RESILIENCE ASSESSMENT OF AQUATIC PRODUCTS SUPPLY CHAIN AND THE ENABLING ROLE OF DIGITAL TECHNOLOGY INNOVATION IN CHINA

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Abstract

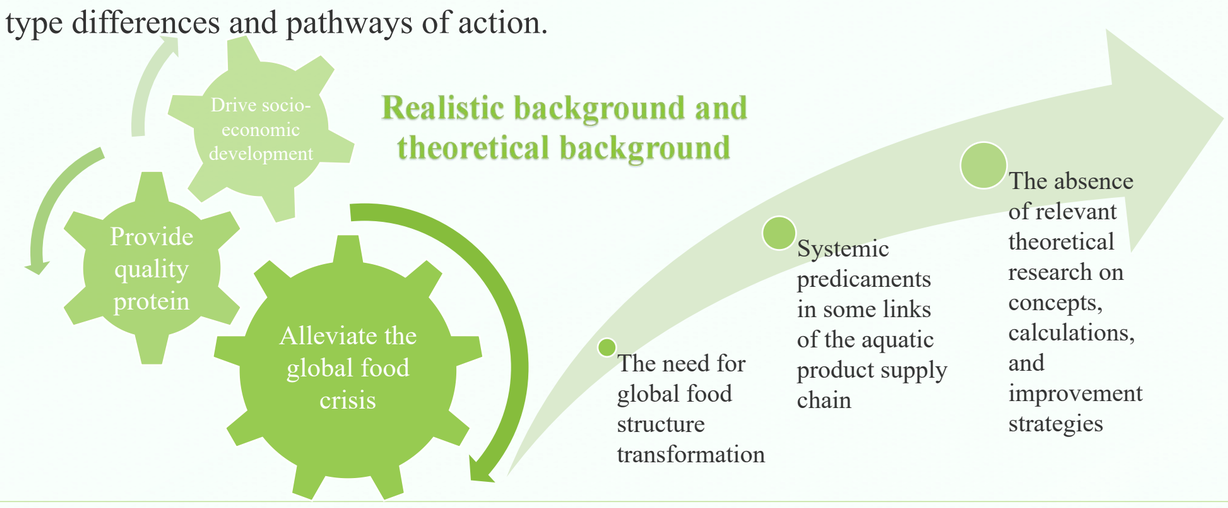
Aquaculture plays a vital role in alleviating global food shortages, supplying high-quality protein, and promoting employment and economic development. However, the aquatic product supply chain is highly vulnerable and prone to supply chain instability. Our study construct a three-dimensional evaluation framework, including risk-resistance capacity, adaptive recovery capacity, and innovation & transformation capacity, evaluate the resilience of aquatic product supply chains, and empirically examine the enabling role of digital technology innovation. The results show that the overall resilience of China's aquatic product supply chain has steadily improved, although significant regional and dimensional disparities persist. Spatially, the supply chain resilience shows a trend toward balanced industrial distribution and collaborative development, accompanied by reduced regional gaps and lower spatial agglomeration. Digital technology innovation significantly enhances supply chain resilience. Invention patents mainly strengthen risk resistance and recovery capacity, while utility model patents primarily promote innovation and transformation capacity. Furthermore, the enabling effect of digital innovation exhibits clear regional heterogeneity, with the strongest impact observed in the eastern. These findings highlight the importance of strengthening risk-resistance and innovation & transformation capacity and promoting regionally differentiated digital Technology development strategies.

Introduction

• In recent years, the global food supply system has been hit multiple times by climate change, geopolitical conflicts, trade protectionism and public health events. Organizations such as the Food and Agriculture Organization of the United Nations have repeatedly proposed that building resilient agricultural and food systems has become one of the most pressing issues for ensuring global food security and addressing uncertainty.

• Due to the unique perishability, seasonality and biological characteristics of aquatic products, the aquatic products supply chain needs to have high timeliness, cold chain system dependence and traceability.

• Existing research mainly focuses on the resilience in manufacturing or enterprise supply chains, quantitative analysis of resilience in aquatic products supply chains is relatively limited, and it is difficult to fully reveal its intrinsic structural characteristics and potential risks. Although the academic community generally agrees that technological innovation plays a key role in the development of industrial resilience, existing research often regards technological innovation as a homogeneous variable and lacks a systematic analysis of its type differences and pathways of action.



Materials and methods

Based on relevant literature, we define the resilience of the aquatic product supply chain as: In the face of external shocks such as water pollution, climate change, and market fluctuations, the aquatic products supply chain can avoid structural disruption and functional transfer, maintain system stability through adjustment, not just restore to the original state, but can drive the chain to achieve innovation and upgrading as a whole (Vlachos and Malindretos, 2023). With the characteristics of the aquaculture industry, our study constructs a multi-level indicator system of aquatic products supply chain resilience.

Table 1 Indicator System of Resilience in aquatic products supply chain

Primary indicators	Secondary indicators	Tertiary indicators	Units	Properties	Indicator weights
Risk-resistance capacity	Factors of production	Aquaculture area	Ten thousand hectares	+	0.0359
		Aquatic seedlings	Billions of tails	+	0.0780
		Number of fishing boats at the end of the year	Ten thousand boats	+	0.0387
		Fishery machinery power	10,000 kilowatts	+	0.0419
		Fishery workers	Ten thousand people	+	0.0360
	Supply chain Foundation	Output of aquatic products	Tons	+	0.0347
		The number of aquatic product processing enterprises	a	+	0.0381
		Total volume of processed aquatic products	Tons	+	0.0410
		Quantity of cold storage for aquatic products	seat	+	0.0393
		Output value of aquatic storage and transportation	100 million yuan	+	0.0497
		Output value of aquatic products circulation	Billion yuan	+	0.0440
Adaptive recovery capacity	Risk exposure	Types of Marine disasters that occur	Kind of	-	0.0275
		The number of deaths and disappearances due to Marine disasters	people	-	0.0256
		Direct economic losses from Marine disasters	Billions of yuan	-	0.0257
	Risk identification	Aquatic product price index	Last year =100	+	0.0264
	Risk response	The proportion of the output value of aquatic products in the output value of the fishery	%	+	0.0276
		Fishery subsidies	100 million yuan	+	0.0423
		Recreational fisheries output value	100 million yuan	+	0.0493
		Foreign trade throughput of aquatic products	100 million tons	+	0.0415
		Total volume of imports and exports of aquatic products	Billions of US dollars	+	0.0406
Innovation transformation capacity	Innovation input	Research funding for fisheries	One billion yuan	+	0.0339
		Number of aquatic science promotion agencies	a	+	0.0350
		The actual number of employees in aquatic research institutions	Thousands of people	+	0.0327
	Innovation output	Demonstration key technologies for aquaculture	a	+	0.0360
		Number of fisheries papers published	article	+	0.0389
		Number of aquatic patent authorizations	item	+	0.0397

• Referring to the research method of Tao et al. (2023) and Wang et al. (2026), the IPC information of patent applications by enterprises in various regions in the current year was matched and aggregated with the International Patent classification numbers in the table to identify and sum up digital technology patents from the "city-year" dimension, thereby obtaining the digital technology innovation levels of different provinces in the main production areas of aquatic products in China.

• Patent data is sourced from the *National Intellectual Property Administration*, and other data mainly come from the *China Fisheries Statistical Yearbook* over the years, the *National Bureau of Statistics*, and the Brick Agricultural Big Data Platform.

• The entropy weight-TOPSIS method was used to measure the resilience level of the aquatic products supply chain in China, the dynamic evolution characteristics were analyzed by the kernel density estimation method and the Moran index, and the bidirectional fixed effects model was used to measure the impact of technological innovation on the resilience of the aquatic products supply chain. The benchmark regression model is as follows:

$$Resilience_{it} = \beta_0 + \beta_1 TI_{it} + \beta_2 Control_{it} + \gamma_i + \varphi_t + \varepsilon_{it} \quad (1)$$

The formulas for kernel density estimation and Moran index calculation are respectively:

$$f_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x_i - \bar{x}}{h}\right), K(x) = \frac{1}{\sqrt{2\pi}} exp^{-\frac{1}{2}x^2} \quad (2)$$

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(y_i - \bar{y})}{\sum_{i=1}^{n}(yi - \bar{y})^2} \quad (3)$$

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Results and discussions

The resilience level of the aquatic products supply chain in China has risen overall, but development is uneven across regions and dimensions.

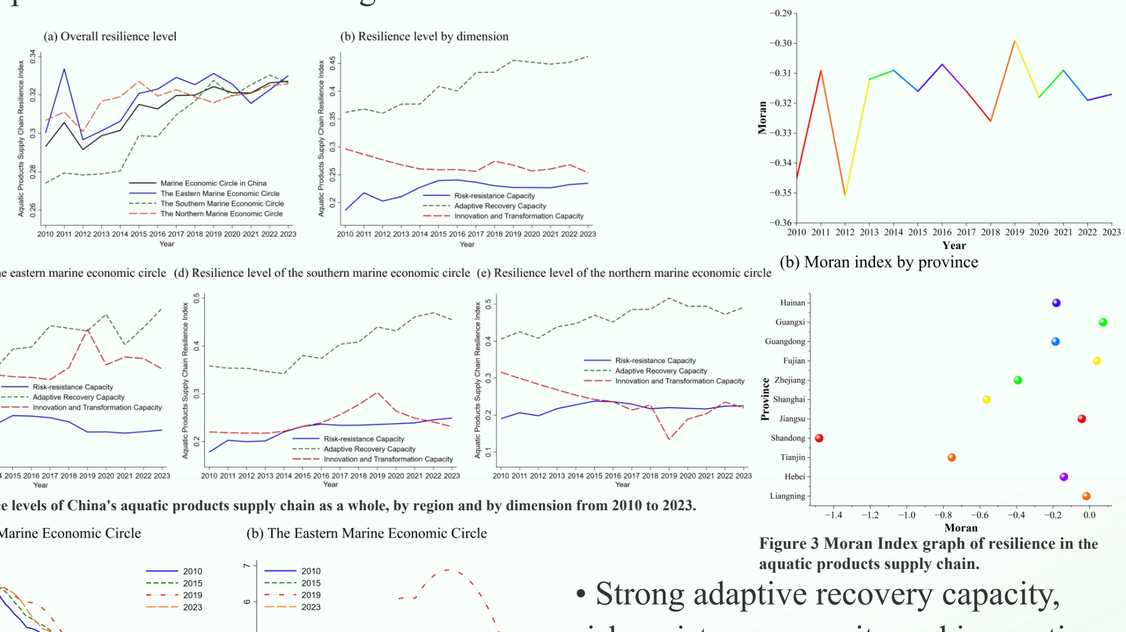


Figure 1 Resilience levels of China's aquatic products supply chain as a whole, by region and by dimension from 2010 to 2023.

Figure 3 Moran Index graph of resilience in the aquatic products supply chain.

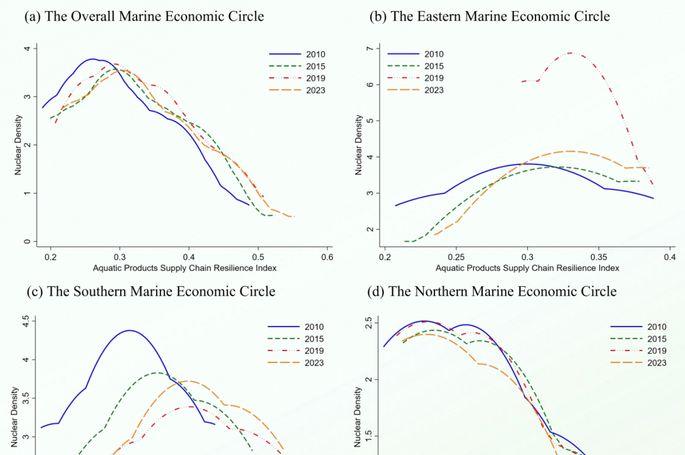


Figure 2 Nuclear density map of resilience of aquatic products supply chain in China and its regions.

• Strong adaptive recovery capacity, risk-resistance capacity and innovation & transformation capacity, and strong in the northeast and catching up in the south (Figure 1).

• The distribution center of resilience in the aquatic products supply chain shifted to the right over time, indicating that the overall resilience level continued to improve, reflecting significant achievements in systemic capacity building at this stage (Figure 2).

• Numerically, the Moran Index of resilience in aquatic products supply chain is largely negative. In terms of the trend of change, the absolute value of the Moran Index shows a decreasing trend over time, indicating that the spatial differences in the resilience are shrinking (Figure 3).

There may be a spatial evolution trend of "industrial equalization and distributed synergy" in the future, and there may also be risks such as weakened short-term economies of scale and regional homogeneous competition.

Table 2 The Enabling Role Of Digital Technology Innovation

Variables	*Aquatic products supply chain resilience*	*Risk-resistance capacity*	*Adaptive recovery capacity*	*Innovation & transformation capacity*
Digital Technology Innovation	0.0370***	0.0141	0.0293	0.0695
	(0.0101)	(0.0121)	(0.0202)	(0.0444)
Patent application inventions	0.0595*	0.0117	0.0490	-0.0648
	(0.0329)	(0.0383)	(0.0638)	(0.1408)
Invention Patent Authorization	0.0670***	0.0760***	0.1063**	0.1097
	(0.0227)	(0.0261)	(0.0439)	(0.0986)
Utility Model Patent	0.0414**	-0.0063	0.0063	0.1291*
	(0.0160)	(0.0189)	(0.0315)	(0.0686)

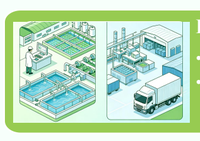
Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels respectively, with standard errors in parentheses.

Table 3 Regional Heterogeneity Regression Results

Variables	*Aquatic products supply chain resilience*		
	The eastern coastal	The southern coastal	*The northern coastal*
Digital Technology Innovation	0.1356**	0.0163*	-0.0004
	(0.0531)	(0.0084)	(0.0158)
Constant	8.7414*	1.1753***	1.5149***
	(4.7405)	(0.1722)	(0.5442)
Control	YES	YES	YES
Time fixed	YES	YES	YES
Regional fixed	YES	YES	YES
Observations	42	56	56
R-squared	0.434	0.906	0.603

• The results in Table 2 indicate that for every 1-unit increase in the level of digital innovation, the resilience level of the aquatic product supply chain will increase by 0.037 units. Additionally, the three dimensions of digital innovation have a significant promoting effect on the three subsystems of the resilience. The results in Table 3 show that the promoting effect of digital innovation on the resilience has regional heterogeneity. Local characteristics should be considered to promote the aquatic industry.

Based on the above results, propose improvement strategies:



Reduce production costs, increase added value, and enhance supply chain resilience

•Optimize the research and application of seedlings, feed and facilities and equipment, reduce costs and enhance supply chain resilience.
•Enhance the processing capacity of high value-added products and emergency reserve capacity, promote the standardization of cold chain logistics.



Build a coordinated emergency response system to strengthen supply chain recovery capabilities

•Insurance companies and governments can use digital twin technology to simulate post-disaster supply chain conditions and optimize recovery paths.
•Optimize the process of fishery disaster relief subsidies and insurance claims, and use digital platforms for rapid declaration and review.



Promote research and technology transfer, and optimize supply chain innovation & transformation capabilities

•Support the establishment of national-level innovation centers for aquatic seed industry, intelligent equipment and green processing technology in regions with good research and development foundations.
•Develop differentiated and functionally complementary regional development strategies.



Take into account green safety and enhance the sustainability of supply chains

•Encourage the development of ecological models such as multi-nutrient-level integrated aquaculture and Marine ranching.
•Encourage qualified enterprises to diversify origin risks through overseas breeding bases, cooperative ports.

Conclusions

There exists a structural contradiction in the resilience of the aquatic product supply chain, "strong adaptive recovery capacity, but weak risk-resistance and innovation&transformation capacity", systematic reinforcement is urgently needed. Although regional differences are narrowing, the weakening of spatial clustering is accompanied by intensified homogenized competition. In the future, differentiated and coordinated development can be promoted. Digital technological innovation can significantly enhance resilience, but the enabling effect shows a regional imbalance of "strong in the east and weak in the south". Emphasizing technological innovation requires precise adaptation to regional characteristics and accelerating technology diffusion.

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