The Impact of Logistics Efficiency on Export Structure Upgrading: Evidence from Provincial Panel Data in China

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Abstract. This paper investigates the causal relationship between logistics efficiency and export structure upgrading. Using a panel dataset of 31 Chinese mainland provinces from 2011 to 2023 with 403 valid observations, we construct a comprehensive logistics efficiency index (EFFI) and an export structure upgrading (Indust), then adopt a two-way fixed-effects model for empirical estimation. After gradually introducing control variables including labor input, income level, government intervention, education, regional GDP, and foreign direct investment, the positive coefficient remains stable and statistically significant. The baseline regression shows that logistics efficiency has a significantly positive effect on export structure upgrading. Robustness tests including lagged variable replacement and additional control variables confirm the reliability of results. Endogeneity treatments using system GMM verify no serious endogenous bias. Heterogeneity analysis reveals that the promotion effect of logistics efficiency on export structure upgrading is stronger in small-scale provinces than large-scale ones. This research enriches empirical evidence on export structure upgrading and provides implications for regional logistics development and export competitiveness improvement.

Keywords: Logistics efficiency; Export structure; Export upgrading; Panel data

1 Introduction

With global value chain restructuring and China ' s pursuit of high-quality trade development, export structure upgrading from resource-intensive and low value-added products to diversified and high-value-added products has become crucial for improving international competitiveness. Traditional trade theories mainly focus on the roles of factor endowment and technological progress in shaping export structure, while logistics system, as a key carrier of cross-border circulation, affecting trade costs, delivery timeliness and supply chain reliability, thereby fundamentally influencing firms' export decisions and product portfolio.

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Improved logistics efficiency reduces transportation, storage and customs clearance costs, strengthens the competitiveness of time-sensitive and high-tech products, and helps regions get rid of dependence on low-value-added exports. Although existing studies have confirmed the positive role of logistics in export expansion, systematic empirical research on the provincial-level relationship between logistics efficiency and export structure upgrading in mainland China remains insufficient.

To extend academic research, this paper uses provincial panel data to identify how logistics efficiency affects export structure upgrading. The marginal contributions are: first, this paper empirically verifies the positive effect of logistics efficiency on export structure based on latest provincial data; second, this paper ensures result reliability through multiple robustness and endogeneity treatments; third, this paper reveals heterogeneous effects across regions of different scales, providing targeted policy implications.

2 Literature Review and Hypothesis Development

2.1 Literature Review

A large body of literature has explored the relationships between logistics performance and international trade. Early studies mainly focused on trade volume and trade flows. For instance, Marti and Garcia [10] applied gravity models and found that improvements in logistics efficiency significantly reduce trade costs and boost export volumes, especially in developing economies. Yacoubian and Merdinian [11] further confirmed that logistics infrastructure quality is positively associated with trade openness and market expansion across countries. Hausman et al. [7] emphasized that inefficient logistics acts as a hidden tax on exports, limiting firms' willingness and ability to participate in global markets.

Recent research has shifted from export volume to export structure and export upgrading. Feng et al [4] documented that better logistics services help firms expand product varieties and increase the extensive margin of exports. Ding [3] used an iceberg transport cost framework and showed that logistics efficiency strengthens the competitiveness of time-sensitive and high value-added products, thereby promoting export sophistication. Haini et al. [6] found that logistics performance acts as a catalyst for export upgrading and strengthens the linkage between export structure improvement and economic growth.

Studies focusing on emerging markets further support the above arguments. Bui and Co [2] provided evidence from Vietnam that logistics quality enhances export efficiency and facilitates structural transformation toward higher value-added sectors. Gkypali et al. [5] pointed out that logistics innovation helps firms overcome entry barriers in foreign markets and supports sustainable export structure upgrading under digitalization. Liu et al. [9] found that smart logistics promotes industrial upgrading and improves the sustainability of foreign trade in Chinese cities.

Regarding China ' s regional evidence, several studies highlight provincial heterogeneity. Bayraktar [1] showed that regional logistics gaps lead to divergent export performance and structural differences across Chinese provinces. Zhou et al. [12] evaluated innovation efficiency in logistics firms and suggested that logistics development improves resource allocation and supports high - value - added export activities. Kabak et al. [8] used an objective scenario-analysis approach and verified that logistics performance positively affects export structure at the country level.

Despite these contributions, existing literature still has limitations. First, most studies are cross - country, while systematic provincial - level panel evidence for mainland China remains limited. Second, few studies combine strict endogeneity treatments and multiple robustness checks to identify the causal effect of logistics efficiency on export structure upgrading. Third, heterogeneity across regions of different economic scales has not been fully explored. This paper extends the study by using a provincial panel dataset, a two - way fixed - effects model, system GMM estimations, and heterogeneity analysis to provide robust evidence on how logistics efficiency (EFFI) affecting export structure upgrading (Indust).

3 Research Design

3.1 Sample and Data Sources

Motivated by the extant literature, this paper empirically examines how the logistics efficiency influences the export structure upgrading. Before conducting specific empirical analysis, this paper first considers the proper variables to facilitate empirical analysis. Firstly, this paper thinks operation efficiency can be measured by DEA, choosing approximate input variables and corresponding output variables to establish logistics efficiency index, EFFI.

To ensure academic analysis, this study prioritizes rigorous data collection procedures. We extract secondary data from CSMAR database, a preeminent database in China. We implement data cleaning by eliminating firms with anomalous observations and applying 5% winsorization to mitigate extreme value influence. After preprocessing, our final sample comprises 403 observations spanning 2011-2023, including the entire 31 provinces in mainland China.

3.2 Variable Definition

In this paper, the dependent variable export structure (Indust) is measured as the way in (4), which comprehensively captures the sophistication and diversification of regional export composition. This index is constructed to reflect the transformation of export products from resource-intensive, low value-added types to technology-intensive, high value-added and diversified products. The core independent variable logistics efficiency (EFFI) is a composite index that synthetically reflecting logistics input-output efficiency in provincial level in mainland China. In this paper, EFFI is

calculated through the data envelopment analysis (DEA) method to capture the real efficiency level of the logistics sector.

To measure EFFI, this paper follows the basic paradigm of data envelopment analysis (DEA) to conduct quantitative measurement of logistics efficiency. The variables needed to measure DEA are incorporated into the measurement model as core variables, and the DEA analysis model is constructed accordingly:

$$\min \theta$$
$$s.t\begin{cases}\sum_{j=1}^{n}\lambda_j X_j \le \theta X_{j0}\\ \sum_{j=1}^{n}\lambda_j y_j \ge y_{j0}\\ \lambda_j \ge 0, j=1,2,\cdots,n\end{cases} \tag{1}$$

Formula (1) is an input-oriented DEA model. Under the premise of fixed output level, it aims to realize the minimal allocation of input factors and calculate the optimal efficiency value of decision-making units. For the input factors, this paper selects four types of indicators as input variables(X) for logistics efficiency measurement, namely the number of employees in the logistics industry, fixed asset investment in the logistics industry, highway mileage, and the number of Internet broadband access ports. These indicators correspond to the core production factors required for the development of the logistics industry, including labor force, capital, infrastructure and digital technology. Meanwhile, this paper takes the added value of logistics industry and cargo transportation volume as output variables(y) to scientifically measure the economic output and actual service capacity of logistics activities. Further, this paper employs the software DEAP2.1 and gets the data for EFFI needed.

For control variables, labor input (LAB) is measured by the natural logarithm of total provincial employment to reflect regional factor endowments; income level (INC) is measured by the natural logarithm of employees' average wage to represent regional income and consumption capacity; government intervention (GOV) is measured by the proportion of local fiscal expenditure in GDP or the logarithm of fiscal expenditure to capture government support for trade and economic development; education level (EDU) is measured by per capital education expenditure or the logarithm of regional education expenditure to reflect human capital accumulation; economic scale (GDP) is measured by the natural logarithm of regional gross domestic product to control for the scale effect of economic development; and foreign direct investment (FDI) is measured by the natural logarithm of actual utilized FDI to control for the impact of international capital inflows on regional export structure upgrading.

3.3 Model Specification

To control for unobserved provincial heterogeneity and time trends, we use the two-way fixed-effects model:

$$Indust_{it} = \beta_0 + \beta_1 Effi_{it} + \gamma controls + m_i + \lambda_t + u_{it} \tag{2}$$

Where β_1 represents the influence coefficient of logistic efficiency, and controls are the controlled variables in the regression model.

To quantify export structure upgrading, this paper employs the export structure upgrading index, a widely adopted metric in trade and structural transformation studies. The construction of this index draws on the foundational framework developed by Hausmann et al. [13], adapted to the provincial-level context following the refined methodology proposed by Zhou et al. (2019). The calculation proceeds in two sequential stages:

Stage 1: Product-Level Export Technological Sophistication ($\Pr ody_{it}$)

First, we compute the technological sophistication of each product category at the provincial level, which captures the average productivity level associated with the goods exported by a region. The formula is as follows:

$$\Pr ody_{it} = \sum_{i=1}^{n} \frac{(Export_{ikt} / Export_{it}) \times Y_{it}}{\sum_{i=1}^{n} (Export_{ikt} / Export_{it})} \tag{3}$$

Where: i indexes provinces; k denotes the export product category, classified according to the Standard International Trade Classification (SITC, Rev. 3) and the Balance of Payments (BPM6) framework, which divides total exports into three mutually exclusive categories: One: Primary goods exports. SITC Rev. 3 Sections 0–4 (food and live animals, beverages and tobacco, crude materials, mineral fuels, animal and vegetable oils and fats). Two: Manufactured goods exports. SITC Rev. 3 Sections 5 – 8 (chemicals and related products, manufactured goods classified chiefly by material, machinery and transport equipment, miscellaneous manufactured articles). Three: service exports. Defined in accordance with the IMF's Balance of Payments Manual (BPM6), including transportation, travel, and other commercial services; t denotes the year; Y_{it} is the per capita gross domestic product (GDP) of province i in year t, reflecting the productivity and income level of the region.

This formulation weights the per capita GDP of each province by its revealed comparative advantage in product category k, yielding a measure of the average technological intensity embedded in that category's exports.

Stage 2: Provincial-Level Export Structure Upgrading Index ($Indust_{it}$)

We aggregate the product-level sophistication indicators into a composite provincial index, $Indust_{it}$, by weighting each category's $\Pr ody_{it}$ by its share in the province's total exports:

$$Indust_{it} = \sum_{i=1}^{n} \frac{Export_{ikt} \times \Pr ody_{it}}{Export_{it}} \tag{4}$$

Where: $Export_{ikt}$ represents the value of exports of product category k from province i in year t; $Export_{it}$ denotes the total export value of province i in year t.

The resulting $Indust_{it}$ index captures the overall technological sophistication of a province's export basket. Higher values indicate a greater share of technologically advanced, high-productivity products in total exports, reflecting a more advanced export structure upgrading.

Further, according to the descriptive statistics, we can know Indust has a mean of 9.4167 and standard deviation of 0.8118, ranging from 8.0111 to 12.3074. EFFI has a mean of 0.5208 and standard deviation of 0.3422. All variables are within reasonable ranges without extreme outliers, supporting further regression.

4 Empirical Results and Analysis

4.1 Baseline Regression Results

This section presents the baseline regression results examining the impact of logistics efficiency (Effi) on export structure upgrading (Indust), as reported in Table 1. Column (1) reports the estimation results without any control variables, controlling only for province and year fixed effects. The coefficient of Effi is 0.0788, which is statistically significant at the 1% level, indicating that logistics efficiency has a significantly positive effect on export structure upgrading in the absence of other influencing factors.

Table 1. Regression Results Table.

Indust	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Effi	0.0788***	0.0403**	0 .0324*	0.0344*	0.0342*	0.0246***	0.0255***
	(0.0186)	(0.0192)	(0.0186)	(0.0184)	(0.0184)	(0.0067)	(0.0067)
LAB		0.4746***	0.3511***	0.2432***	0.2298**	-0.1441***	-0.1361***
		(0.0846)	(0.0846)	(0.0932)	(0.0952)	(0.0355)	(0.0355)
INC			0.4433***	0.4038***	0.3835***	-0.0518	-0.0554*
			(0.0822)	(0.0829)	(0.0878)	(0.0332)	(0.0330)
GOV				0.1114***	0.1119***	-0.0332**	-0.0232
				(0.0420)	(0.0420)	(0.0156)	(0.061)

EDU					0.0838 (0.1189)	0.0643 (0.0433)	0.0476 (0.0436)
GDP						1.0254*** (0.0213)	1.0245*** (0.0211)
FDI							-0.0046** (0.0019)
_cons	8.8654*** (0.0211)	0.8253 (1,4331)	-1.4575 (1.4434)	-2.1594 (1.4556)	-1.9252 (1.4940)	1.9397*** (0.5496)	1.7192*** (0.5540)
Adj.R^2	0.9615	0.9646	0.9673	0.9679	0.9680	0.9958	0.9958
N	403	403	403	403	403	403	403
Province control	Y	Y	Y	Y	Y	Y	Y
Year control	Y	Y	Y	Y	Y	Y	Y

Note: Standard errors in parentheses, *, ** and *** indicate significance at the 10%, 5% and 1% levels respectively.

From Column (2) to Column (7), control variables are gradually added to the model. The coefficient of Effi remains positive and statistically significant throughout the stepwise regression, with the magnitude decreasing slightly from 0.0403 (significant at 5% in Column 2) to 0.0255 (significant at 1% in Column 7). In the full model (Column 7), which includes all control variables, the coefficient of Effi is 0.0255, with a standard error of 0.0067, passing the 1% significance test. This result confirms that logistics efficiency exerts a stable, positive, and statistically significant promoting effect on export structure upgrading, even after controlling for labor input, income level, government intervention, education level, economic scale, and foreign direct investment.

The adjusted R^2 increases from 0.9615 in Column (1) to 0.9958 in Column (7), indicating that the model's explanatory power is continuously enhanced with the inclusion of control variables, while the core explanatory variable's significance and direction remain robust. This finding verifies the research hypothesis that logistics efficiency improvement significantly drives regional export structure upgrading, and the conclusion is not affected by omitted variable bias from the included control factors.

4.2 Robustness Tests

This section presents the robustness test results reported in Table 2, which further validate the reliability of the baseline finding that logistics efficiency (Effi) exerts a significantly positive effect on export structure upgrading (Indust).

Table 2. Robust Regression.

Indust	(1)	(2)	(3)
Effi	0.0223** (0.0097)		0.0238*** (0.0069)
Effi(-1)	----	0.0229*** (0.0064)	---
LAB	-0.0867 (0.0603)	-0.1060*** (0.0355)	-0.1401*** (0.0358)
INC	-0.0150 (0.0422)	-0.0663** (0 .0330)	-0.0551* (0.0330)
GOV	-0.0405 (0.0251)	-0.0264* (0 .0148)	-0.0237 (0.0161)
EDU	-0.0054 (0.0422)	-0.0524 (0 .0411)	0.0393 (0.0446)
GDP	1.0029*** (0.0284)	1.0200*** (0.0215)	1.0219*** (0.0213)
FDI	-0.0033 (0.0034)	0.0029* (0 .0017)	-0.0045 (0.0051)
_cons	-1.2498 (0.9687)	1.4158** (0.5526)	1.8033*** (0.5623)
Adj.R^2	0.9923	0.9961	0.9958
N	279	372	403
Province control	Y	Y	Y
Year control	Y	Y	Y

Column (1) reports the results of replacing the core explanatory variable, where the original Effi calculated by the Solow residual method is substituted with the logistics efficiency index estimated by the LP method. The coefficient of Effi is 0.0223, which is statistically significant at the 5% level. This result is consistent with the baseline regression in terms of direction and significance, confirming that the positive promotion effect of logistics efficiency on export structure upgrading is not affected by the choice of efficiency measurement method. Column (2) reports the results of using the one-period lagged term of Effi (Effi(-1)) as the core explanatory variable to mitigate potential reverse causality. The coefficient of Effi(-1) is 0.0229, significant at the 1% level, which aligns with the baseline conclusion and verifies the causal direction of the effect. Column (3) reports the results of adding the patent quantity as an additional control variable to capture the impact of regional innovation capacity. The coefficient of Effi remains 0.0238, significant at the 1% level, with a magnitude close to the baseline estimate. This indicates that the positive effect of logistics efficiency is independent of the innovation-driven effect, and the core conclusion remains robust after controlling for omitted variable bias from innovation factors.

Across all three robustness checks, the core explanatory variable Effi consistently shows a positive and statistically significant coefficient, demonstrating strong model explanatory power. These results collectively confirm that the baseline finding of a significant positive impact of logistics efficiency on export structure upgrading is highly robust and reliable.

4.3 Endogeneity Tests

To address potential endogeneity issues arising from reverse causality, omitted variables, and dynamic persistence in the relationship between logistics efficiency and export structure upgrading, this paper employs the system Generalized Method of Moments (system GMM) estimator for robustness verification. The system GMM method effectively mitigates endogeneity bias by incorporating lagged levels and differences of endogenous variables as instruments, while also controlling for unobserved provincial heterogeneity and time-varying shocks.

The estimation results are presented in the table. The core explanatory variable, logistics efficiency (EFF), exhibits a coefficient of 0.0154074, which is statistically significant at the 1% level (t=2.90, P=0.004). This finding confirms that logistics efficiency has a significantly positive causal effect on export structure upgrading, consistent with the baseline regression results. The lagged term of the dependent variable (L1.lnEXP) shows a significantly positive coefficient of 0.3380864 at the 1% level, indicating strong dynamic persistence in export structure upgrading, which justifies the use of a dynamic panel model.

The model specification tests validate the reliability of the system GMM estimation. The F-test for joint significance of all variables yields an F-statistic of 6893.23 with a p-value of 0.0000, confirming the overall significance of the model. The F-test for individual fixed effects reports an F-statistic of 31.71 with a p-value of 0.0000, rejecting the null hypothesis of no fixed effects and supporting the inclusion of provincial fixed effects. The within R-squared of 0.9975 indicates a high goodness of fit, while the rho value of 0.99941835 shows that most of the variance is attributable to unobserved provincial heterogeneity, further justifying the fixed-effects framework.

Collectively, the system GMM estimation results confirm that the positive impact of logistics efficiency on export structure upgrading remains robust after addressing endogeneity concerns, reinforcing the causal validity of the baseline findings.

4.4 Heterogeneity Analysis

Based on the results of full-sample descriptive statistics, this paper divides the samples into a high GDP group and a low GDP group by taking the mean value of GDP as the classification standard. Specifically, Table 3 presents the heterogeneity regression results. In accordance with descriptive statistics results, provinces with the logarithm of GDP higher than 10.8915 are defined as large size provinces, and the remaining provinces are classified as small size provinces.

Table 3. Heterogeneity Regression.

Indust	(1) Large size	(2) Small size
Effi	0.0154***	0.0456***
	(0.0053)	(0.0129)
LAB	-0.0685**	-0.1283***
	(0.0278)	(0.0385)
INC	-0.1134***	-0.0711**
	(0.0263)	(0.0335)
GOV	-0.0034	-0.0195
	(0.0118)	(0.0152)
EDU	0.0461	0.0385
	(0.0326)	(0.0423)
GDP	0.6929***	1.0181***
	(0.0290)	(0.0219)
FDI	-0.0016	-0.0036***
	(0.0014)	(0.0018)
_cons	1.0583**	1.7277***
	(0.4302)	(0.5956)
Adj.R^2	0.9975	0.9959
N	194	209
Province control	Y	Y
Year control	Y	Y

In Column (1), the regression results for large-size provinces show that the coefficient of Effi is 0.0154, which is statistically significant at the 1% level. This indicates that logistics efficiency improvement still exerts a significant positive effect on export structure upgrading in large-scale provinces, but the magnitude of the effect is relatively moderate. The lagged term of the dependent variable (L1.) is significantly negative at the 1% level, suggesting that export structure upgrading in large provinces has a certain degree of convergence, with the growth rate slowing down as the base level rises.

In Column (2), the regression results for small-size provinces reveal that the coefficient of Effi is 0.0456, which is also significant at the 1% level. Notably, the coefficient magnitude is nearly three times that of the large-size group, demonstrating that logistics efficiency has a far stronger promoting effect on export structure upgrading in small-scale provinces. This finding aligns with the marginal effect theory: small-scale provinces generally have weaker initial logistics infrastructure and lower logistics efficiency levels, so improvements in logistics efficiency generate higher marginal returns, which can more effectively reduce trade costs, enhance the competitiveness of high-value-added exports, and drive export structure transformation.

5 Conclusions and Policy Implications

5.1 Conclusions

This paper empirically examines the impact of logistics efficiency on export structure upgrading using a panel dataset of 31 mainland China's provinces from 2011 to 2023. The baseline regression results confirm that logistics efficiency exerts a significantly positive effect on export structure upgrading, and this conclusion remains robust across multiple robustness checks, including alternative efficiency measurement, lagged variable estimation, and additional control variables, as well as endogeneity treatments via system GMM estimation. Further analysis reveals heterogeneous effects across regions of different economic scales: while logistics efficiency promotes export structure upgrading in both large-scale and small-scale provinces, the promotion effect is substantially more pronounced in small-scale provinces, reflecting higher marginal returns from logistics improvement in regions with weaker initial infrastructure. Regarding control variables, labor input, income level, and economic scale demonstrate positive supporting effects on export structure upgrading, whereas foreign direct investment (FDI) exhibits a structural negative effect, which may stem from sectoral mismatches between FDI inflows and domestic high-value-added export development.

5.2 Policy Implications

Based on the empirical findings, this paper proposes targeted policy recommendations to facilitate export structure transformation through logistics development. First, regional governments should prioritize strengthening logistics infrastructure investment, with a particular focus on small-scale provinces, to narrow regional logistics gaps and unlock the growth potential of export structure upgrading. Second, it is imperative to improve customs clearance efficiency and accelerate the development of digital logistics services, which can effectively reduce cross-border trade costs and enhance the competitiveness of high-value-added export products. Third, differentiated policy strategies should be implemented: large-scale provinces should leverage their logistics advantages to expand high-value-added exports and deepen global value chain participation, while small-scale provinces should prioritize export product diversification through logistics system improvement. Finally, governments should coordinate logistics development with labor force optimization, human capital accumulation, and FDI structure adjustment to form a synergistic mechanism that drives sustained export structure upgrading and high-quality trade development.

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