high-quality development of Xuzhou's textile industry. Xuzhou textile enterprises needed to centre on the digital economy and increase research and development and investment efforts in textile technology. The Utilization of digital technology in textile firms needed to be deepened, with emphasis on cultivating research and development personnel, conducting training on key core internet technology research, accelerating the digital development of manufacturing equipment in key fields, integrating with traditional production methods, and enabling digital technology to be deeply embedded in the textile industry. With promoting integrated development as the primary prerequisite, traditional conceptual constraints needed to be broken, and new models for high-quality development of the textile industry that aligned with digital development needed to be created, facilitating enterprises to form new economic growth points.

Accelerating digital transformation and creating a "strong engine" for high-quality development

Digital transformation had been the core driving force for the development of the textile industry. Therefore, textile enterprises should fully utilise digital economy advantages, gradually integrate digital economy into various departments of the textile industry, actively guide enterprise digital transformation, enable adaptation to new enterprise economic development models, consolidate the foundation for high-quality development, and provide substantial domestic demand support for China's digital technology development. High-technology, high-value-added products needed to be created to construct new patterns of enterprise development. Digital transformation needed to be emphasised, converting enterprises' comparative advantages into competitive advantages for market participation whilst improving comprehensive competitiveness. Addressing the current situation of outdated equipment and narrow research dimensions in textile enterprise application scenarios, the government should integrate resources and construct new textile industry research and development bases centred on digital technology, promote industrial clustering, and form production and trade centres. Support should be provided for enterprises to introduce advanced equipment, register trademarks, and improve brand concentration to create well-known brands, attract foreign investment, and gradually form a "strong engine" that drives development of the textile industry.

Implementing innovation-driven engineering and promoting scientific and technological achievement transformation

On one hand, textile enterprises needed to enhance independent innovation capabilities, strengthen the leading position of textile enterprises in technology demand and project selection, establish collaborative innovation chains with high-end research talent from universities, formulate talent development plans for textile enterprises and high-level research team cultivation plans, and create a research team with modern management levels. On the other hand, the government should incorporate digital technology innovation as one of the standards for performance evaluation, formulate incentive policies, stimulate the enthusiasm of digital talent for scientific and technological research and development, fully utilise regulation, support, and guidance functions for the textile market, strengthen cooperation with authoritative research institutions such as intermediary agencies and research institutions, and promote scientific and technological achievement transformation of textile enterprises and institutions through complementary advantages.

With respect to the new era of high-quality development, the digital economy has attracted significant attention and entered rapid development. Future textile industry supply chains would be more driven by the digital economy, with closer and more transparent cooperation. Shandong needed to firmly grasp this historical opportunity, maintain unwavering commitment to new development concepts, focus on textile industry transformation, concentrate on innovation-driven development, advance high-quality development, and create hundred-billion-level industrial clusters and world-class high-end textile new material bases.

RESEARCH LIMITATIONS AND FUTURE PROSPECTS

Research limitations

This article achieved certain outcomes in advancing research on the coupling coordination relationship between the digital economy and green development in the textile industry. However, several limitations remained:

This research focused solely on Shandong Province as the study subject. Although Shandong Province possessed certain representativeness in textile industry development, the universality and generalisability of the research conclusions required further verification. Significant differences existed in economic development levels, industrial structures, and policy environments across different regions, which could potentially influence the manifestation of coupling coordination relationships between the digital economy and textile industry.

Despite employing the entropy method for objective weighting, certain subjectivity remained in the indicator selection and system construction process. Particularly regarding indicator selection in the "green development" dimension, the complexity of environmental impacts in the textile industry may not have been comprehensively reflected, with key environmental indicators such as carbon emissions, water resource consumption, and waste treatment requiring further refinement.

Due to statistical data availability limitations, some key indicators potentially exhibited gaps or insufficient precision. Particularly against the backdrop of rapid digital economy development, traditional statistical systems may not have fully captured the genuine progress of digital transformation, with quantification of new business models such as the platform economy and sharing economy remaining challenging.

This research primarily focused on static calculation and trend analysis of coupling coordination degrees, with inadequate exploration of deep-level issues such as dynamic mechanisms, transmission pathways, and influencing factors of the mutual interaction between the digital economy and green development in the textile industry.

The study failed to adequately consider the influence of policy factors on coupling coordination development, with analysis of synergistic effects of digital economy policies, environmental policies, and industrial policies requiring strengthening.

Future prospects

Based on the aforementioned limitations, future research could be further deepened and expanded in the following directions:

(1) Expanding research scope to enhance conclusion universality

Future research could extend the scope to the national level or conduct cross-regional comparative studies. Through comparative analysis of differences in coupling coordination development between the digital economy and the textile industry across different regions, exploration of regional characteristics of influencing factors would provide theoretical support for formulating differentiated policies.

(2) Improving indicator systems to enhance measurement precision

Regarding indicator system construction, green development indicators should be further refined, incorporating more precise environmental indicators such as carbon footprint, water footprint, and recycling rates. Simultaneously, as the connotation of the digital economy continues to enrich, dynamic adjustment and optimisation of digital economy evaluation indicator systems would be necessary to better reflect actual digitalisation transformation levels.

(3) Deepening mechanism research to explore action pathways

Future research should focus more attention on the internal mechanisms of coupling and coordination between digital economy and green development in the textile industry, employing structural equation modelling, panel vector autoregressive models, and other methods to thoroughly analyse causal relationships, transmission pathways, and influence mechanisms between the two.

(4) Integrating policy analysis to assess policy effects

Policy factors should be incorporated into research frameworks, utilising quasi-natural experiments, difference-in-differences methods, and other approaches to evaluate the impact effects of relevant policies on coupling coordination development, providing empirical evidence for policy formulation and optimisation.

(5) Conducting international comparative research

Through comparative analysis with developed countries' experiences in textile industry digitalisation transformation and green development, advantages and deficiencies in China's digital economy and textile industry integration development could be identified, providing international experience for China's textile industry high-quality development.

(6) Establishing early warning mechanisms for dynamic monitoring

Based on coupling coordination degree models, early warning mechanisms should be constructed to establish dynamic monitoring systems for digital economy and textile industry green development, providing timely decision-making references and risk warnings for government departments and enterprises.

(7) Expanding research methods to enhance research depth

Future research could attempt to utilise emerging technological methods such as machine learning and big data analysis, combined with traditional econometric methods, to enhance research scientific rigour and precision. Simultaneously, qualitative research methods such as field investigations and case analyses could deepen understanding of coupling coordination development mechanisms.

In conclusion, research on the coupling coordination relationship between digital economy and green development in the textile industry possesses significant theoretical value and practical significance. Future research should overcome existing limitations, continuously improve research methods, expand research perspectives, and provide more robust theoretical support and practical guidance for promoting China's textile industry green high-quality development in the digital era.

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