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Digital Economy, Industrial Structure Upgrading and Export Technology Complexity: An Empirical Study Based on China's Provincial Panel Data

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Abstract

Based on the panel data of 30 provinces in China from 2015 to 2022, this paper measures the development level of the regional digital economy, the technical complexity of regional exports, and the upgrading coefficient of industrial structure, and empirically tests the impact of digital economy development on export technology complexity and the mechanism of industrial structure upgrading. The results show that the development of the digital economy has significantly promoted the improvement of regional export technology complexity, which is still significant after the robustness test. The upgrading of the industrial structure played a partly intermediary role in the future. Further heterogeneity test shows that the digital economy will increase the technical complexity of exports to a greater extent in areas with low human capital, western China, and low economic level. The results provide theoretical evidence for the effect of the development of digital economy on the technical complexity of regional exports, and put forward targeted policy suggestions.

Keywords

digital economy, export technical complexity, upgrading of industrial structure

1. Introduction

The expansion of the digital economy and international trade has reshaped the way regions participate in international trade by altering production processes, information flows, and factor allocation. Through digital infrastructure platform-based services, and data-driven technologies, firms are increasingly able to reduce transaction costs and improve production efficiency. These changes suggest that the digital economy may play an important role in upgrading the technological content of export products. However, whether and how this effect operates at the regional level remains an open empirical question [1].

By adopting a provincial-level perspective, it provides macro-level empirical evidence on the relationship between the digital economy and export technology complexity, complementing existing micro-level studies. The findings may offer useful insights for policies aimed at promoting high-quality trade development and region-specific digital transformation.

2. Theoretical Analysis and Research Hypotheses

2.1 Digital Economy and Export Technical Complexity

The digital economy facilitates international trade by reducing transaction costs and enhancing production efficiency [2]. By optimizing resource allocation and fostering technology diffusion, digital technologies provide critical support for upgrading export technical complexity.

Based on this, the study proposes Hypothesis H1: **The development of the digital economy positively influences a region's export technical complexity.**

2.2 The Mediating Role of Industrial Structure Upgrading

Digital technologies drive industrial structure upgrading by improving resource allocation across sectors [3, 4]. As traditional industries integrate digital elements, resources shift toward high-value-added sectors, which in turn elevates the technological level of regional exports.

Thus, the study proposes Hypothesis H2: **Industrial structure upgrading plays a mediating role in the impact of the digital economy on regional export technical complexity.**

3. Research Design

3.1 Baseline Model Specification

To examine the impact of digital economy development on regional export technical complexity, the baseline regression model is constructed as follows:

$$Lnex_{it}=\alpha_0+\alpha_1 dig_{it}+\alpha_3 controls_{it}+\varphi_i+\varepsilon_{it} \tag{1}$$

Where:

i and t denote province and year, respectively; $Lnex_{it}$ represents the natural logarithm of regional export technical complexity; dig_{it} indicates the level of digital economy development; controls refers to the set of control variables affecting regional export technical complexity, including foreign investment level, openness degree, industrialization level, and human capital; φ_i and ε_{it} stand for regional fixed effects and random error term, respectively.

3.2 Mechanism Effect Test Model Specification

Based on the theoretical analysis above, it can be inferred that **industrial structure upgrading** may serve as a critical pathway through which digital economy development enhances regional export technical complexity. To examine this **mediating effect**, the following models are established:

$$iss_{it}=\gamma_0+\gamma_1 dig_{it}+\gamma_2 controls_{it}+\varphi_i+\varepsilon_{it} \tag{2}$$

$$Lnex_{it}=\beta_0+\beta_1 dig_{it}+\beta_2 iss_{it}+\beta_3 controls_{it}+\varphi_i+\varepsilon_{it} \tag{3}$$

3.3 Variable Selection and Data Sources

3.3.1 Dependent Variable

Regional Export Technical Complexity

Following the method of Hausmann et al. [5], this study calculates the regional export technical complexity index based on product-level data from China Customs and provincial yearbooks.

In constructing the regional export technology complexity index, this study aggregates product-level complexity measures using export shares as weights, such that products accounting for a larger proportion of a province's export basket exert a correspondingly greater influence on the overall index. In constructing the regional export technology complexity index, this study aggregates product-level complexity measures using export shares as weights. This approach accurately reflects the technological structure of regional exports by emphasizing products that dominate a province's export basket. The calculation preserves the panel structure for 30 Chinese provinces from 2015 to 2022.

3.3.2 Mediating Variable: Industrial Structure Upgrading

The mediating variable is the industrial structure upgrading coefficient (ISS). This study constructs the index by assigning progressive weights (1, 2, and 3) to the GDP shares of the primary, secondary, and tertiary industries, respectively. This standardized metric effectively captures the structural shift and the transition of the regional economy toward higher-value-added sectors.

$$ISS=\sum_{i=1}^{3} Li \times i \quad (4)$$

Where:

K=1,2,3K=1,2,3: Primary (Agriculture), Secondary (Manufacturing), and Tertiary (Services) Sectors, Respectively.

Lkit: Proportion of Sector K'S Output in Province I'S Total GDP at Year T.

Interpretation:

Range: ISS∈[1,3]

Closer to 1: Dominance of low-value-added sectors (e.g., agriculture).

Closer to 3: Advanced economy dominated by high-value-added services.

3.3.3 Control Variables

When examining the determinants of regional export product technical complexity, it is necessary to account for other potential influencing factors in addition to the core explanatory variable - the level of digital economy development. Drawing on existing research, this study selects the following control variables:

Table 1: Control Variables

Variable Type	Variable Name	Symbol	Measurement
Control Variable	Foreign investment level	fdi	Ratio of foreign direct investment to local GDP
Control Variable	Degree of openness	open	Ratio of regional import and export trade volume to local GDP
Control Variable	Industrialization level	gyh	Proportion of industrial value-added to local GDP
Control Variable	Human capital	cap	Ratio of higher education institution enrollment to total population

3.4 Data Sources

The study utilizes panel data from 30 Chinese provinces (excluding Tibet, Hong Kong, Macau, and Taiwan) for the period 2015-2022. The study utilizes panel data from 30 Chinese provinces (2015-2022). Data are primarily collected from the National Bureau of Statistics, the China Statistical Yearbook series, and the China Academy of Information and Communications Technology.

Table 2 shows that all variables maintain reasonable distributions. Notably, the digital economy level (dig) exhibits significant regional disparities (SD=0.138), providing a empirical basis for analyzing its impact on export sophistication.

Table 2: Descriptive Statistics of Variables

Variable Type	Variable Name	Symbol	Mean	Std. Dev.	Min	Max
Dependent Variable	Export Technical Complexity	lnex	9.252	0.175	8.883	9.631
Independent Variable	Digital Economy Level	dig	0.135	0.138	0.005	0.764
Mediating Variable	Industrial Structure Upgrading	iss	2.427	0.114	2.200	2.836
Control Variables	Foreign Investment Level	fdi	0.018	0.018	0.000	0.121
	Openness Degree	open	0.245	0.235	0.008	1.038
	Industrialization Level	gyh	0.311	0.070	0.100	0.499
	Human Capital Level	cap	0.022	0.006		

4. Empirical Results and Discussion

Prior to conducting baseline regression analysis, this study first performed correlation analysis among variables, with results indicating significant inter-variable correlations. Subsequently, multicollinearity tests were conducted, showing all variables had VIF values below 10, with a mean VIF of 1.63, suggesting no substantial multicollinearity issues in the model. Through Hausman testing to determine whether random effects or fixed effects models were more appropriate, results indicated the fixed effects model was better suited for this study. Consequently, fixed effects models were employed for baseline regression analysis.

4.1 Baseline Regression Results

Columns (1) and (2) in Table 3 present regression results without and with control variables respectively. The results demonstrate that the coefficient for digital economy development level on regional export technical complexity remains consistently positive and statistically significant. This confirms that digital economy development positively influences local export technical complexity and enhances export quality, thereby validating Hypothesis 1.

Table 3: Baseline regression

	(1)	(2)
	lnex	lnex
dig	2.472***	1.455***
	(11.573)	(10.037)
cap		44.788***
		(20.072)
gyh		1.296***
		(5.471)
fdi		-1.814***
		(-3.815)
open		0.352**
		(2.192)
_cons	8.918***	7.599***
	(293.970)	(74.853)
R^2	0.391	0.851
F	133.933	234.036

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

4.2 Key Findings from Baseline Regression Results

The baseline regression results indicate that the digital economy development index has a statistically significant and positive effect on regional export technical complexity at the 1% level. This finding suggests that improvements in digital infrastructure, including broadband penetration and advanced communication networks, together with the expansion of digital platforms and the deepening of industrial digitization, contribute to higher export sophistication. These effects operate through several channels, such as faster diffusion of digital technologies, innovation spillovers generated within digitally connected industrial clusters, and efficiency gains that reduce operational costs and enable firms to reallocate resources toward research and development activities.

In addition to the digital economy, several complementary factors are found to play important roles. Human capital exhibits a significantly positive effect at the 1% level indicating that the expansion of higher education provides a skilled labor force capable of supporting research-intensive production and the customization of complex manufactured goods. Moreover, the degree of openness shows a positive and significant coefficient at the 5% level, suggesting that international trade facilitates technology transfer through channels such as joint ventures and the absorption of advanced capital goods.

By contrast, foreign direct investment displays a significantly negative coefficient revealing a potential crowding-out effect. This result may be explained by the composition of FDI flows, which remain concentrated in relatively low-technology manufacturing sectors, as well as by the tendency of multinational enterprises to retain control over core technologies and research activities. As a consequence, domestic firms may become locked into assembly-oriented positions within global value chains limiting their capacity to upgrade technologically.

These findings carry several policy implications. First, policies should strengthen the integration of digital infrastructure and industrial development by promoting digital applications within manufacturing clusters. Second, greater emphasis should be placed on improving the quality rather than the quantity of foreign direct investment, particularly by encouraging technology-intensive projects and strengthening requirements for technology cooperation in strategic sectors. Finally, continued investment in human capital development is essential, including the expansion of science and engineering education and the enhancement of digital skills training, in order to support sustained upgrading of export technology complexity. This evidence-based analysis supports a transition from factor-driven growth toward innovation-driven upgrading in export structures. The results highlight the role of the digital economy as a key enabling mechanism for export sophistication, while also underscoring the importance of carefully managing the heterogeneous effects of foreign direct investment.

4.3 Endogeneity and Robustness Tests

To further validate the baseline regression conclusions, this study conducts the following endogeneity and robustness checks:

4.3.1 Endogeneity Test

To mitigate potential endogeneity bias, we employ the instrumental variable (IV) approach using two-stage least squares (2SLS). Drawing on established methodologies, we construct two instrumental variables:

Historical Telecom Infrastructure. Instrument: tele*tech = ln (1984 landline phones per 100 persons × previous year's national IT service revenue)[6]

Rationale: Pre-existing telecom infrastructure (exogenous) correlates with digital economy development but remains unaffected by current export complexity. Logarithmic transformation improves distribution properties.

Lagged Digital Economy Index. Instrument: dig_lag1 = One-period lagged digital economy development level. Exclusion Restriction: While the current digital economy affects current exports, reverse causality is implausible for lagged values.

Table 4: Endogeneity test

	tele*tech	dig_lag1
	lnex	lnex
dig	3.652***	0.805***
	(4.513)	(9.018)
controls	YES	YES
Kleibergen-Paap rk LM	13.231***	45.32***
Cragg-Donald Wald F	19.425	1.3e+04
R^2	-1.865	0.352
F	13.82	34.088

4.3.2 Robustness Tests

To verify the robustness of the baseline regression conclusions, this study conducts additional tests through (1) alternative core explanatory variable measurement and (2) alternative estimation models.

Following Zhao Tao[7] and Gao Weilong[8], we reconstruct the digital economy index (dig2) using entropy weighting across three dimensions:

Digital Infrastructure (e.g., 5G base stations per km²)

Digital Industries (e.g., software revenue growth rate)

Digital Inclusive Finance (Ant Group SME loan coverage)

Table 5: Robustness tests

	Alternative core explanatory variable	Alternative estimation model
	(1)	(2)
dig		1.210***
		(19.174)
dig2	1.752***	
	(12.022)	
fdi	-1.319***	-2.432***
	(-3.082)	(-7.960)
open	0.338**	0.089**
	(2.255)	(2.495)
gyh	1.070***	0.777***
	(5.042)	(13.554)
cap	41.989***	38.576***
	(19.534)	(36.559)
_cons	7.618***	7.992***
	(81.021)	(204.228)
R^2	0.87	0.929
F	273.434	612.371

4.3.3 Mediation Effect Test

The theoretical analysis indicates that **industrial structure upgrading** is a key mechanism through which the digital economy affects regional export technical complexity. Therefore, we further construct a mediation effect model based on **Equation (2)** to analyze this mechanism.

The mediation analysis in Table 6 confirms the theoretical mechanism. The results indicate that the digital economy significantly facilitates industrial structure upgrading (Column 2), which in turn serves as a critical driver for elevating regional export technical complexity (Column 3). The significant coefficients across all stages provide empirical support for the mediating pathway.Thus, **Hypothesis H2 is validated**.

Table 6: Mediating Effect Test

	Total effect	Industrial structure upgrading effect	
	lnex	iss	lnex
dig	1.455***	0.095***	1.245***
	(10.037)	(3.280)	(9.307)
iss			2.208***
			(7.022)
fdi	-1.814***	-0.212**	-1.345***
	(-3.815)	(-2.233)	(-3.108)
open	0.352**	0.012	0.326**
	(2.192)	(0.367)	(2.256)
gyh	1.296***	-0.913***	3.312***
	(5.471)	(-19.286)	(9.263)
cap	44.788***	-0.377	45.620***
	(20.072)	(-0.845)	(22.687)
_cons	7.599***	2.708***	1.620*
	(74.853)	(133.493)	(1.891)
R^2	0.851	0.741	0.88
F	234.036	117.053	249.207

4.3.4 Heterogeneity Analysis

Significant multidimensional heterogeneity exists in development levels across the 30 provinces. Building upon the full-sample regression, we conduct subgroup analyses based on:

Human Capital Heterogeneity. Using the mean human capital value as the threshold:

Low human capital group: Below mean value

High human capital group: Above mean value

Key results (Table 7 Columns 1-2):

The results reported in Table 7, Columns (1) and (2), indicate that the digital economy has a statistically significant positive effect on export technical complexity in both low and high human capital regions, with coefficients of 1.753 and 1.686, respectively, at the1% significance level. The slightly larger effect observed in low human capital regions may reflect data-related factors as well as differences in factor endowments, as regions with higher human capital tend to specialize in human capital-intensive, high-technology exports, leaving relatively less scope for further improvements driven by digital economy development.

Regional Location Heterogeneity. Following Shen Xiaobo [9], provinces are categorized as follows:

Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan

Central: Shanxi, Jilin, Heilongjiang, Henan, Hubei, Hunan, Anhui, Jiangxi

Western: Guangxi, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Inner Mongolia, Chongqing, Sichuan

Results (Columns 3-5):

All regions show 1%-significant positive effects. Western China demonstrates the strongest impact (3.480***), likely because: Eastern regions face diminishing marginal returns from digitalization due to mature technological infrastructure ; Digital economy helps western regions overcome information asymmetries and transaction costs, enabling leapfrog development.

Economic Development Level Heterogeneity. Using per capita real GDP:

Low-development group: Below national average

High-development group: Above average

The heterogeneity results in Columns (6) and (7) indicate that the digital economy has a significantly positive effect on export technical complexity in both more-developed and less-developed regions, with a larger coefficient observed for the latter. This pattern suggests that while digital development mainly leads to incremental improvements in more-developed regions, less-developed regions benefit more from technology spillovers and innovation diffusion. Accordingly, the findings imply that differentiated policy approaches are needed, with less-developed regions prioritizing digital infrastructure investment and technology transfer, and more-developed regions focusing on frontier digital technologies. Overall, the results indicate that the margin of benefits of digital transformation is greater when regional development gaps are reduced.

All coefficients remain robust to alternative clustering methods and bootstrap standard errors.

This systematic heterogeneity analysis demonstrates how regional characteristics moderate the digital economy's export upgrading effects, providing actionable insights for place-based policymaking.

Table 7: Heterogeneity analysis

	Cap-low	Cap-high	Eastern	Central	Western	Eco-unde	Eco-de
	(1)	(2)	(3)	(4)	(6)	(7)	(8)
dig	1.753***	1.686***	1.174***	1.773***	3.480***	2.320***	1.325***
	(7.032)	(7.196)	(5.922)	(3.169)	(4.607)	(4.326)	(8.016)
controls	YES	YES	YES	YES	YES	YES	YES
_cons	7.706***	7.615***	7.657***	7.680***	7.690***	7.633***	7.498***
	(41.022)	(51.338)	(26.878)	(39.918)	(58.224)	(58.290)	(30.035)
R2	0.747	0.855	0.83	0.901	0.885	0.843	0.867
F	57.13	98.258	70.316	93.32	111.248	136.421	88.479

5. Conclusion

The digital economy significantly enhances regional export technical complexity. This conclusion remains robust after addressing endogeneity through instrumental variable methods and multiple robustness tests, confirming the digital economy's critical role in elevating regional trade competitiveness and advancing

China's "Trade Power" strategy. Industrial structure upgrading serves as a key mediator. Our analysis demonstrates that digital economy development promotes technological innovation and optimal resource allocation, thereby facilitating the transformation of traditional industries toward higher-value-added, intelligent, and environmentally sustainable production models. The heterogeneity analysis shows that the impact of the digital economy on export technical complexity is more pronounced in regions with lower human capital, in western provinces, and in less-developed areas, compared with their more advanced counterparts. This pattern indicates that digital economy development is particularly effective in narrowing technological gaps and enhancing export sophistication in relatively less-advanced regions. Based on these findings, policy efforts should focus on accelerating digital economy development and strengthening its integration with the real economy. In less-developed regions, priority should be given to digital infrastructure investment, enterprise digitalization incentives, and inter-regional cooperation to facilitate technology transfer. In contrast, more-developed regions should place greater emphasis on frontier technological innovation and the expansion of high value-added digital industries. At the same time, promoting industrial structure upgrading through increased research and development investment and talent cultivation remains essential for sustaining the positive effects of digital transformation.

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Conflicts of Interest

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