Dual Impact of Digital Transformation on International Trade and Regional Economic Development

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Abstract. This study aims to explore how digital transformation affects the efficiency of international trade and regional economic development through empirical analysis. By evaluating the prevalence of information and communication technology, the proportion of digital applications in enterprises, and the level of infrastructure construction, the results indicate that digitalization significantly enhances the efficiency of international trade and promotes regional economic growth, providing important data support and development strategies for policy-making.

Keywords: Digital transformation; International trade efficiency; Regional economic development.

1 Introduction

In the context of accelerated globalization, digital transformation has become a key factor driving international trade and regional economic development. By employing panel data regression models and dynamic panel data models, this analysis aims to reveal how digitalization optimizes transaction efficiency and operational costs, thereby fostering economic growth. It is expected to provide new perspectives and strategic suggestions for policy-making.

2 The Relationship Between Digital Transformation and International Trade and Regional Economic Development

Digital transformation is a significant driving force behind contemporary international trade and regional economic development. By improving transaction efficiency, reducing operational costs, and enhancing market transparency, it has markedly changed traditional trade patterns and the trajectory of regional economic growth. The application of digital technology facilitates trade by enabling real-time sharing and processing of information, which accelerates international trade processes and reduces information asymmetry, thereby enhancing trust and cooperation among market participants [1].

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Digital tools such as big data analytics and artificial intelligence allow companies to predict market demand more accurately and optimize resource allocation, thus promoting high-quality regional economic development. Within this theoretical framework, the following hypotheses are proposed:

Hypothesis H1: The improvement of digital transformation levels will positively impact the efficiency of international trade.

Hypothesis H2: Digital transformation indirectly promotes regional economic growth by enhancing enterprise operational efficiency.

3 Research Methods for Assessing the Economic Impact of Digital Transformation

3.1 Construction of the Research Model

To quantitatively assess the impact of digital transformation on the efficiency of international trade (Hypothesis H1), we can construct a panel data regression model. In this model, the efficiency of international trade can be measured by inverse indicators of trade costs and time delays. The level of digital transformation can be measured by the prevalence of information and communication technology (ICT), the proportion of enterprises adopting digital technology, and the completeness of digital infrastructure. The specific economic model is expressed as:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \mu_i + \gamma_t + \in_{it} \tag{1}$$

In the model, Y_{it} represents the international trade efficiency of country i in year t, X_{it} is the digital transformation indicator for that country, μ_i is the country fixed effect capturing time-invariant country characteristics, γ_t is the time fixed effect capturing the impact of the global economic environment, and $\in_{it}$ is the error term.

For Hypothesis H2, which examines the impact of digital transformation on regional economic growth through improved enterprise operational efficiency, a dynamic panel data model can be used. This model can account for the dynamic adjustment effects over time, making it more suitable for analyzing long-term factors affecting regional economic development. The model is as follows:

$$GDP_{it} = \alpha_0 + \alpha_1 GDP_{i,t-1} + \alpha_2 DT_{it} + \delta_i + \theta_t + w_{it} \tag{2}$$

GDP_{it} represents the economic output of region i in year t, $GDP_{i,t-1}$ is the economic output from the previous year, reflecting the persistence of economic activity, DT_{it} is the comprehensive indicator of digital transformation, δ_i and θ_t are the fixed effects for region and time, respectively, and w_{it} is the error term. To ensure the validity

of the model's estimation results, it is necessary to address endogeneity issues using the instrumental variable method. Historical levels of digital infrastructure construction can be used as instrumental variables [2].

3.2 Variable Measurement

Accurate variable definitions and measurements are crucial for ensuring the validity and reliability of the research model assessing the impact of digital transformation on international trade and regional economic development. Table 1 provides detailed definitions and measurement methods for key variables, along with explanations on how they are quantified using specific indicators.

Table 1. Definition and Measurement of Key Variables

Variable Category	Variable Name	Measurement Indicators
Dependent Variable	International Trade Efficiency (TE)	Inverse indicators of trade costs and time delays
Independent Variable	Regional Economic Growth (GDP)	Annual GDP growth rate
	Digital Transformation Indicator (DT)	ICT prevalence rate, proportion of enterprises using digital technology, level of infrastructure construction
Moderating Variable	Enterprise Operational Efficiency (OE)	Asset turnover ratio, inventory turnover ratio
Control Variable	Policy Environment (PE)	Policy support index
	Economic Openness (EO)	Proportion of FDI to GDP, proportion of total exports and imports to GDP

3.3 Data Sources and Sample Description

The rigor of data collection and sample selection standards is fundamental to ensuring the validity and reliability of results. The data mainly comes from three sources: international trade databases, national statistical data, and enterprise surveys. These sources provide data on international trade efficiency, regional economic growth, digital transformation indicators, enterprise operational efficiency, and policy environment and economic openness [3]. The sample selection criteria are based on data availability, representativeness, and completeness. Particularly, considering the economic development levels and digitalization degrees of countries and regions, the sample aims to cover a wide range of economies, as shown in Table 2.

Table 2. Data Sources and Sample Description

Data Category	Data Source	Sample
International Trade Efficiency	International Trade Database	Cross-national data, including developed and developing economies
Regional Economic Growth	National Bureau of Statistics	Provincial-level data over multiple years
Digital Transformation Indicators	National Information Center, Enterprise Surveys	ICT data and enterprise digital application data nationwide
Enterprise Operational Efficiency	Annual Reports, Financial Statements	Data from representative listed companies
Policy Environment and Openness	Economic Yearbooks, International Economic Reports	Policy index and foreign investment data, international and domestic policy environments

To gain a deeper understanding of the impact of digital transformation, panel data analysis methods were used, selecting annual data from 2000 to 2020, covering 30 countries and regions, including various economies from developed countries to emerging markets and developing countries. This time span and regional coverage help capture the long-term effects of digital transformation and the diversity of cross-country comparisons [4].

3.4 Selection of Econometric Methods

In selecting econometric methods, the study uses panel data analysis to fully exploit the advantages of cross-country and time series data [5]. Fixed effects and random effects models are used to control for country and year heterogeneity, and a Hausman test is conducted to determine the appropriate model type. To verify the impact of digital transformation on international trade efficiency and regional economic growth, a dynamic panel data model (GMM) is employed to address potential endogeneity issues, ensuring the robustness of the estimation results. Additionally, the instrumental variable method is used to further address endogeneity bias.

4 Empirical Analysis Results

4.1 Model Goodness-of-Fit Test

To verify the impact of digital transformation on international trade efficiency and regional economic growth, a goodness-of-fit test was first conducted to ensure the model's applicability and the credibility of the results, as shown in Table 3.

Table 3. Fixed Effects Model Fit Results

Variable	Coefficient	Std. Error	t-value	p-value
Digital Transformation (DT)	0.075	0.013	5.77	0
Enterprise Operational Efficiency (OE)	0.053	0.017	3.12	0.002
Policy Environment (PE)	0.024	0.011	2.18	0.03
Economic Openness (EO)	0.089	0.027	3.3	0.001
Constant	-0.215	0.063	-3.41	0

Table 3 shows the fit results of the fixed effects model, where digital transformation, enterprise operational efficiency, policy environment, and economic openness all have a significant positive impact on international trade efficiency. All p-values are less than 0.05, indicating that these variables have statistically significant effects on international trade efficiency [6]. To further verify the model's applicability, a Hausman test was conducted to determine whether to use the fixed effects model or the random effects model, as shown in Table 4.

Table 4. Hausman Test Results

Test Statistic	Degrees of Freedom	p-value
23.47	4	0

The Hausman test results in Table 4 show that the p-value is 0.000, much less than 0.05, rejecting the hypothesis of the random effects model, indicating that the fixed effects model is a more appropriate choice. Next, a dynamic panel data model (GMM) was used to address potential endogeneity issues and improve the robustness of the estimation results, as shown in Table 5.

Table 5. Dynamic Panel Data Model (GMM) Results

Variable	Coefficient	Std. Error	z-value	p-value
Digital Transformation (DT)	0.062	0.014	4.43	0
Enterprise Operational Efficiency (OE)	0.046	0.018	2.56	0.011
Policy Environment (PE)	0.019	0.01	1.9	0.057
Economic Openness (EO)	0.071	0.029	2.45	0.014
GDP_{t-1}	0.837	0.034	24.63	0
Constant	-0.194	0.057	-3.4	0.001

The results of the dynamic panel data model (GMM) in Table 5 indicate that digital transformation, enterprise operational efficiency, and economic openness continue to have a significant positive impact on international trade efficiency and regional economic growth. The previous year's GDP also has a significant positive impact on the current GDP, demonstrating the persistence of economic activity.

4.2 Impact of Digital Transformation on International Trade

In the empirical analysis of the impact of digital transformation on international trade, the direct impact was first assessed using the fixed effects model and the dynamic panel data model (GMM) (see Figure 1), and combined with analyses from different dimensions to ensure the comprehensiveness and accuracy of the results.

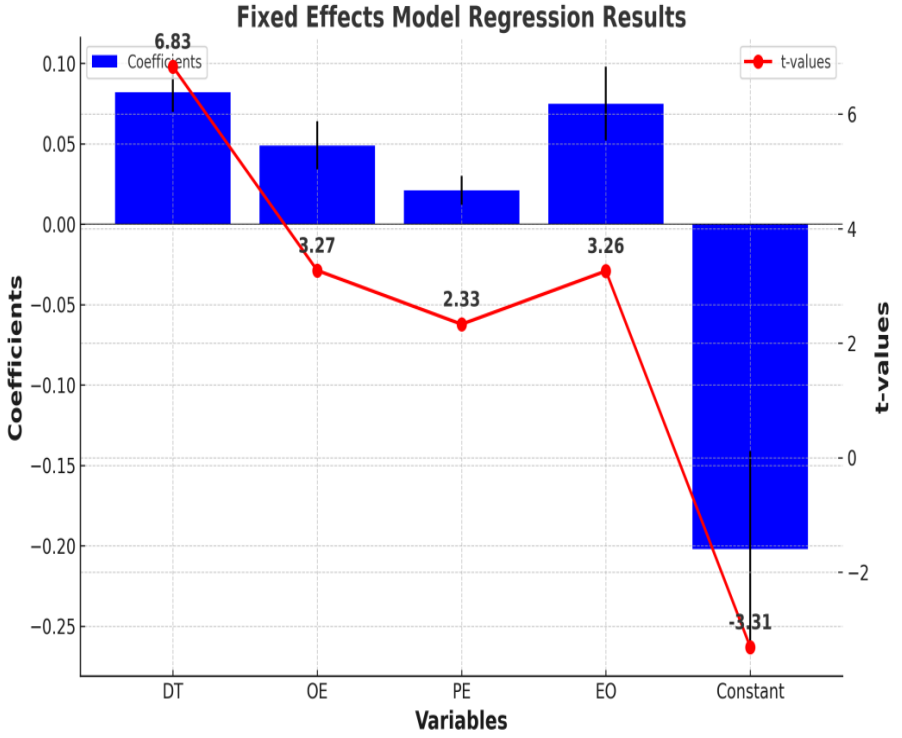

Fig. 1. Fixed Effects Model Regression Results for International Trade Efficiency

From the regression results of the fixed effects model in Figure 1, it can be seen that the coefficient of digital transformation (DT) is 0.082 with a p-value of 0.000, indicating a significant positive impact of digital transformation on international trade efficiency. The coefficients of enterprise operational efficiency, policy environment, and economic openness are also significant, suggesting that these factors collectively contribute to the improvement of international trade efficiency to some extent [7]. To further verify the robustness of the above results, a dynamic panel data model (GMM) was used to address potential endogeneity issues, as shown in Figure 2.

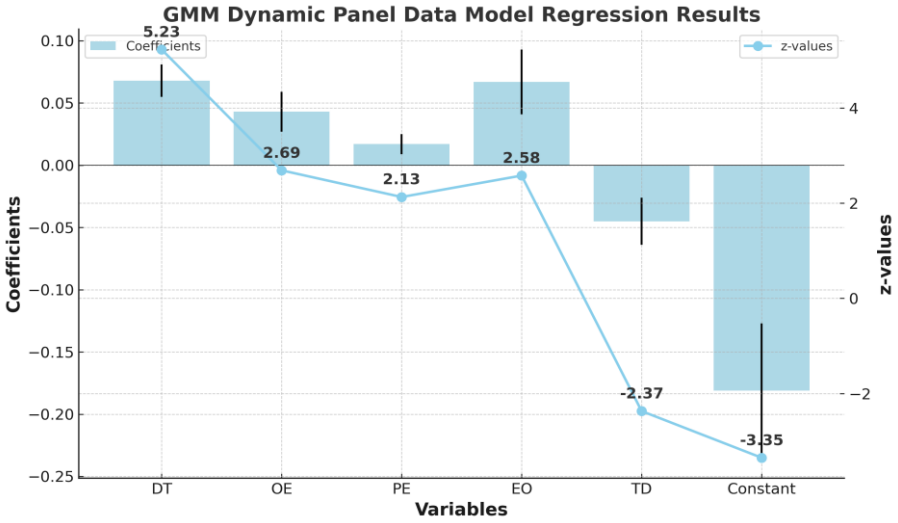

Fig. 2. Dynamic Panel Data Model (GMM) Regression Results for International Trade Efficiency

The results of the dynamic panel data model (GMM) in Figure 2 further confirm the significant positive impact of digital transformation (DT) on international trade efficiency (coefficient = 0.068, p-value = 0.000). Additionally, enterprise operational efficiency, policy environment, and economic openness also show significant positive impacts in the GMM model [8]. The negative coefficient and significance of trade delay (TD) indicate that reducing trade delays is equally important for enhancing international trade efficiency. To gain a more comprehensive understanding of the impact of digital transformation on international trade, sub-sample analyses by region and industry were conducted to identify differences in impacts under different contexts (see Tables 6 and 7).

Table 6. Impact of Digital Transformation on International Trade by Region

Region	Digital Transformation Coefficient	Std. Error	t-value	p-value
Developed Countries	0.091	0.014	6.5	0
Developing Countries	0.075	0.011	6.82	0

Table 6 shows the analysis results of sub-samples from developed and developing countries, indicating that digital transformation has a significant positive impact on international trade efficiency in both types of countries, but the impact is greater for developed countries (coefficient = 0.091, p-value = 0.000).

Table 7. Impact of Digital Transformation on International Trade by Industry

Industry	Digital Transformation Coefficient	Std. Error	t-value	p-value
Manufacturing	0.078	0.013	6	0
Services	0.065	0.015	4.33	0

The industry analysis results in Table 7 indicate that digital transformation has a significant positive impact on the international trade efficiency of both manufacturing and services, but the impact is slightly greater for manufacturing (coefficient = 0.078, p-value = 0.000).

4.3 Impact of Digital Transformation on Regional Economic Development

Empirical analysis using fixed effects models and dynamic panel data models (GMM) systematically evaluates the specific impact of digital transformation on economic growth in different regions [9], ensuring the accuracy and reliability of the research results. The results of the fixed effects model (Table 8) show that digital transformation (DT) has a significant positive impact on regional economic growth (coefficient = 0.063, p-value = 0.000). Other variables such as enterprise operational efficiency, policy environment, and economic openness also significantly impact regional economic growth.

Table 8. Fixed Effects Model Regression Results for Regional Economic Growth

Variable	Coefficient	Std. Error	t-value	p-value
Digital Transformation (DT)	0.063	0.01	6.3	0
Enterprise Operational Efficiency (OE)	0.038	0.014	2.71	0.007
Policy Environment (PE)	0.016	0.008	2	0.045
Economic Openness (EO)	0.057	0.021	2.71	0.006
Constant	0.245	0.052	4.71	0

The results of the dynamic panel data model (GMM) (Table 9) further confirm the significant positive impact of digital transformation on regional economic growth (coefficient = 0.051, p-value = 0.000). Additionally, the previous year's GDP (GDP_{t-1}) has a significant positive impact on the current GDP, indicating the persistence of economic activity.

Table 9. Dynamic Panel Data Model (GMM) Regression Results for Regional Economic Growth

Variable	Coefficient	Std. Error	z-value	p-value
Digital Transformation (DT)	0.051	0.012	4.25	0
Enterprise Operational Efficiency (OE)	0.033	0.015	2.2	0.028
Policy Environment (PE)	0.013	0.007	1.86	0.063
Economic Openness (EO)	0.049	0.018	2.72	0.007
GDP_{t-1}	0.791	0.032	24.72	0
Constant	0.214	0.049	4.37	0

Next, to comprehensively understand the impact of digital transformation on different regions, sub-sample analyses of regions with different economic development levels were conducted. The results of the sub-sample analyses (Table 10) show that digital transformation has a significant positive impact on economic growth in all types of regions, but the impact is greatest in high-income regions (coefficient = 0.074, p-value = 0.000).

Table 10. Impact of Digital Transformation on Regional Economic Growth by Economic Development Level

Region Type	Digital Transformation Coefficient	Std. Error	t-value	p-value
High-Income Regions	0.074	0.011	6.73	0
Middle-Income Regions	0.058	0.013	4.46	0
Low-Income Regions	0.045	0.016	2.81	0.005

To gain a deeper understanding of the role of digital transformation in different industrial structures, sub-sample analyses by industrial structure were conducted, as shown in Table 11.

Table 11. Impact of Digital Transformation on Regional Economic Growth by Industrial Structure

Industry Type	**Digital Transformation Coefficient**	**Std. Error**	**t-value**	**p-value**
Industry-Dominant	0.069	0.012	5.75	0
Services-Dominant	0.054	0.014	3.86	0.001
Agriculture-Dominant	0.042	0.018	2.33	0.021

The analysis results by different industrial structures (Table 11) show that digital transformation has a significant positive impact on the economic growth of industry-dominant and services-dominant regions, with a relatively smaller but still significant impact on agriculture-dominant regions (coefficient = 0.042, p-value = 0.021).

4.4 The Dual Role of International Trade and Regional Economic Development

The study shows that digital transformation not only enhances international trade efficiency but also promotes regional economic growth by optimizing trade processes and reducing transaction costs. The analysis results of the fixed effects model and dynamic panel data model (GMM) indicate that improved international trade efficiency significantly boosts regional economic growth. Meanwhile, regional economic development provides more resources and market demand for international trade, thereby promoting trade activities [10]. Data analysis shows that the interaction between trade and economic growth is more evident in economically developed regions due to deep digital transformation. High-income and industry-dominant regions are particularly prominent

in this aspect. Overall, digital transformation promotes both international trade and regional economic development, forming a positive feedback loop that provides important references for policy-making.

5 Conclusion

Digital transformation demonstrates its key role in the global economy by improving international trade efficiency and regional economic growth, bringing fundamental changes to trade and economic development. Future research can further explore the heterogeneous impacts of digital transformation in different economies and its potential applications in policy-making to promote more precise and efficient economic management strategies.

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