

Original Research Articles

How Digital Transformation of Chinese Fishery Listed Companies Enhances Supply Chain Efficiency

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To cope with the complex and ever-changing business environment, improving supply chain efficiency is an important issue that needs to be studied now. The development of digital technologies provides a new avenue for enhancing supply chain efficiency. Based on the theory of information asymmetry and the TOE framework, this paper uses panel data of 9 Chinese A-share listed fishing companies from 2015 to 2021 to construct a fixed-effects model and explore digital transformation's impact on supply chain efficiency. The results indicate that digital transformation significantly improves supply chain efficiency, and this conclusion remains robust after a series of robustness tests. On this basis, the paper further verifies the positive impact of digital transformation on supply chain efficiency using the fsQCA method based on the TOE framework and provides pathways for improvement. The findings of this study provide a theoretical basis for promoting the digital transformation of Chinese fishery companies and improving supply chain efficiency. Based on research on China's fisheries, this study further explores the implications of digital transformation for the efficiency of foreign fisheries supply chains. Digital transformation is a critical pathway to enhancing the efficiency of global fisheries supply chains. Foreign fisheries can draw on the digital research of China's fisheries supply chains, integrating their characteristics to promote the intelligent upgrading of their supply chains.

INTRODUCTION

In recent years, with the changing external environment, the uncertainty of global supply chains has increased significantly, and many enterprises are facing the risk of supply chain disruptions.¹ The challenges to supply chain security and stability have become more severe. Additionally, the collaboration model between stakeholders in the supply chain, including manufacturers, suppliers, and customers, is gradually shifting from a "chain" structure to a "network" structure, making the supply chain system increasingly complex.² Improving supply chain efficiency and enhancing the ability to respond to supply chain disruption risks have become important issues in supply chain management.

The development of digital technologies enables enterprises to create data-driven intelligent decision-making capabilities, improving overall operational efficiency and collaboration efficiency across the upstream and downstream of the industry chain. Digital transformation refers to the application of digital technologies in the production and

management processes of enterprises,³ aiming to enhance operational efficiency. For example, digital transformation promotes exploratory innovation.⁴ Some scholars have also explored the impact of digital transformation on industries like manufacturing, suggesting that digital transformation significantly enhances operational efficiency in manufacturing.⁵ In the field of supply chain management, many scholars have confirmed that digital transformation helps improve supply chain resilience.⁶

As the world's largest producer and consumer of aquatic products, China's fisheries play a vital role in the national economy and food security. However, the traditional fishery supply chain has long faced numerous challenges, such as information asymmetry, fragmented processes, significant resource waste, and insufficient ability to respond to market fluctuations. Under traditional supply chain management mechanisms, delays and distortions in information transmission are common, making it difficult for companies to track the source, quantity, and quality of catches in real time or accurately predict market demand. This leads to si-

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multaneous issues of overstocking and shortages, resulting in severe resource waste. Inefficient logistics, lacking intelligent scheduling and route optimization, further reduce transportation efficiency and compromise product freshness, weakening market competitiveness. Therefore, digital transformation is not optional for fishery enterprises but a necessity for survival and growth. Only by applying digitalization technology can overcome the efficiency bottlenecks of traditional supply chain management, enabling optimal allocation of fishery resources and sustainable industry development.⁷

Around 2015, the global digital transformation began to accelerate. From 2015 to 2021, China introduced a series of policies to support the digital transformation of its fisheries sector. Today, China's fisheries industry stands at the forefront of the digital revolution. Fishery companies use digital technologies like big data, the Internet of Things (IoT), and artificial intelligence (AI) to improve the precision of fishery production, optimize supply chain management, and enhance sustainable development capabilities.⁸ During this period, the supply chain management of fishery enterprises has significantly improved. According to the Ministry of Agriculture and Rural Affairs, the cold chain circulation rate of aquatic products in China increased from 23% in 2015 to over 35% in 2021. Additionally, the loss rate of aquatic products dropped from 15% in 2015 to around 8% in 2021, reflecting further optimization of supply chain management. However, whether the improvement in fishery supply chain efficiency is linked to digital transformation, and how digital transformation enhances this efficiency, remains underexplored in academic research field. Investigating the impact of digital transformation on fishery supply chain efficiency is not only an assessment of digital technology's effectiveness but also a reflection on the future direction of the fisheries industry. This research is crucial as it can reveal how digital technologies address challenges such as information silos, resource waste, and slow response times in traditional fishery supply chains, providing a roadmap for the transformation and upgrading of fishery enterprises. Moreover, the findings will offer policymakers evidence to promote the development of digital infrastructure in fisheries, supporting sustainable resource utilization and the growth of the industry.

Therefore, this paper selects data from Chinese listed fishery companies from 2015 to 2021 as the research sample, based on the theory of information asymmetry, and constructs a fixed-effects panel data model to explore the impact of digital transformation on supply chain efficiency. Furthermore, based on the TOE framework, this paper uses the fsQCA method to examine the pathways through which digital transformation in fishery companies affects supply chain efficiency. The findings of this study suggest that digital transformation significantly improves the supply chain efficiency of listed fishery companies. The contributions of this research are as follows: (1) The research findings provide empirical evidence for the impact of digital transformation on the supply chain efficiency of Chinese listed fishery companies, adding empirical evidence from the Chinese market to the existing research. (2) This study verifies the

specific pathways of digital transformation improving supply chain efficiency using the fsQCA method under the TOE framework, providing recommendations for improving the efficiency of the fishery supply chain.

The remaining structure of this paper is as follows: Research materials and methods, Results, and Discussion.

RESEARCH MATERIALS AND METHODS

HYPOTHESIS DEVELOPMENT

Under the premise of increasing global supply chain disruption risks, digital transformation has become a key driving force for improving supply chain efficiency and stabilizing supply chain relationships. As a complex network connecting internal and external resources and coordinating production and consumption, the supply chain directly impacts the survival and development of enterprises.

From the perspective of information asymmetry theory, digital transformation can effectively reduce the degree of information asymmetry among participants in the supply chain,⁹ which is equally applicable in the supply chains of listed fishery companies. The comprehensive transmission and sharing of information are crucial for enterprise decision-making. Big data technology enables real-time sharing of vast and accurate information across various nodes in the supply chain of fishery-listed companies, including the growth conditions of aquatic products in breeding bases, feed inventory levels, production progress in processing plants, and the cold-chain status of seafood during transportation. This helps reduce issues caused by information opacity, such as the bullwhip effect, inventory accumulation, or shortages, improving the speed and accuracy of the supply chain's response¹⁰. For example, by analyzing market sales data, companies can predict market demand in advance, reasonably arrange breeding plans and production schedules, and avoid inventory accumulation caused by blind production.

In logistics and distribution, digital transformation also shows significant advantages. The Internet of Things (IoT) technology, by deploying sensors at various stages, such as goods, transportation tools, and warehouses, enables the comprehensive perception and intelligent tracking of logistics elements.^{11,12} This not only provides real-time tracking of the location and status of goods but also allows for the optimal planning of delivery routes based on data analysis, reducing transportation time and costs and ensuring timely and complete delivery of goods, thereby providing a solid foundation for efficient supply chain operations. For example, during transportation, sensors can monitor environmental parameters like temperature and humidity inside the vehicle. In case of any anomalies, alarms are triggered promptly to ensure the quality and safety of seafood.

From a collaborative perspective, digitalization has created conditions for deeper collaboration among the members of the fishery supply chain.¹³ Technologies such as cloud computing and blockchain provide listed fishery companies with secure and efficient collaborative platforms, enabling different enterprises to cooperate closely across

organizational boundaries in areas such as product development, production planning, and quality control. For example, companies like Dahu Co., Ltd. can use cloud computing platforms to share resources such as breeding technology and market information, jointly conducting research projects to improve the technical level and product quality of fishery farming. Taking blockchain technology as an example, its distributed ledger function ensures the authenticity and immutability of data, enhancing trust between enterprises and facilitating smooth collaboration processes. This makes the supply chain operate efficiently like an organic whole, collaboratively responding to market changes and improving efficiency. For instance, the Zero Koi platform uses blockchain technology to provide a controllable, trustworthy, and scalable data flow system for the fishery industry chain, promoting smooth cooperation between upstream and downstream enterprises in seedling supply, product sales, and other areas, making the fishery supply chain run efficiently like an organic whole and respond collaboratively to market changes, thereby achieving efficiency improvements.

Based on the above analysis, we propose the following hypothesis.

H: Digital transformation has a significant positive impact on the fishery supply chain efficiency.

MODEL CONSTRUCTION

In this study, we referred to the research by He et al.¹⁴ and Li et al.¹⁵ and constructed a fixed-effects model to explore the impact of digital transformation on supply chain efficiency. We controlled for year and company-specific fixed effects. For the control variables, the subscripts *i* and *t* represent company *i* and year *t*, respectively.

$$SCE_{i,t} = \beta_0 + \beta_1 DIG_{i,t} + \beta_2 \sum Controls_{i,t} + year_t + id_i + \varepsilon_{i,t}$$

DATA PREPROCESSING

In this study, since the operational conditions and supply chain efficiency of ST and ST* companies may significantly deviate from normal levels, potentially compromising the representativeness of the research findings, it is essential to ensure the financial health, data integrity, and operational stability of the study samples. This approach enhances the scientific rigor, accuracy, and reliability of the research. we excluded the listed companies under ST and ST* and companies with incomplete or severely missing data disclosures. Additionally, to prevent the influence of outliers, we filtered all continuous variables at the 1% and 99% levels.

DATA SOURCES

Around 2015, the global wave of digital transformation began to accelerate, particularly in China, where the government introduced the “Internet Plus” strategy to promote the digital and intelligent transformation of various industries. Data from 2015 to 2021 comprehensively reflects the process of fisheries digital transformation from its inception to initial maturity, while also considering data avail-

ability, the concentration of policy support, and the critical nature of industry changes. Research focusing on this period not only holds theoretical significance but also provides practical guidance for the digital transformation of fisheries supply chains. This study selected a sample of 9 Chinese A-share listed fishery companies from 2015 to 2021, as shown in Table 1, and the analysis was conducted using Stata 18. The supply chain efficiency data mainly comes from the CSMAR database, while financial and digital transformation data for these companies were partly sourced from CSMAR and partly from the annual reports available in the CNINFO database.

INDICATOR SELECTION

SUPPLY CHAIN EFFICIENCY

Supply chain efficiency refers to the ability of a supply chain system to transform raw materials into final products and deliver them to customers with the minimum resource input while achieving the maximum output. In this study, we follow the approach of He et al.¹⁴ and use inventory turnover days to measure supply chain efficiency. The higher the inventory turnover rate and the fewer the inventory turnover days, the higher the supply chain efficiency of the enterprise. The specific calculation formula is as follows:

$$\text{Supply Chain Efficiency} = \ln \left(\frac{365}{\text{Inventory Turnover Ratio}} \right)$$

DIGITAL TRANSFORMATION

We refer to the method of Wu et al.¹⁶ in this study, where Python is used to mine and capture keywords related to digital transformation in the annual reports of companies. The frequency of these keywords is calculated, and the higher the frequency, the higher the level of digital transformation. This method is both more comprehensive and accurate. The specific steps are as follows:

1. Manually download the annual reports of fishery industry companies from 2015 to 2021 from the Cninfo database.
2. Refer to Wu et al.¹⁶ to define a dictionary of words related to digital transformation.
3. Extend the dictionary into Python’s “jieba” dictionary and use machine learning methods to perform text analysis on the “Management Discussion and Analysis” (MD&A) section of the companies’ annual reports. The ratio of the keyword frequency to total word frequency is used to measure digital transformation. To facilitate research, this index is further expanded by a factor of 100. The larger the index value, the higher the level of digital transformation of the enterprise.

CONTROL VARIABLES

This study follows the research of Mikhaylova et al.,¹⁷ Zhang,¹⁸ and Zhang et al.¹⁹ in selecting the following control variables: company size (size), debt-to-equity ratio

Table 1. Basic Information of Listed Fishery Companies

Company name	Stock code	Listed year	Business scope	Total Assets in 2021 (100 million yuan)	Total Revenue in 2021 (100 million yuan)
CNFC OVERSEAS FISHERIES Co.,Ltd.	000798	1998	Marine fishing 、 processing and storage of aquatic products 、 import and export of fishing materials such as fishing boats and fishing machines	20.5	5.2
Yuan Longping High-Tech Agriculture Co.,Ltd.	000998	2000	Taking hybrid rice as the core and seed industry as the main business direction. Mainly through promoting the "Rice Fishery Digital Ecological Circular Agriculture" model involving fisheries	120	35
ZONECO GROUP Co.,Ltd.	002069	2006	With the seed industry of marine treasures, mariculture, and marine food as its main business, it integrates related diversified industries such as cold chain logistics and fishing equipment	25	20
Shandong Dongfang Ocean Science & Technology Co., Ltd.	002086	2006	It is mainly engaged in businesses such as mariculture, food processing, and marine fishing	30	10
Quanyin High-tech Seed Industry Co.,Ltd.	300087	2010	Engage in the research, development, production, and sales of crop seeds, and supply raw materials for fishery feed	50	25
Hainan Shennong Seed Industry Science and Technology Co., Ltd.	300189	2011	It mainly provides hybrid rice seed breeding, seed production, sales, and technical services. In the fishery sector, the business mainly focuses on the integration of the aquatic seed industry	15	5
Shanghai Kaichuang International Marine Resources Co., Ltd.	600097	1997	It is mainly engaged in pelagic fishery, marine food processing, fishery technical services and other businesses	40	20
Dahu Co.,Ltd.	600257	2000	It encompasses fields such as aquaculture, aquatic product processing, aquatic product trade, and biopharmaceuticals. Additionally, it also involves businesses like recreational fisheries and water-based tourism	30	10
Shandong Haodangjia Ocean Development Co., Ltd.	600467	2004	Engage in the research, development, production and sales of marine food, as well as mariculture and marine fishery businesses	50	15

(lev), earnings per share (EPS), board size (Board), proportion of independent directors (Indep), ownership concentration (Top10), ownership type (State), years since listing (Age), research and development expenditure ratio (RDR), and return on assets (Roa). The specific definitions or measurement methods of these variables are shown in [Table 2](#).

RESULTS

EMPIRICAL ANALYSIS AND RESULTS

DESCRIPTIVE STATISTICAL RESULTS

The results of the descriptive analysis are shown in [Table 3](#). The minimum value of digital transformation (DIG) is 0, and the maximum value is 7.378, indicating significant differences in the level of digital transformation among different companies and years. Some companies have very

Table 2. Variable Definition Table

Variable name	Variable symbol	Measurement method
Supply Chain Efficiency	SCE	As mentioned above
Digital Transformation	DIG	As mentioned above
Company Size	size	Take the logarithm of the total assets of an enterprise
Debt-to-equity Ratio	lev	Total liabilities / Total assets
Earnings Per Share	EPS	Total profit / Total share capital
Board Size	Board	Total number of board of directors members
Proportion of Independent Directors	Indep	Number of independent directors / Number of board of directors members
Ownership Concentration	Top10	Shareholding ratio of the top ten shareholders
Ownership Type	State	State-owned enterprises are coded as 1, and other enterprises are coded as 0
Years Since Listing	Age	The difference between the observation year and the market year
Return on Assets	Roa	Net profit / Total assets
Research and Development Expenditure Ratio	RDR	Research and development expenditure / Operating revenue

Table 3. Descriptive Statistical Results

variable	N	Min	Max	Mean	Mediation	SD
SCE	59	4.458	6.526	5.487	5.514	0.581
DIG	59	0.000	7.378	3.843	4.615	2.869
Roa	59	-0.451	0.093	-0.009	0.011	0.092
lev	59	0.059	0.980	0.417	0.387	0.220
size	59	20.563	23.457	21.729	21.628	0.774
EPS	59	-1.201	0.710	0.271	0.044	0.347
Board	59	5.000	22.000	10.508	9.000	4.154
Indep	59	0.250	0.500	0.382	0.375	0.061
Age	59	12.000	26.000	19.610	19.000	4.969
RDR	59	0.000	0.090	0.010	0.000	0.020
State	59	0.000	1.000	0.356	0.000	0.483

low levels of digital transformation. There is also a certain difference between the minimum and maximum values of supply chain efficiency (SCE), suggesting that variations in supply chain efficiency across different companies in the fishery sector may be caused by digital transformation. Additionally, both the mean values of supply chain efficiency and digital transformation are lower than the median, indicating that the overall level of digital transformation and supply chain efficiency in the fishery sector is relatively low, and there is an urgent need to improve the supply chain efficiency in the industry.

BENCHMARK REGRESSION RESULTS

Table 4 presents the regression results for Model (1). The first column of the table shows the analysis results containing only the core explanatory variable, digital transformation (DIG), with a regression coefficient of -0.887. The coefficient is significant at the 5% level, indicating that digital transformation reduces inventory turnover days and im-

proves supply chain efficiency. The second column shows the results after introducing control variables. The regression coefficient of -0.763 remains negative, and the impact of digital transformation on supply chain efficiency is significant at the 10% level. This suggests that digital transformation has a significant positive effect on supply chain efficiency for the fishery sector, supporting the hypothesis.

ROBUSTNESS TEST

1. REPLACING EXPLANATORY VARIABLES

To test the robustness of the conclusions, we replaced the core explanatory variable and conducted the hypothesis test again. For the robustness test, we used the proportion of software and electronic devices related to the digital economy in total assets as a measure of digital transformation. The results are shown in **Table 5**. The impact of digital transformation (Dig) on supply chain efficiency still signifi-

Table 4. Benchmark Regression Results

	(1) SCE	(2) SCE
DIG	-0.887** (-2.39)	-0.763* (-2.17)
Roa		1.934 (1.44)
lev		-0.562 (-0.83)
size		0.118 (1.00)
EPS		-0.443 (-1.37)
Top10		0.009 (1.71)
Board		-0.007 (-0.35)
Indep		-0.332 (-0.41)
RDR		0.589 (0.17)
Age		-0.047 (-1.39)
State		-0.047 (-0.19)
_cons	5.078*** (29.88)	3.718 (1.24)
N	59	59
Individual	Yes	Yes
Year	Yes	Yes
r2	0.881	0.904

t statistics in parentheses :

* p<0.1, ** p<0.05, *** p<0.01

cantly improves supply chain performance, confirming that the conclusions of this paper are robust.

2. REPLACING DEPENDENT VARIABLES

To further test the robustness of the conclusions, we replaced the dependent variable and re-examined the hypothesis. Based on the study by Anand and Grover,²⁰ we constructed five indicators to comprehensively evaluate supply chain efficiency, including upstream, downstream, supply chain management costs, and long-term development quality, as shown in Table 6. According to the direction of impact on supply chain efficiency from these five indicators and referencing the method of Chen et al.,²¹ we used the entropy method to identify two positive indicators (IPT and Q1) and three negative indicators (IAT, ROC, and Q2).

First, data standardization is performed.

For positive indicators (the higher the value, the better), x_{ij} take the original data of the j^{th} index of the i^{th} samples. The formula for standardization is as follows.

$$y_{ij} = \frac{x_{ij} - \min_{1 \leq i \leq m} \{x_{ij}\}}{\max_{1 \leq i \leq m} \{x_{ij}\} - \min_{1 \leq i \leq m} \{x_{ij}\}}$$

For negative indicators (the smaller the value, the better), the standardization formula is as follows:

$$y_{ij} = \frac{\max_{1 \leq i \leq m} \{x_{ij}\} - x_{ij}}{\max_{1 \leq i \leq m} \{x_{ij}\} - \min_{1 \leq i \leq m} \{x_{ij}\}}$$

Calculate the proportion of i^{th} the sample under the j^{th} index.

The formula is $p_{ij} = \frac{y_{ij}}{\sum_{i=1}^m y_{ij}}$, right here $\sum_{i=1}^m p_{ij} = 1$.

Calculate the entropy value of the j^{th} index e_j .

The formula is $e_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij}$, when $k = \frac{1}{\ln m}$, $p_{ij} = 0$, $p_{ij} \ln p_{ij} = 0$.

Calculate the difference coefficient of the j^{th} index g_j .

The formula is $g_j = 1 - e_j$, the larger the difference coefficient, the greater the role this indicator plays in the comprehensive evaluation. Calculate the weight w_j .

The formula is $w_j = \frac{g_j}{\sum_{j=1}^n g_j}$, calculate the weights of each indicator, and then conduct a comprehensive evaluation based on the weights and standardized data. For example, $si = \sum_{j=1}^n w_j y_{ij}$ ($i = 1, 2, \dots, m$) calculate the comprehensive scores to rank the samples.

The results in columns (3) and (4) of Table 5 show the regression analysis after replacing digital transformation. Digital transformation (Dig) significantly improves supply chain efficiency (Score), confirming the robustness of the previous conclusion.

Table 5. Robustness Test Results

	(1) SCE	(2) SCE	(3) Score	(4) Score	(5) SCE
DIG					-0.870** (-2.93)
Dig	-5.846* (-2.29)	-4.360* (-1.87)	2.131** (3.26)	2.660** (2.53)	
Roa		1.731 (1.49)		-0.564 (-1.02)	1.915 (1.31)
lev		-0.309 (-0.42)		-0.193 (-0.78)	-0.517 (-0.72)
size		-1.141 (-0.50)		0.025 (0.34)	2.280 (0.98)
EPS		-0.305 (-0.99)		0.168 (1.16)	-0.472 (-1.46)
Top10		0.003 (0.20)		-0.005 (-1.50)	0.008 (1.37)
Board		-0.011 (-0.32)		-0.006 (-0.52)	-0.004 (-0.23)
Indep		0.125 (0.15)		0.564 (1.34)	-0.126 (-0.13)
RDR		3.082 (0.85)		2.546* (2.24)	0.295 (0.09)
Age		-0.014 (-0.49)		0.027 (1.66)	-0.048 (-1.49)
State		-0.300 (-1.72)		-0.124 (-1.24)	-0.025 (-0.10)
roe					0.035 (0.95)
_cons	4.910*** 8.914	8.914 (1.22)	0.426*** (12.85)	-0.434 (-0.25)	-0.766 (-0.10)
N	59	59	59	59	59
Individual	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
r2	0.882	0.925	0.753	0.797	0.905

t statistics in parentheses :

* p<0.1, ** p<0.05, *** p<0.01

Table 6. Supply Chain Performance Measurement Indicators

Measurement dimension	Corresponding financial indicators
In the upstream of the supply chain	Inventory Turnover Ratio/Accounts Payable Turnover Ratio(IPT)
In the downstream of the supply chain	Inventory Turnover Ratio/Accounts Receivable Turnover Ratio(IAT)
Supply chain management cost	Cost of Goods Sold /Operating Revenue(ROC) Growth Rate of Operating Profit - Growth Rate of Operating Revenue(Q1)
Quality of long - term development	[(Net cash flow from operating activities + net cash flow from financing activities)/ cash outflow from investing activities - 1]/(Q2)

3. ADDING CONTROL VARIABLES

In addition to the variables already included in the model, there may be some omitted variables that could affect the results. Return on equity (roe) is a key indicator of a company's profitability, reflecting its ability to generate net profits from the net value of assets. Therefore, we choose to include roe to address potential omitted variable bias. Af-

ter adding roe, we perform regression analysis again, and the results are shown in column (5) of [Table 5](#). The results indicate that digital transformation remains significantly correlated with supply chain efficiency, and the sign remains consistent. This suggests that after considering roe, the impact of digital transformation on improving supply chain efficiency still holds. This further confirms our re-

search conclusion and demonstrates the robustness of our model.

FUZZY SET QUALITATIVE COMPARATIVE ANALYSIS (FSQCA)

To further verify the path through which digital transformation improves supply chain efficiency, we use Fuzzy Set Qualitative Comparative Analysis (fsQCA) for path analysis, combined with the Technology-Organization-Environment (TOE) framework to select antecedent conditions.

The TOE framework integrates three key dimensions: Technology (T), Organization (O), and Environment (E), which is highly authoritative in the field of research on technological development and innovation behavior in enterprises. Many academic studies have confirmed its effectiveness in analyzing the driving forces behind organizational change. Chinese scholars have applied this theory to research areas such as big data and digitalization.⁸ Given this, this study uses the QCA method under the TOE framework to further explore the path through which digital transformation enhances supply chain efficiency.

SELECTION AND CALIBRATION OF VARIABLES

According to the TOE framework, antecedent conditions are determined from the three levels: Technology, Organization, and Environment. At the technological level, we select variables related to digitalization.⁸ Combining this with the basic regression in the study, we choose digital transformation (DIG) as the antecedent condition for the technology dimension. The organizational dimension includes ownership type, managerial awareness, and enterprise resources.²² This study believes that digital transformation reduces management expense ratios, so we choose ownership nature (State) and management expense ratio (fe) as the antecedent conditions for the organizational dimension. The environmental dimension encompasses institutional, economic, social, and cultural aspects. Following Li et al.,²² we select corporate competitiveness (Comp) as the antecedent condition for the environmental dimension. Supply chain efficiency (SCE) is selected as the outcome variable.

According to the operational guidelines of fsQCA, in order to convert traditional ratio scale variables and interval scale variables into fuzzy sets, they need to be calibrated to match or remain consistent with external standards. Based on the four antecedent conditions and one outcome variable, we identify three qualitative breakpoints for fuzzy sets: the threshold for full membership (fuzzy score = 0.75), the threshold for full non-membership (fuzzy score = 0.25), and the crossover point (fuzzy score = 0.5).²³ The calibration results are shown in [Table 7](#).

NECESSITY ANALYSIS

Before conducting configuration analysis, a necessity analysis is required to determine whether there are necessary conditions. Specifically, we analyze whether the four antecedent conditions—digital transformation (DIG), own-

ership nature (State), management expense ratio (fe), and corporate competitiveness (Comp)—are necessary conditions for supply chain efficiency (SCE). The consistency threshold is set to 0.9. If the consistency is greater than 0.9, the condition is considered necessary; if the consistency is less than 0.9, it is not a necessary condition. As shown in [Table 8](#), the consistency of all four antecedent conditions is less than 0.9, indicating that none of these four conditions alone can improve supply chain efficiency. This suggests that these variables, when considered individually, cannot independently guarantee a high level of supply chain efficiency. Further analysis of the configurations of the four antecedent conditions is conducted.

CONFIGURATIONAL PATHS

Using QCA to analyze A-share listed companies in the fisheries sector from 2015 to 2021, the truth table filters cases by measuring raw consistency and PRI consistency. Raw consistency values below 0.8 indicate substantial inconsistency. Therefore, we selected configurations with a consistency level greater than or equal to 0.8 and set the frequency to 1. Finally, through standardized analysis, we identified two configurations that improve supply chain efficiency. Combining the parsimonious solution and intermediate solution, the results are presented in [Table 9](#). In the results, the overall coverage is 0.478 and the overall consistency is 0.883, indicating that the condition combinations explain 47.8% of the cases and have strong explanatory power. These two configurations can be considered as sufficient conditions for improving supply chain efficiency.

For Configuration 1, DIG and Comp are core conditions, and State is a marginal condition. First, from the consistency perspective, the value is 0.870, indicating a very strong positive correlation between DIG, State, and Comp when DIG and Comp have strong advantages. When DIG and State coexist with Comp, there is a very strong positive association with the outcome variable. From the perspective of DIG, it is an important component of this configuration, working with other factors to produce a stable improvement in the outcome variable. Second, from the coverage perspective, the unique coverage of Configuration 1 is 0.127, indicating that 12.7% of the cases are explained solely by this configuration, with no explanation from other paths. This highlights the unique value of DIG in this configuration, which, together with State and Comp, forms a relatively unique condition combination that explains the outcome variable and plays an irreplaceable role in explaining the result.

Specifically, especially for state-owned enterprises, digital transformation (DIG) can leverage the competitive or complementary advantages (Comp) of the enterprises under a sound organizational and regulatory state (State) (such as optimizing production processes, improving market responsiveness, etc.) to improve supply chain efficiency (SCE). Therefore, from the DIG perspective, it is an indispensable positive factor in the first path, which reaffirms the research hypothesis that DIG can improve supply chain efficiency.

Table 7. Calibration of Outcome and Condition Variables

Conditional and Outcome Variable	Calibration		
	full membership (75)	the crossover point (50)	full non-membership (25)
SCE	411.524	243.253	130.671
DIG	0.102	0.043	0.000
fe	1.223	0.092	0.062
State	1.000	0.000	0.000
Comp	0.124	0.061	-0.007

Table 8. Necessity Analysis

Conditional Variable	High SC E		Low SC E	
	Consistency	coverage	Consistency	coverage
DIG	0.562	0.559	0.566	0.552
fe	0.557	0.546	0.553	0.532
State	0.712	0.545	0.854	0.640
Comp	0.798	0.771	0.367	0.347

For Configuration 2, DIG is absent as a core condition, while management expense ratio (fe) is present as the core condition, with State and Comp as marginal conditions. Similar to the analysis of Configuration 1, from the consistency perspective, Configuration 2 also shows good consistency. Even if the company has not undergone digital transformation, if the management expense ratio is low, i.e., if the conflicts between shareholders and management are not prominent and agency costs are minimized, the advantages of state-owned enterprises and strong competitiveness can also collaborate to improve the company's supply chain efficiency. However, from the perspective of raw coverage, the value of Configuration 2 is 0.351, which is lower than Configuration 1, meaning that fewer cases are explained by Configuration 2. Additionally, the net coverage of Configuration 2 is 0.107, also lower than Configuration 1, indicating that when DIG is absent as a core condition, the unique explanatory power of Configuration 2 weakens. This further validates that DIG is an indispensable positive factor in the path to improving supply chain efficiency, confirming the research hypothesis once again that DIG can improve supply chain efficiency.

DISCUSSION

MAIN CONCLUSIONS

Based on the theories of information asymmetry and the TOE (Technology, Organization, Environment) framework, this study constructs a fixed-effects model using Chinese fishery listed companies as the research sample and applies fsQCA (fuzzy-set Qualitative Comparative Analysis) to explore how digital transformation impacts supply chain efficiency. The findings reveal that digital transformation sig-

nificantly enhances supply chain efficiency. After a series of robustness tests, the conclusions remain valid.

RECOMMENDATIONS

On one hand, the research findings provide new theoretical and empirical pathways for accelerating digital transformation in the fisheries industry to improve supply chain efficiency. First, the fixed-effects model validation clearly demonstrates that digital transformation can significantly enhance supply chain efficiency. The results from the fsQCA method also indicate that digital transformation is an indispensable condition for improving both supply chain efficiency and business competitiveness. In today's world, where digital technologies are sweeping across every corner, fishery enterprises must proactively embrace new technologies and collaborate across the technical, organizational, and environmental dimensions of their business, according to the TOE theory, to steadily advance supply chain efficiency. This study extends the literature on the application of the TOE theory from the perspective of digital transformation, reaffirming the authority of the TOE framework. Secondly, the fishery supply chain involves multiple stakeholders such as fishermen, distributors, processing plants, and consumers, and issues such as poor information flow and information asymmetry have persisted. This study, based on the theory of information asymmetry, demonstrates that digital transformation can improve supply chain efficiency. It establishes a "high-speed channel" for information sharing, enabling all parties involved to access key information in real time, such as fish supply, market demand, and price fluctuations, thus reducing product backlog or supply shortages caused by information gaps and lowering market risks. Therefore, this study also extends the literature on the application of information

Table 9. Configuration Paths

Conditional Variable	Configuration 1	Configuration 2
DIG	●	⊗
fe		●
State	.	.
Comp	●	.
Raw Coverage	0.371	0.351
Unique Coverage	0.127	0.107
Consistency	0.870	0.941
Overall Coverage		0.478
Overall Consistency		0.883

Note:● indicates the presence of core conditions;· indicates the presence of marginal conditions;⊗ indicates the absence of core conditions;⊙ indicates the absence of marginal conditions;The blank part means it can be either present or absent.

asymmetry theory in supply chain contexts and contributes to its development in related research fields.

On the other hand, the findings offer valuable management insights. The production and operation processes in the fishery industry are complex, and digital transformation acts as a “universal key.” It not only streamlines the cumbersome operations in the fishery supply chain but also improves product processing efficiency through automated equipment, significantly reducing operating costs. This implies that if fishery companies want to enhance their competitiveness and improve supply chain operations, actively embracing digital technology and increasing investment in information technology, smart devices, and e-commerce channels are critical path. Fishery listed companies should seize this opportunity, develop a digital strategy tailored to their characteristics, and integrate digital principles across the entire value chain—from fish fry breeding to terminal sales—to achieve industry-wide upgrades.

IMPLICATIONS FOR FISHERIES LISTED COMPANIES IN OTHER COUNTRIES AND REGIONS

The accelerating development of global trade and the increasing complexity of global supply chains have also affected the fisheries sector, with long and complex supply chains posing efficiency challenges abroad. The findings of this study on how digital transformation in Chinese fisheries impacts supply chain efficiency provide valuable insights for fishery companies in other countries aiming to improve their supply chain efficiency.

First, digital transformation can optimize supply chain operations for foreign fishery companies. Technologies such as the Internet of Things (IoT) for real-time monitoring and precise positioning of fishing vessels can enhance capture efficiency. At the same time, automation in processing equipment can improve processing workflows, product quality, and production efficiency, strengthening the market competitiveness of fishery companies.

Second, information asymmetry in the global fishery market is a prominent issue. Digital transformation can build platforms for information sharing, enabling real-time global data exchange. International fishery companies can

then promptly access information about global market demand, prices, and policy changes, which enhances decision-making efficiency.

Third, foreign fishery companies should attach importance to the impact of digital technologies on supply chain efficiency. They should gradually increase investment in areas such as the Internet of Things and big data. Based on the company’s scale, resources, and market positioning, a comprehensive digital strategy should be formulated, integrating digital concepts into the operation, production, and sales processes.

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COMPETING OF INTEREST – COPE

The authors declare that there are no recognized competing financial interests or personal relationships that could have had an impact on the research in this paper.

INFORMED CONSENT STATEMENT

All authors and institutions have confirmed this manuscript for publication.

DATA AVAILABILITY STATEMENT

All are available upon reasonable request.

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