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Research on the Synergistic Development Model of Cotton and Textile Industry Based on Digital Supply Chain: A Case Study of Xinjiang, Western China

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Article

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ABSTRACT

This paper investigates the synergistic development model of the cotton and textile industry in Xinjiang, Western China's core cotton region, driven by the digital supply chain. The research aims to address the challenges of inadequate information sharing, low collaboration efficiency, and weak risk resistance in the traditional industrial chain. A synergistic development model based on the digital supply chain is proposed, encompassing a technology-driven layer, a data-driven layer, and a business-driven layer. Taking the cotton and textile industry in Xinjiang as a case study, this paper collects and analyzes panel data from 2011 to 2021. A comprehensive evaluation index system for the synergistic development level is constructed, and the coupling coordination degree model is used to empirically analyze the synergistic development level in the region. The results show that the overall synergistic development level of the cotton and textile industry in Xinjiang has shown a general upward trend and reached the intermediate coordination stage by 2021, although the overall level is still not high. The synergy between the Cotton and Textile Industry Subsystem and the Digital Supply Chain Subsystem has not yet been fully realized. Based on the research findings, this paper proposes corresponding countermeasures and suggestions from the perspectives of government, industry, and enterprises, aiming to provide a theoretical reference and practical guidance for the high-quality development of the cotton and textile industry in Xinjiang, with implications for other regions in Western China.

KEYWORDS

cotton and textile industry, synergistic development, digital supply chain, coupling coordination degree model, western China

INTRODUCTION

The cotton and textile industry is a traditional pillar and an important "people's livelihood"industry in China, playing a significant role in vitalizing the market, expanding exports, absorbing employment, and promoting rural revitalization [1,2]. Western China, especially the Xinjiang region, is the main cotton-producing area in the country, possessing unique resource endowments [3]. Given Xinjiang's dominant role in the nation's cotton production, it serves as the most critical and representative case for studying the cotton and textile industry's supply chain in Western China. However, for a long time, the development of the cotton and textile industry in Western China has faced challenges such as a long industrial chain, disconnected production and sales, and low value-added products. The traditional supply chain management model can no longer meet the modern textile market's demands for rapid response, personalized customization, and green sustainability [4,5].

In recent years, with the rapid development of new-generation information technologies like big data, cloud computing, and the Internet of Things, the digital supply chain has emerged as a new paradigm for supply chain management [6,7]. Characterized by being data-driven, with networked collaboration and intelligent decision-making, the digital supply chain can effectively improve the operational efficiency and market responsiveness of the industrial chain [8,9]. Therefore, exploring the synergistic development model of the cotton and textile industry based on the digital supply chain holds significant theoretical and practical importance for understanding the transformation, upgrading, and high-quality development of the industry in Western China. This paper focuses on this synergistic development, aiming to construct a corresponding model and empirically analyze its level and influencing factors, thereby providing a theoretical basis and practical guidance for the industry's digital transformation.

LITERATURE REVIEW

Digital Supply Chain

The concept of the digital supply chain has emerged with the deep integration of digital technology and supply chain management. Scholars generally believe that the digital supply chain is a new type of supply chain that utilizes modern information technology to achieve data-driven operations, intelligent decision-making,

and collaborative optimization [8,10]. Compared to the traditional supply chain, the digital supply chain offers significant advantages in information sharing, process visualization, flexible response, and risk management [8,11]. In the textile industry, its application can effectively mitigate the "bullwhip effect," reduce inventory costs, and improve the rapid response capability to the market.

Industrial Synergy

Industrial synergy refers to the phenomenon where different industries, or different links within the same industry, achieve a "1+1>2" effect through mutual cooperation and resource integration [12,13]. Research on this topic mainly focuses on its connotation, measurement, and influencing factors. In the textile sector, the synergy between the upstream cotton industry and the downstream textile industry is crucial for the healthy development of the entire industrial chain [14]. Some scholars have studied the synergistic development of the textile industry from the perspectives of the industrial chain, innovation chain, and value chain.

Synergistic Development of Cotton and Textile Industry

The synergistic development of the cotton and textile industry is a classic issue in industrial economics. While existing research has extensively discussed its importance and realization paths, most of it is based on the traditional industrial chain perspective, with less consideration for the synergistic relationship withthe digital supply chain [15,16]. In the context of the digital economy, how to leverage the digital supply chain to promote this synergy has become a new research topic. This paper attempts to integrate the digital supply chain into the research framework, construct a corresponding theoretical model, and conduct an empirical analysis to enrich and develop the existing research.

Literature on Measurement and Index Selection

A review of the existing literature reveals established approaches for quantifying the development of the subsystems relevant to this study.

For the industrial subsystem, scholars commonly assess development from a multi-dimensional perspective, typically encompassing: 1) Industrial Scale (measured by indicators such as total output value or proportion of industrial output); 2) Industrial Structure (measured by the ratio of planting areas or output of specific

products like chemical fibers); and 3) Industrial Benefit (measured by economic outcomes like industry profit and export value).

For the digital supply chain subsystem, direct measurement of advanced technology (e.g., IoT, AI) adoption at a macro-level is difficult. Therefore, existing research often relies on proxy indicators to represent the digital environment. This approach, as adopted by numerous studies, typically evaluates: 1) Digital Infrastructure (using metrics like optical cable length and mobile user penetration); 2) Digital Application Level (using metrics like e-commerce volume and information technology employment); and 3) Development Potential (using metrics like IT fixed asset investment and patents granted).

Based on this established literature, and adhering to the principles of scientificity, operability, and data availability for the Xinjiang region, this paper constructs its evaluation index system (as shown in Table 1) to measure the two subsystems.

Table 1. Comprehensive Evaluation Index System for the Synergistic Development of the Cotton and Textile Industry in Xinjiang

Subsystem	Indicator Layer	Indicator	Unit	Attribute
Cotton and Textile Industry	Scale of Development	Total output value of the cotton and textile industry	100 million CNY	+
		Proportion of textile industry in total industrial output value	%	+
	Structure of Development	Ratio of cotton planting area to crop planting area	%	+
		Output of chemical fiber	10,000 tons	+
	Benefit of Development	Profit of the cotton and textile industry	100 million CNY	+
		Export value of textiles and apparel	100 million USD	+
Digital Supply Chain	Infrastructure	Length of optical cable lines	10,000 km	+
		Number of mobile phone users	10,000 households	+

	Application Level	E-commerce transaction volume	100 million CNY	+
		Number of employees in the information technology service industry	10,000 people	+
	Development Potential	Investment in fixed assets of the information technology industry	100 million CNY	+
		Number of patents granted in the information technology industry	pieces	+

CONNOTATION AND MODEL OF SYNERGISTIC DEVELOPMENT

Connotation of Synergistic Development

The synergistic development of the cotton and textile industry based on the digital supply chain refers to the process in which upstream cotton planting, ginning, and warehousing are closely linked with downstream textile manufacturing, brand design, and retail sales through a digital supply chain platform. This process achieves data interoperability, business collaboration, and value co-creation, thereby enhancing the overall competitiveness and sustainable development capability of the industrial chain. This synergistic development is mainly reflected in three aspects:

- Information Synergy: Breaking down information silos and achieving real-time sharing of data on cotton quality, inventory, logistics, and textile market demand.
- Business Synergy: Optimizing business processes, such as joint procurement, collaborative production, and coordinated logistics, to improve operational efficiency and reduce costs.
- Value Synergy: Promoting the co-creation and sharing of value in the industrial chain through brand building, product innovation, and service enhancement.

Synergistic Development Model

Based on the above connotation, this paper constructs a synergistic development model, as shown in Figure 1.

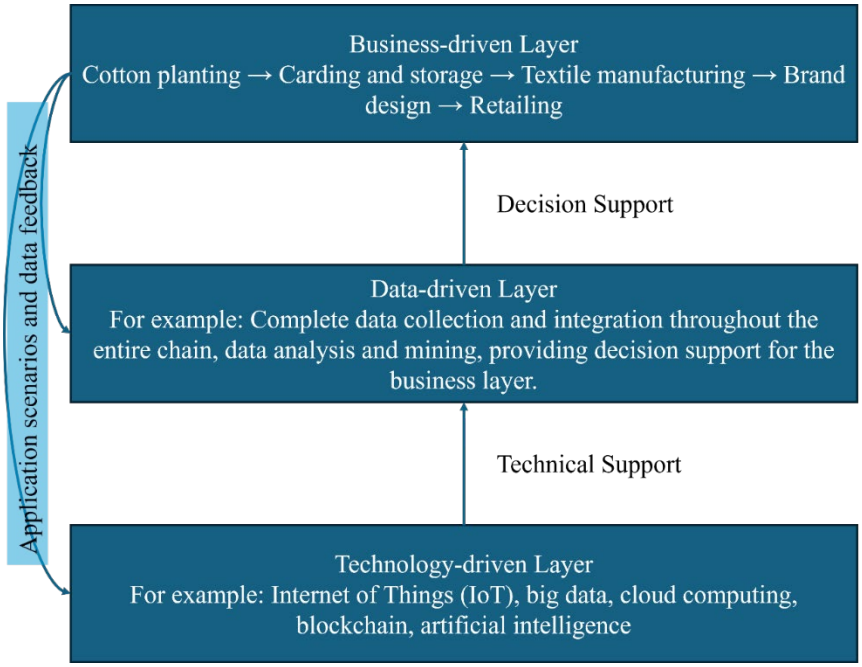

Figure 1. Synergistic Development Model of Cotton and Textile Industry Based on Digital Supply Chain

The model consists of three layers:

- Technology-driven Layer: This is the foundation of the digital supply chain, including key technologies such as the Internet of Things (IoT), big data, cloud computing, blockchain, and artificial intelligence. These technologies provide the means for data collection, transmission, storage, and analysis.
- Data-driven Layer: This is the core of the digital supply chain. Through the technology-driven layer, massive data from all links of the industrial chain are collected and integrated. Data analysis and mining are then carried out to provide decision support for the business-driven layer.
- Business-driven Layer: This is the application layer of the digital supply chain, which runs through the entire process of the cotton and textile industry, including cotton planting, ginning, warehousing, logistics, textile manufacturing, brand design, and retail sales. Driven by data, this layer achieves business process optimization and business model innovation.

The three layers are interconnected and mutually reinforcing. The technology-driven layer provides technical support for the data-driven layer, the data-driven layer provides decision support for the business-driven layer, and the business-driven layer provides application scenarios and data feedback for the other two layers, thus forming a closed loop of synergistic development.

EMPIRICAL RESEARCH ON THE SYNERGISTIC DEVELOPMENT OF COTTON AND TEXTILE INDUSTRY IN XINJIANG

Research Area and Data Sources

This paper takes the Xinjiang Uygur Autonomous Region, the core area of the cotton and textile industry in Western China, as the research object for the period of 2011 to 2021. The data are mainly sourced from the "Xinjiang Statistical Yearbook," the "China Textile Industry Yearbook," the National Bureau of Statistics, and the China Cotton Association website. The interpolation method was used to supplement individual missing data points.

Construction of the Evaluation Index System

Following the principles of scientificity, systematicness, and operability, this paper constructs a comprehensive evaluation index system from two dimensions: the cotton and textile industry subsystem and the digital supply chain subsystem. When constructing the indicator system, it is necessary to acknowledge the limitations in obtaining data at the macro-regional level.

Firstly (for the digital supply chain indicators), for the period under study (2011-2021), we were unable to obtain long-term panel data to measure the specific application of specific digital supply chain technologies (such as the Internet of Things, blockchain, cloud SCM) in the industry. Therefore, this study used regional digital infrastructure (such as the length of optical cable lines, the number of mobile phone users) and the overall scale of the digital economy (such as e-commerce transaction volume, investment in information technology industry) as proxy variables to represent the necessary technological foundation and enabling environment for the development of DSC (rather than directly measuring its specific adoption and maturity in enterprises).

Secondly (for the value synergy indicators), this data limitation also applies to measuring the "value synergy" as defined in the theoretical model. We were unable to obtain specific indicators such as product innovation rate or joint R&D expenditure for value co-creation. Therefore, this study used "profit in the cotton textile industry" and "export value of textiles and clothing" as the measurement standards for "development benefits". These indicators should be interpreted as the final economic outcomes and macro-level manifestations of the collaborative effect, rather than a direct measurement of the collaborative process of value co-creation.

Research Methods

Entropy Method

- To avoid the subjectivity of manual weighting, this paper uses the entropy method to determine the weight of each indicator. The specific steps are as follows:
- Data Standardization: Let x_{ij} be the value of the j-th indicator in the i-th year. For positive indicators: $x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$.
- Calculate Proportions: Calculate the proportion of the indicator value: $p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}}$.
- Calculate Information Entropy: $e_j = -k \sum_{i=1}^{m} p_{ij} \ln(p_{ij})$,where $k = \frac{1}{\ln(m)}$ and m is the number of years.
- Calculate Redundancy: The information redundancy is calculated as $d_j = 1 - e_j$.
- Calculate Weights: The final weight of each indicator is $w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$.

Coupling Coordination Degree Model

This model is used to measure the degree of interaction and coordination between the two subsystems. The classification of coupling coordination degree is shown in Table 2.

- Comprehensive Evaluation Index:$U_k = \sum_{j=1}^{n} w_j x'_{ij}$. Here, U_1 and U_2 are the comprehensive indices for the cotton and textile industry and digital supply chain subsystems, respectively.
- Coupling Degree (C):$C = 2 \times \frac{\sqrt{U_1 \times U_2}}{U_1 + U_2}$.
- Coupling Coordination Degree (D):$D = \sqrt{C \times T}$, where T is the comprehensive coordination index,$T = \alpha U_1 + \beta U_2$. In the coupling coordination degree model, the determination of weights α and β often relies on expert opinions or other weighting methods. However, when there is a lack of prior theoretical basis or consensus to distinguish the importance of the two subsystems, this paper follows the common practice in the literature and sets α = β = 0.5. This establishes a (neutral methodological baseline, allowing the model to reveal the relative development and coordination status of the two systems based on experience without pre-setting imbalance, rather than treating it as an assumption that the two are

"equally important" in terms of economy. The reliability of this benchmark setting will be verified in the subsequent robustness tests.

Table 2. Classification of Coupling Coordination Degree

Coupling Coordination Degree (D)	Level
0.0 ≤ D < 0.1	Severe Dysregulation
0.1 ≤ D <0.2	Moderate Dysregulation
0.2 ≤ D < 0.3	Mild Dysregulation
0.3 ≤ D < 0.4	On the Verge of Dysregulation
0.4 ≤ D < 0.5	Barely Coordinated
0.5 ≤ D < 0.6	Primary Coordination
0.6 ≤ D < 0.7	Intermediate Coordination
0.7 ≤ D < 0.8	Good Coordination
0.8 ≤ D < 0.9	High-quality Coordination
0.9≤ D ≤ 1.0	Extreme Coordination

Results and Analysis

Analysis of Subsystem Development Levels

As shown in Figure 2, the comprehensive development level of the cotton and textile industry subsystem in Xinjiang showed a gradual upward trend, despite some fluctuations, from 2011 to 2021, mainly due to strong national policy support and continuous industrial structure optimization. The digital supply chain subsystem also showed a steady upward trend, which accelerated significantly after 2015 with the implementation of national strategies like "Made in China 2025" and "Internet Plus". As clearly shown in Figure 2, this accelerated growth in the digital supply chain subsystem, particularly post-2015, led to a near convergence of the

two indices by 2021. This indicates that the development gap between the systems, while persistent for most of the decade, was rapidly closing by the end of the study period.

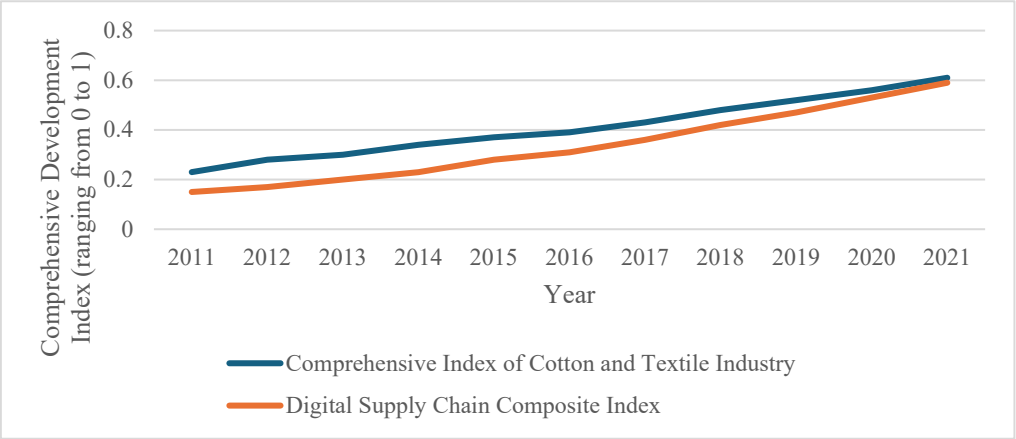

Figure 2. The comprehensive development level of Xinjiang's cotton and textile industry and its digital supply chain subsystem (2011 - 2021)

Analysis of the Coupling Coordination Degree

As shown in Figure 3, the coupling coordination degree has generally trended upward, albeit with volatility, improving from "mild dysregulation" in 2011 to "intermediate coordination " in 2021. This indicates that the degree of integration between the two has been continuously improving. However, the overall coordination level is still not high and has significant room for improvement. The development can be divided into two stages:

- 2011-2016 (Dysregulation and Transition Period): In this stage, the development of the digital supply chain was relatively lagging, and its empowering effect on the cotton and textile industry was not yet apparent, keeping the coordination degree at a low level.
- 2017-2021 (Coordinated Development Period): With the rapid development of the digital economy, the integration of the two systems deepened, and the coordination degree steadily increased, entering a period of intermediate coordination. An analysis of the results suggests that the development of the digital supply chain still lags behind that of the cotton and textile industry, which has become a major factor associated with the difficulty in further improvement of the synergistic development level.

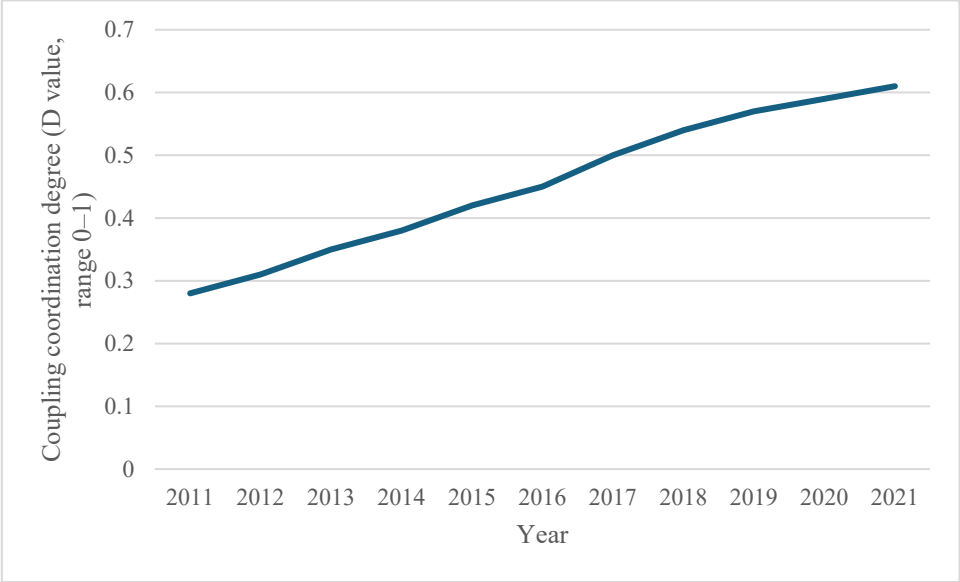

Figure 3. The Coupling Coordination Degree of Xinjiang Cotton and Textile Industry with Digital Supply Chain (2011 - 2021)

Robustness Test

To test the reliability of the weight setting (α = β = 0.5) in the model, a robustness test was conducted. The weights were adjusted to create two asymmetric scenarios: (1) α =0.6, β =0.4 (emphasizing the cotton and textile industry) and (2) α =0.4, β =0.6 (emphasizing the digital supply chain). After recalculating the coupling coordination degree, it was found that although the absolute D-values changed slightly, the overall trend over time (a fluctuating increase) and the distinct stage characteristics remained highly consistent with the baseline scenario. This indicates that the core conclusions of this study are robust and not substantially altered by minor adjustments to the weights. More importantly, even under these two asymmetric scenarios (emphasizing the industry or emphasizing the digital supply chain), the core finding that the digital supply chain subsystem's development index consistently lags behind that of the cotton and textile industry remains unchanged. This confirms that the paper's main conclusion—that the lagging digital supply chain is a key restricting factor—is a robust finding derived from the data, and not merely an artifact of the 0.5/0.5 baseline assumption. Therefore, the baseline scenario is considered reliable for this analysis.

CONCLUSIONS AND SUGGESTIONS

Conclusions

This paper constructs a synergistic development model of the cotton and textile industry based on the digital supply chain and conducts an empirical analysis using the cotton and textile industry in Xinjiang as an example. The main conclusions are as follows:

- The construction of a synergistic development model of the cotton and textile industry based on the digital supply chain has important theoretical and practical value for promoting the high-quality development of the industry.
- The empirical analysis confirms that while the coupling coordination between Xinjiang's cotton and textile industry and its digital supply chain has improved over the decade, it remains at a relatively low level of ' intermediate coordination.' A persistent gap exists where the development of the digital supply chain subsystem lags behind the industrial subsystem, indicating that deep integration has not yet been achieved. A notable characteristic is the dynamic gap between the two subsystems. Although the digital supply chain's comprehensive index has historically lagged behind the cotton and textile industry, its rapid growth rate led to a significant narrowing of this gap and a near convergence by 2021. This historical asynchronicity, despite the recent catch-up, helps explain why the overall coordination level is still in a intermediate coordination level.

Limitations and Future Research

Finally, the limitations of this study must be acknowledged. As noted in the index construction, the empirical analysis relied on regional-level data for digital infrastructure as proxies for the 'digital supply chain subsystem' due to data availability. Consequently, the empirical results reflect the synergy between the textile industry and the broader regional digital environment rather than the specific, technologically-advanced DSC model proposed theoretically. Similarly, the measurement of 'Value Synergy' was operationalized using macro-level outcomes (profit and export) instead of direct metrics of collaborative innovation (like joint R&D), due to data unavailability. Future research should strive to develop more granular metrics or conduct case studies to measure the direct impact of specific DSC technologies and the precise mechanisms of value co-creation as data becomes more accessible.

Most significantly, this study was unable to empirically measure the core challenges of 'inadequate information sharing' and 'low collaboration efficiency' identified in the abstract. Due to the unavailability of macro-data on firm-level collaboration, data interoperability, or shared platform usage, our empirical model lacks direct indicators for these critical DSC functions. Consequently, while our findings reflect the coordination of the development levels of the two subsystems, they cannot directly evaluate the extent to which the specific problems of information sharing and collaboration are being solved. Future research, likely through firm-level surveys or specific case studies, is necessary to measure the true adoption and impact of these collaborative mechanisms.

Additionally, the study's timeframe (2011-2021), resulting in a sample size of n=11, provides a clear overview of the general trend but limits the ability to perform more fine-grained econometric analyses, such as identifying specific structural breaks or technological inflection points that may have occurred with the acceleration of digitalization post-2015.

Suggestions

Based on the above conclusions, this paper proposes the following suggestions:

Government Level

- Provide targeted fiscal incentives for upstream digitization: Instead of broad subsidies, the government should establish targeted fiscal incentives (e.g., tax credits, dedicated grants) for cotton ginning, carding, and warehousing enterprises. These incentives should be specifically aimed at the adoption of digital technologies for quality testing, inventory management, and data upload, addressing the upstream bottlenecks.Improve infrastructure: Accelerate the construction of new infrastructure such as 5G networks and industrial internet in Western China to lay a solid foundation for the development of the digital supply chain.

Lead the standardization of raw cotton data exchange: When building the public service platform, the government must prioritize the creation and enforcement of a unified data exchange standard for raw cotton. This standard should cover quality metrics (e.g., micronaire, length, strength), origin, and moisture content, ensuring data interoperability from the point of ginning.

Industry Level

- Establish a mandatory quality traceability standard: The industry association must move beyond voluntary guidelines to formulate a binding 'seed-to-garment' quality traceability standard. This standard should leverage technologies like blockchain and IoT to ensure immutable data records, connecting upstream cotton quality directly to downstream textile manufacturing and enhancing value.
- Promote industry-university-research cooperation: Encourage cooperation between textile enterprises, universities, and research institutes to jointly develop key technologies for the digital supply chain.
- Strengthen talent training: Cultivate a cohort of composite talents who are proficient in both textile technology and digital technology.

Enterprise Level

- Prioritize investment in traceability and integration: Enterprises, especially upstream ginning and warehousing firms, must move beyond enhancing general 'digital awareness.' They should prioritize investment in specific systems (e.g., IoT sensors, warehouse management systems) that enable real-time data capture for quality and inventory, and actively integrate these systems with the broader industry data platform.
- Increase investment in information technology: Increase investment in information technology, introduce advanced digital supply chain management systems, and improve the level of enterprise informatization.
- Strengthen cooperation with upstream and downstream enterprises: Actively participate in the construction of the digital supply chain platform, strengthen cooperation with upstream and downstream enterprises, and jointly build a collaborative and win-win industrial ecosystem.

Author Contributions

Kaixuan Gui designed, collected and analyzed the data, and drafted the manuscript. Kaixuan Gui conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Kaixuan Gui participated fully in the work, take public responsibility for appropriate

portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflicts of Interest

The author declares no conflict of interest.

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Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

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Not applicable.

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