

Research on the Impact of Industrial Intelligence on Export Resilience

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Abstract. With the continuous progress of the new round of the technological revolution and the increasingly complex international environment, industrial intelligence and export resilience have become hot topics for scholars at home and abroad. This paper uses provincial panel data from 2011 to 2022 to examine the impact of industrial intelligence on export resilience. The research findings are as follows: First, the development of industrial intelligence has significantly enhanced export resilience. Second, from a regional perspective, the impact of industrial intelligence on export resilience is highest in the central region, followed by the western region, and is not significant in the eastern region. Third, industrial intelligence affects export resilience by promoting technological innovation.

Keywords: Industrial intelligence, export resilience, technological innovation.

1. Introduction

Against the backdrop of accelerating global integration and deepening international division of labor, China's manufacturing sector has achieved rapid development by actively participating in the international division of labor, leveraging its advantages such as abundant labor resources. Since 2010, when China's manufacturing value-added first surpassed that of the United States, it has consistently ranked first in the world. Meanwhile, with the deep integration of cutting-edge technologies such as artificial intelligence and big data into the real economy, intelligent manufacturing has encountered significant opportunities for development. China has made substantial investments in intelligent equipment, including industrial robots. According to data from the National Bureau of Statistics, China's industrial robot production reached 429,500 sets in 2023, and grew by 14.2% year-on-year in 2024. In 2023, the "Robot+" Application Implementation Plan was officially put into effect, aiming to accelerate the cross-sectoral penetration of robotics technology, broaden application scenarios, and stimulate innovation. Overall, China is actively embracing industrial intelligence transformation, driven by policy support and technological innovation, to accelerate the upgrading of its manufacturing sector and enhance its global competitiveness.

Industrial intelligence has become a research hotspot, with the relevant literature mainly focusing on two aspects: the measurement of industrial intelligence and its economic effects. Regarding measurement methods, one strand of research uses industrial robots as indicators [1][2], while another constructs multi-dimensional composite evaluation systems [3][4]. In terms of economic effects, existing studies largely concentrate on labor markets. Wang et al. find that industrial intelligence in China primarily exhibits a substitution effect on employment, with negative spillovers to neighboring provinces [5]. Shi and Ye suggest that increasing the proportion of high-skilled labor and reducing the employment share of low-skilled labor can enhance the contribution of artificial intelligence to high-quality development [6]. Yin et al., from the perspective of labor productivity, find that industrial intelligence not only improves labor productivity but also generates significant positive spatial externalities [7]. Furthermore, scholars have begun to examine its impact on international trade. Meltzer argues that artificial intelligence expands trade volumes by boosting global productivity and accelerates the transition to service-based economies [8]. Zhao et al. point out that industrial intelligence improves both the quantity and quality of export products, while also promoting imports and service trade [9]. Huang et al. propose that industrial intelligence serves as a new engine for

attracting foreign investment into China by enhancing labor supply quality, promoting industrial upgrading, strengthening innovation capacity, and fostering agglomeration economies [10].

Exports have long been a key engine of China's economic growth. Since the reform and opening-up, the scale of China's exports has continued to expand. However, in recent years, uncertainties such as the Sino-US trade friction, deglobalization, rising trade protectionism, and the COVID-19 pandemic have posed serious challenges to China's open economy. Since 2014, the importance of "China's economic resilience" has been repeatedly emphasized. As a critical component of economic resilience, export resilience is essential for trade stability and sustainable development. Current research on the drivers of export resilience mainly focuses on digitalization, innovation capacity, and related diversification. In terms of digitalization, Su et al. find that the development of the digital economy enhances export resilience by reducing costs and boosting innovation and entrepreneurial vitality [11]. Zhang et al. theoretically demonstrate that corporate digital transformation helps mitigate the impact of trade frictions [12]. Regarding innovation capacity, Bian et al., using provincial panel data, find that regional innovation capacity positively contributes to export resilience, and moderate trade barriers can strengthen this effect [13]. In terms of diversification, Nazarczuk et al. note that export specialization positively affects export resilience at the regional level but has the opposite effect at the national level [14]. Liu et al., using firm-level data, find that market diversification strategies help enhance export resilience [15]. Geng et al., employing survival analysis models, find that industrial intelligence reduces firms' export survival risks and extends their survival time, thereby improving export resilience [16].

In summary, no unified standard has yet been established for measuring industrial intelligence, and research on its economic effects remains at a developmental stage. In particular, the relationship between industrial intelligence and export resilience remains underexplored. To address this gap, this paper constructs an evaluation system for industrial intelligence from three dimensions: intelligent input, production application, and innovation and efficiency. Using a fixed-effects model, we empirically examine the impact of manufacturing intelligence on export resilience, followed by heterogeneity analysis and mediation mechanism tests.

2. Research hypothesis

2.1. Direct Impact of Industrial Intelligence on Export Resilience

Industrial intelligence enhances export resilience by improving production efficiency and product quality. Through the adoption of advanced intelligent equipment and systems, firms can automate and intellectualize production processes, thereby increasing efficiency and shortening product delivery cycles. Meanwhile, intelligent technologies enable real-time monitoring and adjustment of production, ensuring product quality stability and consistency [17]. This efficient and high-quality production model makes provincial export products more competitive in international markets, helping to withstand various external shocks and challenges while maintaining steady export growth.

Industrial intelligence also promotes industrial upgrading and structural adjustment within provinces, creating new growth drivers for exports. With the widespread application of intelligent technologies, traditional manufacturing is transforming toward smart manufacturing, and emerging industries are continuously developing [18]. Such industrial upgrading and structural adjustment not only raise the level of provincial industrial structure but also provide new product categories and market opportunities for exports. For instance, high-end equipment and smart manufacturing devices have become important components of provincial exports, strongly supporting export resilience.

Furthermore, industrial intelligence strengthens provinces' ability to adapt and respond to changes in external markets. The application of intelligent technologies enables firms to quickly access market information, analyze demand, and flexibly adjust production strategies and export plans in response to market changes. This flexibility and adaptability allow provinces to react swiftly to external challenges such as fluctuations in international market demand and trade barriers, thereby maintaining export stability and sustained growth [16]. In addition, intelligent technologies help improve supply

chain management in areas such as logistics and warehousing, reduce operating costs, and further enhance export competitiveness [19].

Hypothesis 1: Industrial intelligence can enhance export resilience.

2.2. Indirect Impact of Industrial Intelligence on Export Resilience

The development of industrial intelligence enhances provincial innovation levels primarily through two channels. On the one hand, industrial intelligence replaces human labor in performing heavy, dangerous, or repetitive tasks, thereby freeing up human resources and allowing talent to engage more in high-value-added innovation activities. This effective combination of human resources and skills provides a solid foundation for R&D and innovation. On the other hand, the application of industrial intelligence spans multiple fields such as mechanical design and automatic control, prompting firms to seek collaboration with other enterprises or research institutions to jointly advance the R&D and innovation of intelligent technologies. Such collaboration accelerates the sharing of technology and knowledge [20], thereby raising the overall level of innovation. Technological innovation plays a crucial role in social development, serving as a key factor in driving social progress and improving production efficiency, and significantly promotes the development of a region's export trade. Bian et al. argue that innovation capacity, on the one hand, enhances firms' export competitiveness by improving their production efficiency and activity level, thereby increasing export resilience [13]; on the other hand, it increases the value added of export products, strengthens firms' core competitive advantages in export markets, and thus enhances export resilience. Chen et al. also note that in the constantly changing international trade environment, technological innovation is key for China to overcome the negative effects of non-tariff trade barriers set by developed countries and the containment of key technologies. It helps strengthen export competitive advantages and stabilize the development of export trade when facing external shocks, i.e., enhance export resilience [21].

Hypothesis 2: Industrial intelligence promotes technological innovation, which in turn enhances export resilience.

3. Research design

3.1. Model construction

To examine the impact of industrial intelligence on export resilience, this paper constructs a two-way fixed effects model based on existing empirical literature and corresponding tests. The specific model is specified as follows:

$$RES_{it} = \alpha_0 + \alpha_1 \cdot INL_{it} + \sum_c \alpha_c \cdot C_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In this model, i represents province (or municipality), and t denotes the year. RES_{it} stands for the provincial export resilience, INL_{it} represents the level of industrial intelligence, and C_{it} represents control variables. μ_i and γ_t denote province and year fixed effects, respectively, and ε_{it} denotes the random error term.

3.2. Variable Selection

Dependent variable: Export Resilience (RES). The term "resilience" originates from the Latin word "Resilio," meaning "to return to the original state." This concept first appeared in physics and was later introduced into ecology by American ecologist Holling to describe the ability of a system to return to its original state after being disturbed [22]. Subsequently, resilience gradually gained attention in economics and became a popular topic in fields such as regional economics and economic geography. In this context, Martin defined resilience as the capacity of an economic agent to resist crises, recover from them, achieve self-renewal, and reposition itself [23]. Therefore, the concept of resilience is often used in academic research to analyze the impact of external shocks on regions, industries, or firms. Drawing on the approach of He and Chen, this paper uses risk resistance capacity

as an indicator to measure export resilience [24]. The deviation of each province's export value from its 2008 export level is employed as the measure of risk resistance capacity, with the formula as follows:

$$RES_{it} = (export_{it} - export_{i2008}) / export_{i2008} \quad (2)$$

where $export_{it}$ and $export_{i2008}$ represent the export value of province i in year t and 2008, respectively. A larger value of RES_{it} indicates a smaller decline in the region's export value, stronger risk resistance capacity, and greater export resilience.

Independent variable: Industrial Intelligence Level (INL). Following the approach of Sun and Hou [3], this paper constructs an indicator system from three dimensions: intelligent input, production application, and innovation and efficiency. The entropy method is employed to comprehensively measure the industrial intelligence level index, as shown in Table 1.

Table 1. Industrial intelligence level evaluation index system

First-level indicator	Second-level indicator	Measurement method
Intelligent input	Basic internet infrastructure	Optical cable line length / Provincial area
	Intelligent funding input	R&D funds in high-tech manufacturing
	Intelligent talent input	Number of employees in high-tech manufacturing / Number of employees in industrial enterprises
	Intelligent equipment input	Fixed asset investment in information transmission, software, and information technology services
Production application	Software popularization and application	Revenue from software products / Main business revenue of industrial enterprises
	Intelligent product development	Revenue from embedded system business / Main business revenue of industrial enterprises
	Intelligent enterprise development	Main business revenue of high-tech manufacturing / Main business revenue of industrial enterprises
	Intelligent technology application level	New product sales revenue of high-tech manufacturing / Main business revenue of manufacturing
Innovation and efficiency	Innovation capability	Number of patent applications and grants / Number of R&D personnel
	Intelligent market profit	Total profit of high-tech manufacturing
	Intelligent market efficiency	Main business revenue of high-tech manufacturing / Number of employees in high-tech manufacturing
	Social benefit	Energy consumption per unit of GDP

Mediating variable: Technological Innovation (TI), measured by the logarithm of full-time equivalent of R&D personnel.

Control variables: (1) Openness to trade (OPEN), measured by the ratio of total provincial trade to gross domestic product, reflecting the province's participation in international trade. (2) Government support (GOV), measured by the ratio of local general fiscal expenditure to regional GDP. (3) Economic size (LnGDP), measured by the logarithm of real GDP of each province, with 2008 as the base year and deflated using the corresponding production index to eliminate the influence of price factors.

3.3. Data Sources

The research sample of this paper covers data from 30 Chinese provinces (municipalities) over the period 2011–2022 (Tibet, Hong Kong, Macau, and Taiwan are excluded due to data availability). The data are sourced from the National Bureau of Statistics, *China Statistical Yearbook*, *China Statistical Yearbook on High Technology Industry*, *China Statistical Yearbook on Science and Technology*, and various provincial statistical yearbooks. Descriptive statistics of the variables are presented in Table 2.

Table 2. Descriptive statistics

Variable		N	mean	sd	min	max
Dependent variable	RES	360	1.533	2.056	-0.735	12.72
Independent variable	INL	360	11.21	10.49	0.337	61.85
Mediating variable	TI	360	10.67	1.389	7.054	13.56
Control variables	OPEN	360	27.16	28.10	0.763	146.4
	GOV	360	25.90	11.15	10.50	75.83
	LnGDP	360	9.103	0.863	6.884	10.76

4. Empirical results analysis

4.1. Benchmark regression

Before conducting the baseline regression, a Hausman test was performed on the data. The test results rejected the null hypothesis at the 1% significance level, indicating that a fixed-effects model is more appropriate for the regression analysis. To avoid the influence of multicollinearity on the regression results, independent variables were added to the model one by one, and the significance of the coefficients was observed. The regression results are presented in Table 3.

It can be seen that as independent variables are gradually added to the model, the correlation coefficient between industrial intelligence and export resilience continues to increase, showing a significantly positive relationship, indicating that the model is relatively robust. In terms of coefficients, the average regression coefficient of industrial intelligence is 0.1075, which is significantly positive at the 1% level, suggesting that industrial intelligence significantly promotes export resilience. Regarding the control variables, the coefficients of openness to trade, government support, and economic size are all significantly positive, indicating that a higher degree of openness, government intervention policies, and a larger economic scale all help enhance provincial export resilience.

Table 3. Baseline regression results

Variable	(1)	(2)	(3)	(4)
INL	0.0652*** (3.36)	0.1271*** (7.11)	0.1249*** (6.92)	0.1128*** (6.29)
OPEN		0.0723*** (10.25)	0.0724*** (10.26)	0.0770*** (11.00)
GOV			0.0184 (0.90)	0.0724*** (2.98)
LnGDP				5.404*** (3.89)
Constant	-2.1592*** (-4.29)	-10.7094*** (-11.38)	-11.0343*** (-10.95)	-64.0097*** (-4.69)
Province fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
R-squared	0.8024	0.8516	0.8520	0.8588

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-value. The same applies below.

4.2. Endogeneity and Robustness Tests

In the stepwise regression analysis of the impact of industrial intelligence on export resilience, the model may suffer from endogeneity due to omitted variables and reverse causality. First, unobservable factors may affect export resilience, leading to correlation between the core independent variable and the error term. Second, regions with higher export resilience tend to have higher levels of industrial intelligence, suggesting possible reverse causality. These issues may bias the estimated coefficient of industrial intelligence. Therefore, this paper uses the lagged term of industrial

intelligence(L.INL) as an instrumental variable and employs the two-stage least squares (2SLS) method for estimation. The results are shown in column (1) of Table 4. The findings indicate that the coefficient of the core independent variable—industrial intelligence—remains significantly positive, suggesting that even after accounting for endogeneity, the development of industrial intelligence remains a key factor in enhancing export resilience. Thus, the main conclusions of this paper are robust.

To further enhance the robustness of the results, this paper substitutes industrial intelligence with inter-provincial robot installation density(RD) (calculated as the robot installation volume in Chinese industries multiplied by the share of manufacturing employment in each province/municipality) for a robustness test. The regression results are presented in column (2) of Table 4. The coefficient of industrial intelligence development remains significantly positive, consistent with the baseline regression results.

In addition, this paper excludes the municipality samples. Considering that developed regions may have higher levels of industrial intelligence as well as stronger export resilience, the exclusion of municipalities helps mitigate the potential influence of these samples. The regression results are shown in column (3) of Table 4. The coefficient of industrial intelligence remains significantly positive, again consistent with the baseline regression results.

Table 4. Robustness tests

Variable	(1)	(2)	(3)
L.INL	0.0750*** (4.58)		
RD		0.0638* (1.84)	
INL			0.1467*** (8.91)
Constant	19.2566*** (6.86)	-73.6643*** (-5.14)	-65.8455*** (-5.47)
Control variables	YES	YES	YES
Province fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
R-squared	0.6998	0.8427	0.6765
N	330	360	312

4.3. Heterogeneity Analysis

At the aggregate level, improving industrial intelligence helps enhance export resilience. However, given the imbalanced development across Chinese regions and significant differences in resource endowments, the impact of industrial intelligence on export resilience may vary by region. Therefore, this paper divides the sample into eastern, central, and western regions to explore the differential impact of industrial intelligence on export resilience from the perspective of locational characteristics. The regression results are presented in Table 5.

It can be seen that the impact of industrial intelligence on export resilience in the eastern region is not significant. In contrast, the coefficients for both the central and western regions are significantly positive at the 1% level, with the central region exhibiting a larger coefficient than the western region. This can be attributed to the fact that, in order to promote coordinated regional development, China has implemented strategies such as the Western Development and the Rise of Central China, facilitating the transfer of industries to the central and western regions. These regions have relatively weaker economic foundations, and the development of industrial intelligence significantly improves production efficiency and reduces costs, helping them better adapt to changes in market demand. By contrast, the eastern region is economically developed and faces intense market competition, where the efficiency gains brought by industrial intelligence may be insufficient to significantly enhance export resilience in such a highly competitive market.

Table 5. Regional heterogeneity results

Variable	Eastern	Central	Western
INL	0.0005 (0.03)	0.3212*** (7.22)	0.2640*** (5.91)
OPEN	0.0254*** (3.86)	0.2012*** (5.90)	0.2646*** (9.67)
GOV	0.0446*** (3.02)	0.1333*** (3.19)	0.0786** (2.41)
LnGDP	7.0526** (2.44)	1.5528 (1.34)	1.5868 (0.57)
Constant	-71.2634** (-2.53)	-19.7997* (-1.80)	-18.8484 (-0.76)
R-squared	0.8150	0.9686	0.9391
N	132	96	132

4.4. Mediation Effect Test

The results of the baseline regression analysis indicate that, holding other variables constant, an increase in the level of industrial intelligence significantly enhances export resilience. According to the theoretical analysis above, technological innovation is an important channel through which industrial intelligence improves export resilience. To empirically test this theoretical proposition, this paper conducts a mediation effect test following the approach of Jiang [25]. The specific model is specified as follows:

$$TI_{it} = \beta_0 + \beta_1 INL_{it} + \sum_c \beta_c \cdot C_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

The test results are shown in Table 6. It can be seen that the coefficient of the core explanatory variable—industrial intelligence development—is significantly positive, indicating that the development of industrial intelligence helps improve provincial innovation levels. Industrial intelligence enhances innovation through substitution effects and knowledge sharing, and such improvement in innovation is an important factor in strengthening export resilience. Therefore, industrial intelligence promotes export resilience by fostering technological innovation.

Table 6. Mediation Analysis Results

Variable	TI
INL	0.0325*** (7.59)
OPEN	0.0125*** (7.49)
GOV	0.0003 (0.05)
LnGDP	2.1003*** (6.32)
Constant	-11.4607*** (-3.51)
R-squared	0.5367

5. Discussion and Conclusions

Using data from 30 Chinese provinces from 2011 to 2022, this paper examines the impact of industrial intelligence on export resilience. The results show a significant positive correlation between industrial intelligence and export resilience at the 1% level, indicating that the development of industrial intelligence promotes export resilience. From a regional perspective, the positive effect of industrial intelligence on export resilience is strongest in the central region, followed by the western region, while it is insignificant in the eastern region. The mediation effect test reveals that industrial

intelligence enhances export resilience by promoting technological innovation. Based on these findings, the following policy recommendations are proposed.

First, actively promote the development strategy of the industrial intelligence industry. Industrial intelligence is an important driver for enhancing export resilience. Raising the level of industrial intelligence not only improves export production efficiency and product quality, promotes industrial upgrading and structural adjustment, but also strengthens provinces' ability to adapt and respond to changes in external markets, thereby enhancing export resilience. Therefore, local governments need to formulate and implement strategies for the development of intelligent industries, focusing on breakthroughs in key areas and technologies to raise urban industrial intelligence levels. This can be achieved through measures such as government funding support, investment in innovative startups, and the establishment of technology innovation centers. In addition, governments should accelerate the construction of digital infrastructure, including high-speed internet, cloud computing services, and big data centers, to support the development of industrial intelligence. The improvement of such infrastructure has a significant impact on the stable growth of export trade, particularly in high-tech industries.

Second, focus on differentiated policy adjustments. Given the imbalanced development levels and regional disparities in resource endowments across China, the impact of industrial intelligence on export resilience exhibits significant regional heterogeneity. The government should increase fiscal support and policy preferences for the central and western regions, encouraging investment from social capital. Moreover, differentiated regional development strategies should be implemented, formulating tailored support policies based on the industrial base and level of intelligent development in different regions. For example, the central region could focus on developing intelligent manufacturing equipment and industrial chain collaboration, while the western region could prioritize the intelligent transformation and green upgrading of resource-based industries. Furthermore, a cross-regional cooperation mechanism for industrial intelligence should be established, encouraging the transfer of advanced technologies and management experience from the eastern region to the central and western regions. Through measures such as technical assistance and industrial chain integration, coordinated development among regions can be promoted.

Third, actively leverage the key role of technological innovation in promoting export resilience. Against the backdrop of increasingly fierce global economic competition, increasing the technological content and value added of export products is crucial for the sustained and healthy development of China's export trade. On the one hand, efforts should be made to strengthen the innovation capacity of enterprises. Governments can encourage firms to increase R&D investment, establish R&D institutions, participate in the formulation of international standards, and enhance independent innovation capacity through incentive measures such as tax reductions, R&D subsidies, and innovation vouchers. On the other hand, the deep integration of industry, academia, and research should be promoted. A closer mechanism for industry-university-research-application collaboration should be established to facilitate synergistic innovation among universities, research institutions, and enterprises, accelerating the transformation of scientific and technological achievements into productive forces. In particular, cooperation between small and medium-sized enterprises and large firms as well as research institutions should be supported to enhance their technological absorption and innovation capacity. At the same time, the intelligent transformation of traditional industries must be advanced. Traditional export-oriented industries should undergo intelligent upgrading, utilizing technologies such as artificial intelligence, the Internet of Things, and big data to optimize production processes, improve production efficiency and product quality, and enhance the international competitiveness of export products.

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