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Research on the Impact of Digital Economy Development on China's Provincial Trade Openness: Empirical Evidence Based on Panel Data from 2011 to 2023

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Abstract: With globalization growing faster and information technology advancing, the digital economy is increasingly becoming key to promoting high-quality economic development. Using data from 2011-2023, the impact of digital economy development on China's provincial trade openness is investigated by constructing a fixed effects model, robustness test, and heterogeneity test. Studies indicate that the digital economy significantly enhances trade openness, although its effects vary by region; the influence is more substantial in the eastern and central zones, while the western region shows a minimal impact. Foreign investment, R&D investment, and human capital positively affect trade openness. Going forward, efforts should focus on advancing coordinated digital growth, increasing the input of factors, and deepening regional synergy to promote high-level trade openness and high-quality economic development.

1. Introduction

1.1. Background and Significance of the Research

Amid digital transformation, the economy is now primarily powered by digital advancements. The report of the 20th CPC National Congress proposed the objective of “accelerating the building of a trade powerhouse,” positioning the digital economy as a key driver for shaping a new development framework, emphasizing the upgrading of traditional industries and trade model innovation empowered by digital technology. According to China Digital Economy Development Report (2024), the scale of China’s digital economy has grown from less than 10 trillion yuan in 2011 to 53.9 trillion yuan in 2023, accounting for 42.8% of GDP, showing strong growth momentum. However, the degree of trade openness among provinces and regions reveals significant regional imbalances, mainly due to variations in resource allocation, policy orientation, and technology application levels.

Using provincial panel data from 2011 to 2023 constructs a fixed-effects model to explore the mechanism of the impact of the level of digital economy development on trade openness. It is

expected to assist policymakers and promote the coordinated development of the regional economy so as to elevate China's standing in the international economic arena.

1.2. Literature Review

Today, digital and ICT advancements have significantly amplified the digital economy's impact on global trade, particularly in lowering transaction costs and enhancing trade efficiency. Zhang et al. find that a digitally enabled economy promotes exports through technological advancements; central and western provinces, as well as lower-tier urban areas, experience disproportionately larger effects [1]. Tang et al. find that the digitalized economy significantly promotes China's outward foreign direct investment (OFDI) through a two-way mechanism of lowering trade costs and enhancing technological innovation, with the ASEAN countries being particularly prominent[2].

Scholars have investigated the digital economy's drivers from multiple dimensions. Research by Gu & Liu reveals a growing interconnection of digital economy and regional resilience, displaying distinct east-west spatial disparities, and that the import and export of foreign capital and the ability to make online payments are the key influences [3]. Zhu et al., with a sample of 281 cities, confirm that the digital economy enhances the export complexity of cities through human capital accumulation and technological innovation through a chain-mediated effects model [4]. Bai & Shen target 30 underdeveloped cities, emphasizing that the digital economy needs to synergize with the combination of conditions, such as industrial structure and openness, to promote sustainable development [5].

In addition, the economic effects of digital advancement vary substantially across regions. Zhao et al. use panel regression and geographically weighted regression to find that the digital economy promotes regional economic growth through transportation, technology, and other factors, and the network focus indirectly affects economic development with regional heterogeneity [6]. Based on inter-provincial panel data, Chen & Xiong reveal that the digital economy enhances employment quality through the human capital and salary package paths, with more significant effects in the eastern region [7].

2. Research Hypothesis

2.1. Digital Economy Development and Trade Openness

The digital economy plays a crucial role in reducing transaction costs, enhancing the efficiency of international trade and deepening globalization. With the wide application of ICT, digital technology effectively solves the problem of information asymmetry in the market, makes the transaction process smoother, and also makes transactions more transparent and efficient. In terms of infrastructure, the popularization of the Internet has made it quick and easy for enterprises to access international market information. The development of cross-border e-commerce eliminates the geographical and time limitations associated with traditional trade, allowing more enterprises and individuals to join the global market and thus promoting an increasing degree of global openness.

Therefore, the digital economy's transformative impact on global trade and economic structures will intensify, driving high-quality trade development. This study hypothesizes:

Hypothesis 1: The digital economy has a positive and significant impact on the degree of trade openness of each province.

2.2. Regional Differences in Digital Economy Development and Trade Openness

Regional disparities in digital trade openness stem from uneven development in digital infrastructure, policy environment, and economic foundation in each region. Eastern coastal regions typically have better digital infrastructure, higher levels of IT application, and more effective policy support, enabling them to fully seize opportunities and enhance trade openness. The central region has benefited from digital infrastructure investments and industrial relocation under the "Rise of Central China" strategy. The transformation of traditional manufacturing industries by digital technology has had a significant impact, and the technological content of export products has also increased. Meanwhile, the Western region lags behind in terms of digital infrastructure and technology application, which limits its trade liberalization potential and actual impact. This study hypothesizes:

Hypothesis 2: There are heterogeneous differences in the level of digital economy development on trade openness in different regions.

3. Research Design

3.1. Model Construction

A benchmarking model is constructed to assess how the digital economy index influences trade openness with the following formula:

$$OPEN_{i,t} = \alpha_0 + \varphi_i DIGI_{i,t} + \sum_k \beta_k X_{k,i,t} + \varepsilon_{i,t} \quad (1)$$

Where the explanatory variable OPENi,t represents trade openness index of the ith province and city in year t, the explanatory variable DIGIi,t is the digital economy development index of the ith province and city in year t.φi is its coefficient, which, if φi >0 is significant, indicates that the development of the digital economy promotes the expansion of the degree of trade openness. The coefficient is expected to be significantly positive. Xk,i,t(k= 1,2,3...) is each control variable, α0 is the intercept term and εi,t is the random error term.

3.2. Description of Variable Selection and Measurement

(1) Explained variable: trade openness. This paper draws on Han & Niu and constructs it in three dimensions: trade openness, investment openness, and technological openness[8], as shown in Table 1.

Table 1: Trade openness indicator system

Primary Indicators	Secondary Indicators	Units	Attributes
Import and export openness	Import/GDP ratio	%	+
	Export/GDP ratio	%	+
Investment openness	FDI/GDP ratio	%	+
	Number of foreign-invested enterprises	enterprise	+
	Total actual utilization of foreign capital	ten thousand dollars	+
	Outward foreign direct investment	thousand dollars	+
Technical openness	Number of new product development projects	per	+
	Technology market turnover	billions	+
	Number of international patent applications	per	+

(2) Core explanatory variable: digital economy development level. Following Bian & Shen's approach, this paper develops a digital economy assessment framework across four key dimensions, including digital economy infrastructure, digital industrialization, industrial digitization, and digital innovation ability[9], as shown in Table 2.

Table 2: Indicator system for the level of development of the digital economy

Primary Indicators	Secondary Indicators	Units	Attributes
Digital economy infrastructure	Internet broadband access port	ten thousand	+
	Number of Internet broadband access subscribers	also translated as Marquis	+
	Domain registrations	ten thousand	+
	Number of pages	ten thousand	+
	Cellular adoption rate	per hundred inhabitants	+
	Fiber optic line length	million/km	+
Digital Industrialization	Software/GDP ratio	%	+
	IT services/GDP ratio	%	+
	Information services workforce size	ten thousand	+
	Telecom revenue-to-GDP ratio	%	+
Industrial Digitization	E-commerce adoption rate among firms	%	+
	E-commerce contribution to GDP	%	+
	PCs/100 enterprise employees	per	+
	Websites/100 businesses	per	+
	Digital Financial Inclusion Index	/	+
Digital innovation capabilities	FTE R&D workforce in large-scale industrial firms	FTE personnel	+
	R&D spending by large-scale industrial firms	ten thousand yuan	+
	Industrial R&D project count enterprises above designated size	per	+
	Valid invention patents held by large-scale industrial firms	piece	+
	Granted patent count	piece	+

(3) Control variables. Referring to Yang et al. and Chu et al., this paper selects government intervention, urbanization, industrial structure, foreign investment, human capital, and R&D intensity as control variables[10, 11], as shown in Table 3.

Table 3: Description of variables

	Variable Name	Variable Definition	Symbol
Explained Variable	Trade openness	Entropy measurement	OPEN
Explanatory Variable	digital economy development level	Entropy measurement	DIG
Control Variable	Government intervention	Fiscal Expenditure/GDP	GOV
	Urbanization	Urban population/total population at year-end	URB
	Industrial structure	Tertiary Industry/Secondary Industry	IND
	Foreign investment	Foreign Direct Investment/GDP	FDI
	Human capital	HE enrollment/population	HC
	R&D intensity	R&D Expenditure/GDP	RD

3.3. Data Sources and Data Description

This paper collects panel data from 2011 to 2023 for 31 provinces and cities in China except

Hong Kong, Macao, and Taiwan China and obtains a total of 403 valid samples. Using the entropy weight method, this study calculates both the digital economy development index and trade openness degree. Data sources include China Statistical Yearbook, CSMAR database, and IncoPat patent database. For the missing values in the samples, the interpolation method and the complementary average growth rate method were applied to fill in the blanks. Descriptive statistics for each variable appear in Table 4:

Table 4: Descriptive statistics

	VARIABLES	N	Mean	SD	Min	Max
Explained Variable	open	403	0.057	0.072	0.001	0.476
Explanatory Variable	dig	403	0.168	0.111	0.015	0.666
Control Variable	gov	403	0.596	0.426	0.213	2.708
	urb	403	0.593	0.13	0.227	0.896
	ind	403	1.295	0.732	0.518	5.69
	fdi	403	0.019	0.02	0	0.121
	hc	403	0.021	0.006	0.008	0.045
	rd	403	0.011	0.006	0	0.032

4. Results

4.1. Benchmark Regression

Each control variable is introduced step by step in columns (1) to (7) of Table 5. Findings indicate digital economic advancement substantially boosts trade liberalization in all provinces, with coefficients ranging from 0.306 to 0.394 and t-values ranging from 7.91 to 13.61, all of which are significant at the 1% level of significance, indicating that the development of the digital economy can significantly enhance trade openness. Accordingly, Hypothesis 1 is established.

Meanwhile, the estimated coefficients of foreign investment, human capital, and R&D intensity on trade openness are all significantly positive, indicating that increasing foreign investment, improving human capital, and enhancing R&D intensity can effectively promote provincial trade openness. The estimated coefficients of government intervention and urbanization are all negative, inhibiting trade openness. The estimated coefficient of industrial structure on trade openness is not significant, implying limited influence on trade liberalization.

Table 5: Benchmark regression results

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DIG	0.307***	0.306***	0.378***	0.394***	0.369***	0.369***	0.364***
	(13.61)	(13.53)	(9.85)	(8.24)	(7.93)	(7.95)	(7.91)
GOV		-0.013	-0.027	-0.024	-0.037*	-0.035	-0.041*
		(-0.63)	(-1.23)	(-1.09)	(-1.69)	(-1.61)	(-1.90)
URB			-0.128**	-0.127**	-0.100*	-0.196**	-0.261***
			(-2.30)	(-2.28)	(-1.84)	(-2.57)	(-3.26)
IND				-0.004	0.004	0.003	0.008
				(-0.56)	(0.51)	(0.38)	(0.93)
FDI					0.589***	0.627***	0.493***
					(5.11)	(5.36)	(3.85)
HC						1.620*	1.619*
						(1.79)	(1.80)
RD							2.351**

							(2.47)
Constant	0.005	0.014	0.086**	0.087**	0.060*	0.082**	0.096***
	(1.33)	(1.00)	(2.51)	(2.54)	(1.78)	(2.30)	(2.68)
Observations	403	403	403	403	403	403	403
R-squared	0.333	0.334	0.343	0.344	0.387	0.393	0.403

***, **, and * indicate that they remain significant at the 1%, 5%, and 10% levels, respectively, and t-values are within ().

4.2. Robustness Test

To test the reliability of baseline regression findings and ensure the credibility and reliability of the conclusions obtained, this paper tests the robustness of the study by adding control variables, eliminating outliers, and employing the instrumental variable method. The final results are shown in Table 6.

Table 6: Robustness test results

VARIABLES	(1)	(2)	(3)	(4)
	OPEN	OPEN	DIG	OPEN
DIG	0.341***	0.358***		0.5184***
	(7.41)	(7.36)		(16.07)
IV			1.0027***	
			(92.10)	
GOV	-0.026	-0.040*	-0.0009	-0.0115**
	(-1.15)	(-1.70)	(-0.49)	(-2.11)
URB	-0.366***	-0.226***	0.0032	-0.0619**
	(-4.27)	(-2.64)	(0.34)	(-2.18)
IND	0.008	0.011	0.0040**	-0.0035
	(1.00)	(1.23)	(2.56)	(-0.74)
FDI	0.460***	0.469***	0.0741*	0.7565***
	(3.62)	(3.43)	(1.96)	(6.77)
HC	0.309	1.280	-0.5215***	-1.9766***
	(0.32)	(1.35)	(-4.20)	(-5.32)
RD	2.607***	2.330**	0.6158***	2.9447***
	(2.76)	(2.30)	(3.42)	(5.43)
TI	-0.066***			
	(-3.20)			
Constant	0.344***	0.080**	0.0117***	0.0119
	(4.04)	(2.07)	(2.59)	(0.90)
Anderson canon. corr. LM statistic			356.693***	
Weak IV test			8482.305 [16.380]	
Observations	403	372	372	372
R-squared	0.419	0.402		0.778
Province fixed	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes

***, **, and * indicate that they remain significant at the 1%, 5%, and 10% levels, respectively,

t-values within (), and values within [ ] are Stock-Yogo weak identification test critical values (10% level).

(1) Adding control variables

Referring to Jia. & Song., incorporate the urban-rural income gap (TI) as an additional control variable in our baseline specification. As presented in Column (1) of Table 6, the digital economy development index demonstrates a statistically significant positive coefficient of 0.341 (t=7.41, p<0.01). Indicating that the higher the digital economic development index is, the greater the degree of openness to trade in Chinese provinces, and the conclusion is solid [12].

(2) Removing outliers

2020 is a special year, as the world faces the COVID-19 pandemic, and the economic activities of all countries are affected to varying degrees. Column (2) of Table 6 conducts a robustness test by excluding the special year 2020 to further verify the impact of the level of digital economy development on the trade openness of each province. The coefficient for the level of digital economic development is 0.358 (t = 7.36, p < 0.01), demonstrating persistent trade openness enhancement when the special year 2020 is excluded.

(3) Instrumental variable method

To improve the feasibility of the empirical findings, referring to Huang et al., digital ability (IV) with one period lag was selected as an instrumental variable [13]. The regression results of the instrumental variable method based on the two-stage least squares (2SLS) realization are shown in Table 6, column (3) and column (4), and the coefficient of the level of digital economic development in the second stage is 0.5184 (t=16.07, p<0.01). Empirical results confirm that digital economy's trade-boosting effect remains significant after endogeneity is taken into account, further validating Hypothesis 1.

4.3. Heterogeneity Test

According to the previous study, this paper categorizes China's 31 provinces into eastern, central, and western zones based on geographical disparities. To examine regional disparities and precisely evaluate digital economy heterogeneity across trade openness levels, this study employs grouping tests, with results presented in Table 7.

Table 7: Results of heterogeneity test

VARIABLES	(1)	(2)	(3)	(4)
	Overall	Eastern	Central	West
DIG	0.364***	0.151**	0.248***	0.033
	(7.91)	(2.02)	(2.70)	(0.27)
GOV	-0.041*	-0.129	-0.063***	-0.001
	(-1.90)	(-1.18)	(-3.27)	(-0.03)
URB	-0.261***	0.130	-0.236**	0.153
	(-3.26)	(0.61)	(-2.39)	(1.20)
IND	0.008	0.032**	0.015*	-0.004
	(0.93)	(2.31)	(1.87)	(-0.34)
FDI	0.493***	0.995***	-0.697***	0.350
	(3.85)	(4.70)	(-4.12)	(0.95)
HC	1.619*	6.159**	-0.282	-0.769
	(1.80)	(2.31)	(-0.34)	(-0.81)
RD	2.351**	0.895	5.361***	0.793
	(2.47)	(0.47)	(6.44)	(0.46)

Constant	0.096***	-0.199**	0.112**	-0.052
	(2.68)	(-2.10)	(2.53)	(-0.94)
Observations	403	143	104	156
R-squared	0.403	0.573	0.764	0.114

***, **, and * indicate that they remain significant at the 1%, 5%, and 10% levels, respectively, with t-values within ().

The following are discussed in the overall, eastern, central and western regions, respectively:

(1) Overall

From the overall viewpoint, provincial trade openness rises with digital economic advancement. However, regional effects vary, based on which Hypothesis 2 is established. The reasons for this are that digital infrastructure development, the popularization of information technology, the degree of financial support for foreign investment and the policy support of local governments are the key factors affecting the effectiveness of the digital economy in each region.

(2) Eastern Region

The eastern region demonstrates a significant positive effect (0.151**, t = 2.02), primarily due to its well-developed digital infrastructure. Eastern zones demonstrate robust technological integration and innovation-led growth, which enhances the driving force of the digital economy on trade openness.

(3) Central Region

The central region demonstrates a strongly significant positive effect (0.248***, t=2.70). Mainly because the central region relies on location advantages to undertake the eastern manufacturing transfer, through the “central rise” strategy, traditional industries undergo a clear digital-driven transformation.

(4) West Region

The impact of the western region is relatively weak (0.033, t=0.27), regional digitalization is yet to mature. Digital infrastructure and technology applications are lagging, while western provinces experience population scarcity. The return on investment in building digital infrastructure is low, and the cost of enterprise digital transformation is high. In addition, there is insufficient synergy between geographic location and policy. Although there is support for the “Belt and Road” policy, Belt-Road nations show divergent digital advancement, cross-border e-commerce cooperation is slow, and effectively driving the opening up of trade proves difficult for the digital economy.

5. Conclusions and Revelations

5.1. Conclusions

Using 2011-2023 provincial panel data from Chinese mainland, assess digital economy-trade openness linkages. Empirical evidence demonstrates:

(1) Digital economy development positively correlates with trade openness (0.364***, t=7.91), indicating that the development of the digital economy promotes the growth of trade openness. After introducing different control variables, this positive effect fluctuates but is eventually significant, indicating that a combination of factors influences digital-trade openness relationship.

(2) Foreign investment, human capital, and R&D intensity all contribute significantly to trade openness. Among them, for every 1% increase in FDI, trade openness rises by 0.493%; human capital and R&D investment promote trade upgrading by improving labor quality and technological innovation capacity, respectively. Government intervention and urbanization have inhibiting effects on trade openness. Excessive government intervention reduces allocation efficiency, while the lack of industrial synergy in the process of urbanization will easily lead to “diseconomies of scale” and

hinder trade openness.

(3) Heterogeneity tests reveal regional variations in digital economy's trade openness effects. The eastern region shows a notable positive impact (0.151**, t = 2.02). Relying on the perfect digital infrastructure and innovation ecology, the digital economy and trade openness have formed a benign interaction. The central region shows a highly significant positive effect (0.248***, t=2.70), benefiting from the digital infrastructure investment and industry transfer under the “Rise of Central China” strategy. The coefficient for the western region is only 0.033, insignificant, and the pulling effect of the digital economy on trade openness has not yet emerged due to the lagging digital infrastructure, the loss of talent, and the lack of digital synergy among B&R partner nations.

5.2. Revelations

To foster economic stability, prioritizing digital economy development is essential, as well as the healthy and orderly development of open trade. Based on the research results, strategic recommendations are presented, highlighting how digital economic growth contributes to stability.

Conclusion 1 confirms digital economic mechanisms lower transactional expenses while boosting commercial efficiency. Accordingly, it is recommended that: first, efforts to enhance digital infrastructure must be consistently reinforced, and the coverage of digital technology should be expanded by taking indicators such as network connection points and smartphone diffusion levels as benchmarks; second, converging digital industrial transformation with traditional sector modernization should be accelerated, and the innovation of trade mode should be promoted by increasing the proportion of software business income and the scale of e-commerce transactions of enterprises; third, the experience of the eastern region should be drawn upon to build a benign interactive ecology between digital technology and trade opening. Trade opens up a benign interactive ecology.

According to conclusion 2, policy optimization should focus on: first, expanding foreign investment access to high-tech industries, raising FDI’s share in a gross domestic product through tax incentives and other policies, and reinforcing the pull effect of foreign investment on trade; second, increasing investment in higher education and R&D expenditure, and upgrading the trade structure driven by developing collective expertise and technological innovation; third, reducing the government’s administrative intervention in the market, optimizing the structure of fiscal expenditure, and promoting the synergistic development of urbanization and industrial structure to avoid “diseconomies of scale”.

Conclusion 3 highlights the value of cyber-infrastructure advancements, the impact of industry relocation, and the importance of coordinated regional policies. It is suggested to promote in three aspects: First, eastern provinces capitalize on cyber-infrastructure strengths like internet user penetration and web address allocations, should explore the innovation of digital trade rules and create a benchmark region for the global digital economy; second, the central region, relying on the strategy of “The Rise of Central China,” should increase the investment in infrastructure such as the laying of fiber-optic transmission links and the digital inclusion of financial services, and Accelerate corporate digital upgrades; third, the western region should give priority to making up for the trade synergy effect of industry transfer by cellphone diffusion metrics and online content volume.

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