



## The Impact of Data Factor Flow Environment on Export Resilience

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### Abstract

Based on panel data from 30 Chinese provinces between 2009 and 2023, this study innovatively constructs an indicator system for the data factor flow environment and empirically examines its impact mechanism on export resilience using a two-way fixed effects model. The findings reveal that optimizing the data factor flow environment significantly enhances export resilience, a conclusion robust to a series of tests. Furthermore, such optimization indirectly boosts export resilience by driving industrial structure upgrading and generating technology spillover effects. Heterogeneity analysis indicates that the enhancing effect of the data factor flow environment on export resilience is more pronounced in central and western regions and within pilot free trade zones. This research confirms that the market-oriented allocation of data factors, by reducing information friction costs and accelerating the recombination of innovation factors, has become a central engine for strengthening export resilience in the digital economy era.

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### 1. Introduction

With the United States imposing "reciprocal tariffs" on its trading partners in 2025, global trade risks have increased, and the security of Chinese enterprises' export trade is facing severe tests. Resilience has become a key capability for enterprises to cope with risks. As early as 2014, General Secretary Xi Jinping put forward the judgment that "the strong resilience of the Chinese economy is the most powerful support for preventing risks". Export resilience is the ability of the export trade system to avoid external shocks and return to its original state <sup>[1]</sup>. Strengthening export resilience is of great significance for stabilizing the basic role of China's foreign trade and promoting the high-quality growth of foreign trade. With the development of the digital economy, the data factor flow environment is based on the Internet, big data, etc., and emerging technologies continue to evolve, which can reduce trade costs and improve information matching efficiency. The "14th Five-Year Plan for the High-Quality Development of Foreign Trade" also proposes to promote the deep integration of digital technology and trade development. However, the current data factor flow environment is still subject to multiple obstacles, which may have a squeezing effect on the real economy. Therefore, the impact of the data factor flow environment on export resilience, the mechanism of action, whether it can be a path to enhance export resilience, and whether there are regional and policy heterogeneities are all issues worthy of in-depth study.

The value of data factors lies in their flow, and the optimization of their flow environment can improve allocation efficiency. Chadeiaux (2014) defined the attributes of data as a production factor <sup>[2]</sup>, later scholars defined it as an ecosystem supported by digital technology. In recent years, the research focus has shifted to economic benefits. For example, Lu H, Song C, Lingling L (2021) found that the data factor flow environment has a moderating effect on the urban innovation gap <sup>[3]</sup>, and it can enhance economic resilience and growth by promoting industrial structure upgrading <sup>[4]</sup>. Export resilience, as a key manifestation of economic resilience, has also received attention. Van den Berg and Jaarsma (2017) defined export resilience as the degree of rebound in export trade following a trade collapse <sup>[5]</sup>. He C F, Chen T (2019) argued that the connotation of resilience in export

trade lies in withstanding shocks, achieving robust recovery, and upgrading and optimizing the export structure. They also proposed the measurement method of export resilience for the first time, and empirically verified that diversified industrial structures and export modes can enhance export resilience<sup>[6]</sup>. Some studies have touched on the relationship between the digital economy and export resilience, believed that digital transformation can improve the export resilience of enterprises by improving the quality of product exports. Tian Y, Guo L (2023) have verified from the provincial or urban level that the development of the digital economy is conducive to improving export resilience<sup>[7]</sup>. The existing research has laid a foundation for understanding the importance of the data factor flow environment and export resilience, but the literature directly and systematically empirically testing the influence mechanism of the data factor flow environment itself on export resilience is still insufficient. This paper focuses on this, aiming to reveal its action path and boundary conditions.

## 2. Mechanism Analysis

The optimization of the data element flow environment enhances export resilience through the following mechanisms. First, its direct mechanism lies in the fact that an optimized environment can leverage technologies such as big data, the Internet of Things (IoT), and artificial intelligence (AI) to effectively reduce information asymmetry and trade costs, improve supply chain response efficiency and resource allocation effectiveness, thereby directly strengthening the ability of the export system to cope with external shocks. Second, it exerts an indirect impact by driving industrial structure upgrading: the flow of data elements promotes the digital and high-end transformation of traditional industries, spawns new business formats, and guides the allocation of resources to high-value-added links; the upgrading of industrial structure in turn supports export enterprises to elevate their position in the global value chain, making the structure of export commodities more in line with market demand and enhancing risk resistance. Finally, it empowers through the technology spillover effect: an efficient data flow environment facilitates knowledge sharing, R&D collaboration, and the agglomeration of innovation factors. This not only improves the efficiency of enterprises' technological innovation and the speed of achievement transformation, but also enhances enterprises' ability to develop new products and explore new markets by reducing R&D sunk costs, thereby significantly boosting the international competitiveness and resilience of export products.

In view of the above analysis, this paper puts forward the following hypothetical framework:

**Hypothesis 1:** The optimization of the data element flow

environment can significantly improve export resilience.

**Hypothesis 2:** The optimization of the data element flow environment improves export resilience through industrial structure upgrading.

**Hypothesis 3:** The optimization of the data element flow environment strengthens export resilience through the technology spillover effect.

## 3. Empirical Analysis

### 3.1. Model Construction

To verify the aforementioned research hypotheses and explore the impact of the data element flow environment on China's export resilience, this study constructs a two-way fixed effects model using panel data from 30 Chinese provinces (excluding Tibet, Hong Kong, Macao, and Taiwan) spanning 2009–2023. The calculation formula is as follows:

$$ExpRes_{it} = \beta_0 + \beta_1 Data_{it} + \beta_3 X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

In the equation,  $ExpRes_{it}$  denotes the export resilience of region in year  $i$ ;  $Data_{it}$  denotes the data element flow environment index of region in year  $i$ ;  $\beta_1$  represents the regression coefficient, the focus of this study, reflecting the impact of the data element flow environment on export resilience;  $X_{it}$  represents a set of control variables;  $\mu_i$  denotes regional fixed effects;  $\delta_t$  denotes time fixed effects;  $\varepsilon_{it}$  and is the random error term.

### 3.2. Variable Selection

#### 3.2.1. Explanatory Variable: Data Element Flow Environment.

Currently, no unified measurement system has been formed for the quantitative assessment of the data element flow environment, leaving a research gap in the academic community. Yang Yan's research team (2021) innovatively applied the entropy weight method to construct an evaluation system for the "Data Element Flow Environment Index"<sup>[8]</sup>. From a technical perspective, this system focused on hardware indicators such as the length of optical fiber cable lines, Internet broadband penetration rate, and the number of mobile phone base stations, but overlooked the market transaction dimension.

Based on the principles of indicator scientificity and availability, this paper constructs an index system for the data element flow environment from three perspectives: communication environment, Internet environment, and market environment. Using the entropy weight method, it selects statistical data from 30 Chinese provinces (excluding Tibet, Hong Kong, Macao, and Taiwan) between 2009 and 2023 as the research sample, with missing data supplemented by the linear interpolation method. The results calculated using the entropy weight method are as follows:

**Table 1:** Indicator System for the Data Element Flow Environment Index

| Level-1 Indicator                   | Level-2 Indicator         | Level-3 Indicator                                                              | Attribute | Score  |
|-------------------------------------|---------------------------|--------------------------------------------------------------------------------|-----------|--------|
| Data Element Flow Environment Index | Communication Environment | Total Postal Business Volume                                                   | +         | 0.1525 |
|                                     |                           | Total Telecommunication Business Volume                                        | +         | 0.1032 |
|                                     |                           | Number of Postal Letters                                                       | -         | 0.1385 |
|                                     |                           | Mobile Phone Switching Capacity                                                | +         | 0.0594 |
|                                     |                           | Mobile Phone Penetration Rate                                                  | +         | 0.0427 |
|                                     | Internet Environment      | Length of Long-Distance Telecommunication Optical Fiber Cable Lines            | +         | 0.0811 |
|                                     |                           | Number of Internet Users                                                       | +         | 0.0635 |
|                                     |                           | Number of Internet Broadband Access Ports                                      | +         | 0.0740 |
|                                     |                           | Number of Internet Broadband Access Subscribers                                | +         | 0.0752 |
|                                     | Market Environment        | Number of Granted Patents                                                      | +         | 0.0858 |
|                                     |                           | Number of Commodity Trading Markets with Annual Turnover over 100 Million Yuan | +         | 0.1241 |

The Data Element Flow Environment Index exhibits a significant positive correlation with market vitality. The improvement of this index directly indicates the degree of improvement in the data element circulation mechanism, and exerts a multiplier effect on the vitality of market entities through paths such as reducing transaction costs and optimizing resource allocation.

### 3.2.2. Explained Variable: Urban Export Resilience

For export resilience, this study draws on the measurement method proposed by the Canfei and Chen Tao (2019). The export resilience under the impact of the financial crisis is measured by the degree of deviation between the export volume of each province in China from 2009 to 2023 and that in 2008. The calculation formula is as follows:

$$ExpRes_{it} = \frac{export_{it} - export_{2008}}{export_{2008}}$$

Where  $i$  represents the region and  $t$  represents the year;  $ExpRes_{it}$  denotes the export resilience of region  $i$  in year  $t$ ; and  $export_{it}$  and  $export_{2008}$  respectively stand for the export volume of region  $i$  in year  $t$  and 2008.

### 3.2.3. Control Variables

In addition to the core explanatory variables, selects the following control variables:

Educational Expenditure Level (edu): Reflects the priority given by local governments to human capital investment, measured by the proportion of educational expenditure in the general public budget. Foreign Trade Openness (open): Measures the depth of a region's participation in globalization, expressed as the ratio of the region's total import and export trade volume to its gross domestic product (GDP). Government Expenditure Level (gov): Serves as a core indicator for measuring the intensity of government economic regulation, quantified by the ratio of the total general public budget expenditure of local governments to the regional GDP. Number of Medical and Health Institutions (health): Gauges the level of infrastructure development in the region. Technology Market Level (tec): Indicates the efficiency of technological achievement transformation,

measured by the ratio of the total transaction volume of technology contracts to the regional GDP.

### 3.2.4. Mediating Variables

Industrial Structure Upgrading (ISU): The flow of data elements optimizes resource allocation, thereby promoting an increase in the proportion of the tertiary industry. This transforms the export structure from low-value-added manufacturing to high-value-added service industries or technology-intensive industries, which helps mitigate risks from external shocks and enhance the level of export diversification and risk resistance capacity. Therefore, ISU is measured by the proportion of the added value of the tertiary industry in the regional GDP.

Technology Spillover Effect (TED): The flow of data elements accelerates knowledge sharing and R&D collaboration, which in turn enhances the regional R&D intensity and technology absorption capacity. Thus, TED is measured using the regional R&D intensity, i.e., the ratio of R&D expenditure to the regional GDP.

### Baseline Regression

Table 2 reports the regression results regarding the impact of the Data Element Flow Environment on export resilience. Column (1) includes only the core variables, and the coefficient of Data (Data Element Flow Environment) is significantly positive at the 5% significance level. After gradually adding control variables, Column (2) shows that the coefficient of Data remains significant at the 1% significance level; the results remain robust even after controlling for time and provincial fixed effects, thus verifying Hypothesis 1.

Regarding control variables: Foreign trade openness (open) and the number of medical and health institutions (health) both exert a significantly positive impact on export resilience, which is consistent with theoretical expectations. In contrast, educational expenditure (edu) and government expenditure (gov) have significantly negative coefficients. This may be attributed to inefficiencies in public resource allocation and the inhibitory effect of excessive government intervention. The  $R^2$  of the models ranges from 0.772 to 0.791, indicating a good fit.

**Table 2:** Baseline Regression Results

|                | (1)                 | (2)                  |
|----------------|---------------------|----------------------|
| Variable       | ExpRes              | ExpRes               |
| Data           | 4.962**<br>(2.258)  | 6.284***<br>(2.243)  |
| edu            |                     | -23.65***<br>(5.740) |
| open           |                     | 7.063***<br>(1.479)  |
| gov            |                     | -8.268**<br>(3.540)  |
| health         |                     | 3.541**<br>(1.570)   |
| tec            |                     | 9.910<br>(7.720)     |
| Constant       | 2.102***<br>(0.375) | -29.22*<br>(16.03)   |
| N              | 450                 | 450                  |
| R <sup>2</sup> | 0.772               | 0.791                |
| FE             | Yes                 | Yes                  |

Notes: 1. \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels, respectively;  
2. standard errors are in parentheses, and the same applies below.

### Robustness Tests

To further verify the robustness of the baseline regression results, this study employs methods including lagging explanatory variables, excluding partial samples, and redefining the explained variable, as detailed below:

#### 1. Reconstruction of Explanatory Variable Measurement

To address potential measurement bias in index construction, the Principal Component Analysis (PCA) method is used to reconstruct the Data Element Flow Environment Index (denoted as PCAdata). As shown in Column (1) of Table 5, the estimated coefficient of the reconstructed core explanatory variable is significantly positive at the 5% significance level. Both the direction and significance level are highly consistent with the baseline model, confirming that differences in measurement methods do not lead to systematic bias.

#### 2. Lagging the Core Explanatory Variable

Considering the time-lag characteristics of policy effects and the transmission mechanism of economic variables, dynamic panel models with the 1<sup>st</sup> lag (lag1\_Data) and 2<sup>nd</sup> lag (lag2\_Data) of the core explanatory variable are constructed. Specific results are presented in Columns (2) and (3) of Table 5: the coefficients of the lagged terms remain significantly positively associated at the 5% level. This not only confirms the sustained effect of export resilience improvement but also indirectly mitigates the endogeneity bias caused by reverse

causality through the instrumental variable method.

#### 3. Exclusion Test of Special Samples

Given the extreme characteristics of data element endowments and economic structures in Beijing, Shanghai, and Guangdong, this study follows the robustness test paradigm proposed by Fan H, Wu T (2022) and re-estimates the model using a subsample of 27 provinces after excluding the aforementioned three regions <sup>[9]</sup>. The estimated coefficient of the core variable remains significantly positive at the 1% level, demonstrating the cross-regional universality of the research conclusions.

#### 4. Reconstruction of the Explained Variable

Drawing on the research approach of Xu Chaokai and Liu Hongman (2023), the natural logarithm of urban export volume is decomposed using the Hodrick-Prescott (HP) Filter. A dynamic resilience indicator (ExpRes = Trend/Cycle) is constructed as the ratio of the trend component (Trend) to the cyclical component (Cycle). This measurement effectively captures the elasticity of deviation between actual export growth and its potential path <sup>[10]</sup>. Here, the smoothing parameter is set to 6.25, and the regression is conducted using the logarithm of 100 times ExpRes with cluster-robust standard errors. As shown in Column (5), the coefficient is significantly positive at the 5% level, further confirming the robustness of the results.

**Table 3:** Robustness Test Results

| Variable          | (1)<br>Reconstruction | (2)<br>1 <sup>st</sup> lag | (3)<br>2 <sup>nd</sup> lag | (4)<br>Exclusion    | (5)<br>Reconstruction |
|-------------------|-----------------------|----------------------------|----------------------------|---------------------|-----------------------|
| PCAdat            | 0.493***<br>(0.160)   |                            |                            |                     |                       |
| lag1_Data         |                       | 5.505**<br>(2.424)         |                            |                     |                       |
| lag2_Data         |                       |                            | 5.463**<br>(2.346)         |                     |                       |
| Data              |                       |                            |                            | 9.730***<br>(3.581) | 4.079**<br>(1.485)    |
| Constant          | -26.20*<br>(15.88)    | -24.99<br>(16.21)          | -25.72<br>(16.46)          | -29.34*<br>(17.00)  | -19.51**<br>(9.352)   |
| N                 | 450                   | 420                        | 390                        | 405                 | 450                   |
| R <sup>2</sup>    | 0.792                 | 0.752                      | 0.761                      | 0.798               | 0.209                 |
| Control Variables | Yes                   | Yes                        | Yes                        | Yes                 | Yes                   |
| FE                | Yes                   | Yes                        | Yes                        | Yes                 | Yes                   |

### Mechanism Test

The baseline regression results confirm that the Data Element Flow Environment exerts a significant positive driving effect on export resilience. To examine whether the Data Element Flow Environment influences export resilience through the two mechanisms of Industrial Structure Upgrading (ISU) and Technology Spillover Effect (TED), this study builds on the traditional mediating effect method and draws on the suggestions of Jiang Ting (2022) regarding the traditional stepwise regression mediating effect method: instead of including the explained variable, mediator, and core explanatory variable in the same regression equation, the mediating effect test is conducted using the first two regression equations in the three-step regression <sup>[11]</sup>.

The mediating effect test results show that the flow of data elements significantly enhances export resilience (ExpRes) through dual transmission paths. First, as shown in Column (1) of Table 5, the Data Element Flow Environment Index has a significant promoting effect on Industrial Structure Upgrading (ISU), verifying Hypothesis 2. Second, Column (2) indicates that the Data Element Flow Environment also exerts a significant positive impact on the Technology Spillover Effect (TED), which is significant at the 1% level. Notably, the direct effect and mediating effect of data elements coexist—this implies that data elements can not only directly enhance resilience through the reorganization of traditional production factors but also achieve indirect empowerment through structural transformation.

### 4. Heterogeneity Analysis

#### 4.1. Regional Heterogeneity

To examine the characteristics of regional heterogeneity, 30 provinces were divided into two major groups: eastern regions and central-western regions, for grouped regression. The results, shown in Column (3) of Table 5, indicate that Data is only statistically significant at the 5% level in central-western regions. This demonstrates that the strengthening effect of Data on export resilience exhibits significant regional heterogeneity.

#### 4.2. Establishment of Pilot Free Trade Zones (FTZs)

This section explores whether the establishment of FTZs significantly alters the impact of the data factor flow environment on regional export resilience. First, inter-provincial data were grouped: regions without an FTZ were assigned a value of 0, while those with an FTZ were assigned a value of 1. Column (4) of Table 5 passed the significance test, suggesting that the establishment of FTZs better facilitates the improvement of regional export resilience.

#### 4.3. Heterogeneity of Location Factors

This part investigates whether geographical location remains a key factor influencing the development of regional export trade. The results, presented in Columns (5) and (6) of Table 5, show certain differences between the two columns. However, Data passed the significance test in both cases. Therefore, this study concludes that data factor flow exerts a consistent impact on export resilience regardless of whether the region is coastal, riverside, or inland. Nevertheless, this implies that geographical location may exert a substitution effect on data factors through traditional trade channels.

**Table 4:** Heterogeneity Analysis Results

| Variable          | (1)<br>ISU            | (2)<br>TED          | (3)<br>central-western | (4)<br>FTZ          | (5)<br>Non-coastal  | (6)<br>Coastal    |
|-------------------|-----------------------|---------------------|------------------------|---------------------|---------------------|-------------------|
| Data              | 0.0959***<br>(0.0338) | 4.780***<br>(0.499) | 14.35**<br>(6.690)     | 4.908***<br>(1.640) | 20.15*<br>(10.65)   | 2.562*<br>(1.520) |
| Constant          | -0.662***<br>(0.221)  | -1.722<br>(2.475)   | -16.06<br>(23.27)      | -36.67**<br>(15.44) | -79.44**<br>(39.27) | -9.936<br>(12.63) |
| N                 | 450                   | 450                 | 285                    | 270                 | 180                 | 270               |
| R <sup>2</sup>    | 0.953                 | 0.945               | 0.804                  | 0.910               | 0.717               | 0.900             |
| Control Variables | Yes                   | Yes                 | Yes                    | Yes                 | Yes                 | Yes               |
| FE                | Yes                   | Yes                 | Yes                    | Yes                 | Yes                 | Yes               |



## 5. Results and Discussion

### 5.1. Research Conclusions

As the core production factor in the digital economy, data factors have become a focal point of attention in both policy and academic circles. Based on China's provincial panel data from 2009 to 2023, this study empirically examines the impact mechanism of the data factor flow environment on export resilience. The core conclusions are as follows:

1. The data factor flow environment exerts a significant and robust promotional effect on export resilience. Verified by the two-way fixed effects model, instrumental variable method, and multi-dimensional robustness tests, optimizing this environment can effectively enhance regional export resilience. Moreover, improving data infrastructure and smoothing factor circulation channels serve as the key foundation for this enhancement.
2. Data factors indirectly empower export resilience through the dual pathways of "industrial structure upgrading" and "technology spillover effect". On one hand, data flow drives the evolution of industrial structure toward higher value-added sectors, solidifying the micro-foundation of export resilience. On the other hand, it builds an efficient knowledge sharing platform, accelerating technology spillovers to improve enterprises' R&D efficiency and product competitiveness.
3. The driving effect of data factors exhibits significant heterogeneity. In terms of spatial dimension, the enhancement effect in central and western regions is significantly stronger than that in eastern regions, reflecting a "catch-up effect". In terms of policy dimension, the establishment of Pilot Free Trade Zones (FTZs) strengthens the positive role of data factors. From the perspective of geographical location adjustment, data factors in inland regions may play a more critical role as a "substitutional" competitive advantage.

### 5.2. Policy Recommendations

1. Deepen institutional opening-up of data factors and strengthen policy empowerment for FTZs. With FTZs as the core, launch pilot projects for classified management of cross-border data flow and establish a "data customs" regulatory framework. Endow FTZs with greater autonomy in the market-oriented allocation of data factors, and implement a "negative list + white list" system for cross-border data flow. Furthermore, improve rules for data ownership confirmation, pricing, and security protection, align with high-standard international economic and trade rules to remove cross-border data flow barriers, and incorporate enterprises' data management capabilities into the export credit rating system.
2. Implement a regional gradient development strategy for data factors. Prioritize the layout of national-level data exchange centers in western hubs (e.g., Chengdu-Chongqing, Gui'an). Reduce enterprises' data usage costs through policies such as financial subsidies and tax incentives, and convert the potential of data factors into export momentum.
3. Promote in-depth integration of data factors with industries. In eastern regions, launch the "Data Factor × Initiative" and explore the mechanism for recognizing

data assets in financial statements. In central and western regions, implement the "Data Factor Substitution Initiative", guide data factors to tilt toward industries with distinctive advantages, and support these industries in moving up the value chain.

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