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Digital Trade and Regional Economic Resilience: A Case Study from China

Handel cyfrowy i regionalna odporność gospodarcza: studium przypadku z Chin

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Abstract
Given the intricate and dynamic international political and economic landscape, effectively preventing and resolving risks and challenges while bolstering the resilience of economic development has emerged as a focal point for both political and academic spheres. Utilizing panel data from Chinese provinces spanning 2013 to 2021, this study employs the entropy weight method to gauge the level of digital trade and economic resilience in each region, subsequently exploring the impact of digital trade on regional economic resilience along with its underlying transmission mechanisms. The findings reveal a significant positive effect of digital trade on regional economic resilience, which is robustly supported by endogeneity test. Mechanism testing demonstrates that this impact primarily stems from upgrading effects in industrial structure at the production end and resource allocation effects, whereas consumption-driven upgrading effects at the consumption end are not deemed significant. Moderation effect testing further indicates that improvements in transportation infrastructure can enhance the promotion of digital trade on regional economic resilience. Regionally, central regions and regions with higher marketization levels exhibit the strongest promotional effect of digital trade on economic resilience. Additionally, there exists a spatial spillover effect stemming from digital trade development's influence on economic resilience.

Key words: digital trade, economic resilience, industrial structure, resource allocation efficiency, transportation infrastructure

Streszczenie
Biorąc pod uwagę zawiły i dynamiczny międzynarodowy krajobraz polityczny i gospodarczy, skuteczne zapobieganie i rozwiązywanie zagrożeń i wyzwań przy jednoczesnym wzmacnianiu odporności rozwoju gospodarczego stało się punktem centralnym zarówno dla sfery politycznej, jak i akademickiej. Wykorzystując dane panelowe z chińskich prowincji z lat 2013–2021, badanie to stosuje metodę wag entropijnych do pomiaru poziomu handlu cyfrowego i odporności gospodarczej w każdym regionie, a następnie bada wpływ handlu cyfrowego na regionalną odporność gospodarczą wraz z jego podstawowymi mechanizmami transmisji. Wyniki pokazują znaczący pozytywny wpływ handlu cyfrowego na regionalną odporność gospodarczą, co jest solidnie poparte testem endogeniczności. Testowanie mechanizmów pokazuje, że wpływ ten wynika przede wszystkim z efektów modernizacji w strukturze przemysłowej na końcu produkcji i efektów alokacji zasobów, podczas gdy efekty modernizacji napędzane konsumpcją na końcu konsumpcji nie są uznawane za znaczące. Testowanie efektów moderacji wskazuje ponadto, że ulepszenia infrastruktury transportowej mogą zwiększyć promocję handlu cyfrowego w kontekście regionalnej odporności gospodarczej. Regionalnie, regiony centralne i regiony o wyższych poziomach komercjalizacji wykazują najsilniejszy efekt promocyjny handlu cyfrowego w kontekście odporności gospodarczej. Ponadto istnieje efekt rozprzestrzeniania się w przestrzeni, wynikający z wpływu rozwoju handlu cyfrowego na odporność gospodarczą.

Słowa kluczowe: handel cyfrowy, odporność ekonomiczna, struktura przemysłowa, efektywność alokacji zasobów, infrastruktura transportowa

1. Introduction

Faced with the escalating trend of trade protectionism, frequent global public health events, and geopolitical conflicts, the intricate and volatile international economic landscape necessitates bolstering the resilience levels of industrial chains, supply chains, and value chains. How to further enhance the overall resilience of economies becomes a strategic imperative that countries must prioritize in their economic development process (L. Liu et al., 2022). Economic resilience refers to an economy's capacity to adapt to shocks and swiftly recover from them. It reflects a country's or region's ability to withstand external risks (Zhang & Tian, 2024). In the period of global pandemic, China effectively coordinated epidemic prevention and control measures with economic development. The nation promptly restored social and economic order, becoming the first country to resume work and production while stabilizing its economic situation. Behind this achievement lies China's robust economic resilience, immense potentiality, vibrant vitality, and ample room for maneuver (Feng et al., 2023; Wang et al., 2022). Against the backdrop of an accelerating evolution of unprecedented changes spanning a century, global economies have been subjected to frequent external shocks such as natural disasters, economic crises, trade frictions, and geopolitical conflicts. These events have exerted varying degrees of influence on macroeconomic operations, industrial structure transformation, and production activities across nations. Consequently, they pose a formidable test to the economic resilience of these countries (Lu & Yang, 2024). For China, after more than four decades of rapid development, the traditional growth model heavily reliant on resource-intensive and high-consumption patterns has gradually lost momentum (Tang et al., 2023). As a result, policymakers and academia are increasingly focused on seeking new drivers for economic development and enhancing economic resilience.

Foreign trade, as a crucial component of international economic activities, serves as a significant manifestation of the interconnection between nations and the global community (Zheng & Jin, 2023). Moreover, it also represents a sector that exhibits sensitivity to external shocks. However, with the digital economy increasingly assuming its role as the primary driving force behind industrial transformation (Gu & Zhang, 2023), digital trade emerges as a novel form of commerce in this era. It not only offers new avenues for leveraging domestic and foreign markets and resources but also presents fresh opportunities for bolstering regional economic resilience. In 2021, the Ministry of Commerce of China issued the *Plan for High-Quality Development of Foreign Trade in the 14th Five-Year Period*, which explicitly advocated for robust advancement in digital trade. The report from the 20th CPC National Congress provided significant directives to accelerate the establishment of a dominant force in digital trade, emphasizing attracting global resources and elements through domestic circulation while enhancing synergies between domestic and international markets and resources. Furthermore, it emphasized expediting digital trade development to construct a formidable trading powerhouse. Leveraging rapid advancements in digital infrastructure and technologies, China's digital trade has witnessed continuous expansion. According to a joint report on digital trade development and cooperation released by the Development Research Center of the State Council and China Academy of Information and Communications Technology, China's exports of digital services reached USD 35.97 billion in 2021, representing a year-on-year growth rate of 22.3%. The evolution of digital trade has reshaped trading patterns and methods by effectively reducing costs, improving transaction efficiency, facilitating market integration and efficient resource allocation, driving industrial structure optimization and upgrading. 1. Moreover, the influence of digital trade on the three pillars of sustainable development, namely, environmental, economic, and social dimensions, merits significant attention. Regarding its environmental impact, digital trade contributes to a reduction in greenhouse gas emissions and environmental pollution by diminishing the need for transportation and logistics associated with traditional physical trade processes. For instance, engaging in online transactions and offering digital services can lead to a decrease in the transportation of tangible goods, thereby lessening their ecological footprint. Furthermore, the advancement of digital trade stimulates growth in service sectors such as research and development, design, and management consulting; it fosters employment opportunities while enhancing overall quality of life. It is anticipated that this will serve as a new engine for bolstering economic resilience within its new development paradigm.

Faced with a complex and challenging internal and external environment, the development of digital trade and the enhancement of regional economic resilience have become inevitable requirements for ensuring the stable and healthy growth of China's economy. In this context, this paper aims to explore and validate the impact of digital trade on regional economic resilience from both production and consumption perspectives. Additionally, it further analyzes the role that infrastructure plays in influencing the impact of digital trade on economic resilience, as well as potential variations in different regions. The potential marginal contributions that may arise from this research include: Firstly, this paper quantifies the extent of digital trade and regional economic resilience, and integrates them within the same research framework, thereby addressing the existing research gap on the impact of digital trade on economic resilience. Second, this paper analyzes the impact effects and transmission mechanisms of digital trade on economic resilience from both the production end and consumption end, enriching the research on the influence effects of digital trade development. Third, from the research value perspective, this paper accurately identifies the impact mechanisms of digital trade enabling economic resilience, which is of great theoretical significance and practical value in revealing the economic effects of digital trade and enhancing the region's ability to withstand risks. This not only helps guide digital trade to enhance regional economic resilience, providing theoretical and decision support for the realization of stable and healthy economic operation in various regions, but also helps provide policy reference for the inclusive and sustainable development of digital trade in developing countries.

2. Literature review

The literature closely related to this article can be divided into three categories: the definition of digital trade, the impact effects of digital trade development, and the factors affecting economic resilience.

2.1. Digital trade and its economic effects

With the acceleration of the new round of information and communication technology revolution and industrial transformation, digital trade is reshaping the trade landscape and industrial competitive landscape globally, and is gradually gaining attention from various sectors of society (Arvin et al., 2021). At present, scholars have not reached a consensus on the definition and connotation of digital trade. Xiong et al. (2011) conducted an early study on digital trade, defining it as a business model that provides digitalized electronic information required by supply and demand parties based on the Internet and digital exchange technology, and realizes trade with digitalized information as the object. Ma et al. (2018), integrating the interpretation of the digital economy from the G20 Hangzhou Summit and the research approaches of other scholars, posit that digital trade is a new form of trade activity. This activity utilizes modern information networks as its vehicle to achieve efficient exchanges of traditional physical goods, digital products and services, as well as digitized knowledge and information. Furthermore, it facilitates the transformation from consumer internet to industrial internet, ultimately leading to the intelligentization of manufacturing. The definition of digital trade in the *China Digital Trade Development Report 2021* released by the Service Trade and Commercial Services Department of the Ministry of Commerce can be refined as follows: it encompasses a series of foreign trade activities that leverage information and communication technology to enhance efficiency, optimize structures, and prioritize data resources as a key production factor, while modern information networks serve as crucial carriers. It is evident that although scholars and research institutions may exhibit slight variations in their definitions and connotations of digital trade, its fundamental essence lies in the digitization of trading methods and objects.

Based on this, numerous scholars have conducted extensive research and discussions on the impact of digital trade, with a primary focus on its implications for international economic theory (Ma et al., 2018), how it reshapes the comparative advantages of countries and enterprises (H. K. Liu et al., 2022), as well as the dismantling of international trade barriers (Wen et al., 2023). In empirical studies, most existing research has examined the economic effects of digital trade development from various perspectives including export technological complexity, upgrading industrial structure, enhancing consumption patterns and influencing manufacturing employment. For instance, Y. Liu et al. (2023) conducted a study using provincial panel data from 2011 to 2020 in China to examine the relationship between digital trade and the complexity of exported technology. Their findings indicate that technological innovation and human capital play a mediating role in enhancing the technological complexity of manufacturing exports through the development of digital trade. Additionally, Yao (2021) employed structural equation modeling and mediating effect modeling to demonstrate that information technology level, government spending on science and technology, import and export trade, as well as labor productivity can act as mediators in facilitating the impact of digital trade on improving the complexity of exported technology. Many scholars have also paid attention to the impact of digital trade on industrial structure. Tang and Lan (2024) found that digital trade promoted the transformation and upgrading of China's manufacturing industry and explored the mechanisms behind it. Zhu and Jiang (2022), on the other hand, studied the impact of China's digital service trade exports on global industrial structure upgrading based on the perspective of resource misallocation, finding that they could promote global industrial structure upgrading by suppressing capital and labor factor misallocation. In the related research on digital trade and resident consumption, Zhang and Zhang (2024) showed that the impact of digital trade on the upgrading of resident consumption is manifested in the expansion of quality consumption scale, improvement of consumption quality, and upgrading of consumption structure. Regarding the impact of digital trade on employment, He and Wang (2023) consider cross-border e-commerce pilot zones as a quasi-natural experiment and ascertain that digital trade not only expands the scale of manufacturing employment but also facilitates the optimization and upgrading of employment structure.

2.2. Factors Affecting Economic Resilience

The concept of *resilience* originated in physics and later expanded to encompass various fields of social science research, including economics (Feng et al., 2023; Zhang & Tian, 2024). Economic resilience can be defined as the capacity of an economic system to adapt to disturbances, withstand their impact, and swiftly recover from them

(Tian & Guo, 2023a). The identification of factors influencing economic resilience has consistently been a significant research topic within regional economics and geographic economics. Diversification and upgrading of industrial structure are widely recognized by scholars as important factors that can enhance the resilience of regional economies (Brown & Greenbaum, 2017; Duan et al., 2022; Tan et al., 2020). From the perspective of industrial agglomeration, Zhang et al. (2021) found that industrial diversified agglomeration has a significant positive impact on urban economic resilience but did not find that industrial specialized agglomeration has a positive impact on economic resilience. Du et al. (2023) also found similar results, where they also examined urban economic resilience as the subject of study. The empirical results show that diversified productive service can enhance the ability to cope with economic shocks, while specialized productive service have a negative impact on economic resilience. Demographic factors are also an important aspect that affects regional economic resilience. Jiang et al. (2022) conducted a study with the 2008 global financial crisis as the research background, finding that population concentration not only enhances China's urban economic resilience but also generates positive spatial spillover effects on surrounding cities. As for the relationship between population size and economic resilience, there is abundant evidence showing that population decline reduces the city's economic resilience (Sun et al., 2023; Xie et al., 2022). As a pivotal driver of economic growth, innovation has garnered increasing scholarly attention due to its role in bolstering the resilience of the economic system against exogenous shocks. Bristow and Healy (2018) discovered that regions with robust innovation capabilities demonstrate greater resilience during crises and are more likely to recover from crises in the short term. In a study conducted by He et al. (2023), the impact of technological complexity on regional economic resilience was explored from an innovation process perspective, revealing a diminishing marginal effect in terms of promoting economic resilience. Additionally, other scholars have explored the mechanisms by which various factors influence economic resilience from multiple dimensions, such as financial development (Hou et al., 2023; Yang et al., 2024), regional integration (Feng et al., 2023; Jiang & Jiang, 2024), and human capital (L. Liu et al., 2023), providing valuable insights for this paper.

Through the aforementioned literature review, it becomes evident that the existing body of literature has extensively examined the concept, connotation, and measurement of digital trade. Furthermore, it has analyzed the economic impacts associated with its development and substantiated that digital trade not only facilitates industrial structure optimization and upgrading but also fosters consumption structure enhancement. However, limited attention has been given by scholars to whether digital trade can enhance economic resilience. Additionally, there is a dearth of research comprehensively discussing the transmission mechanism from the perspectives of resource allocation efficiency, industrial structure, and consumption structure. Consequently, this paper aims to fill this gap by exploring these aspects in order to contribute significantly to existing knowledge.

3. Theoretical analysis and research hypothesis

3.1. Digital trade and economic resilience

From the production perspective, the development of digital trade can effectively reduce the organizational and coordination costs associated with global value chains, thereby optimizing the allocation efficiency of production factors for enterprises. Additionally, by digitizing production processes, enterprises are expected to achieve energy savings and promote green and sustainable development (Xu et al., 2022). As data emerges as a crucial production factor, China's abundant data resources enable it to leverage this advantage in actively participating in the integration and value chain upgrading within global value chains, thus enhancing its resilience against external economic shocks. From the perspective of circulation, commodity circulation serves as an intermediate link between production and consumption. The widespread application of digital technology and information communication technology has greatly reduced transaction costs and information search costs in various trade links, thereby improving trade efficiency (Abeliansky & Hilbert, 2017; Zhu & Zhou, 2024). Traditional industries can also leverage digital information technology to replace their sales and trade models, and promote goods trade, service trade, and cross-border data flow through digital interaction, thereby timely absorbing outdated and excess production capacity (Li & Zhang, 2022). In addition, the intelligent operation of digital trade in the logistics process will also help reduce logistics costs. From a consumption perspective, on one hand, digital trade expands market boundaries by facilitating the exchange of previously untradeable or challenging-to-trade goods on a global scale, thereby enhancing the variety and quantity of tradable products. Consequently, this fosters domestic consumer welfare, promotes resident consumption upgrading, and gives rise to new business models and industries (Zhu & Zhou, 2024). On the other hand, digital trade can stimulate consumers' more personalized and diverse consumption needs, which will be fed back to the R&D, design, and production processes of manufacturing enterprises. In order to meet these needs, enterprises will strive for flexible transformation of their production processes, thereby achieving digital and intelligent upgrades (Ma et al., 2018). This process not only enhances various organizations' ability to withstand market risks but also strengthens their capacity to cope with technological risks. Based on this, the paper puts forward the following hypothesis:

H1: Digital trade can promote regional economic resilience.

3.2. The transmission mechanism of digital trade to enhance economic resilience

3.2.1. Factor allocation effect and industrial structure optimization effect

Firstly, from the current development state of digital trade, the widespread application of digital technologies such as big data, cloud computing, blockchain, and artificial intelligence has effectively broken down the physical barriers between regions and industries, promoting the circulation of data, talent, and capital as productive factors, achieving efficient and precise matching of various resources and factors, and improving market distortions and factor misallocation within and outside the region and industry (Habib et al., 2022; Ning & Yao, 2023). The development of information and communication technologies such as the internet has broken through the original spatial and temporal limitations and traditional industrial boundaries, reducing the degree of information asymmetry between supply and demand sides of factors, and greatly reducing intermediate links, creating convenient conditions for various market entities to widely participate in industry division and close cooperation. Moreover, digital trade facilitates the active participation of small and micro enterprises in international trade, enabling their integration into the global value chain system. This not only enhances market vitality and competition but also benefits the survival of superior enterprises while promoting the efficient allocation of production factors to more productive sectors, thereby improving resource allocation efficiency and overall economic performance (Li & Yang, 2021). Consequently, when an economy faces external shocks, its internal economic system exhibits flexible adjustment capabilities, ensuring smooth economic circulation and realizing the resilience-enhancing factor allocation effect of digital trade.

Secondly, the industrial structure is profoundly influenced by the development of digital trade. From the perspective of digital industrialization, technological advancements and the continuous expansion of digital technology are broadening the scope of trade and application scenarios. Digital products and services such as digital education, film and television animation, and digital healthcare are experiencing rapid growth. Additionally, data, a novel production factor, is constantly stimulating the emergence of new products and business models (Liang & Tan, 2024). From the perspective of industrial digitalization, digital industries offer technological advancements, products, and service solutions to traditional industries, facilitating the integration of digital technology with conventional sectors. This integration drives traditional industries towards intelligent transformation and upgrading (Yuan et al., 2021). Enterprises that adopt advanced digital technologies can expedite their own internal digital transformation process, enhance the efficient flow of production factors within their operations, optimize resource utilization efficiency, and compel other enterprises in the supply chain to embark on their own digital transformations. Consequently, this improves the overall level of digitization within the supply chain and promotes coordinated development across its entirety while accelerating industrial structural upgrades (Tang & Lan, 2024). The industrial structure is widely recognized as one of the most influential factors shaping economic resilience (Tang et al., 2023). The adjustment and optimization of the industrial structure entail diversification, which not only enhances risk resistance by dispersing input-output demands (Doran & Fingleton, 2017) but also offers additional avenues for regional adjustment and recovery during economic revitalization (Zhang et al., 2021). Building upon this premise, we propose the following research hypothesis:

H2: Digital trade can enhance regional economic resilience through the effects of factor allocation and industrial structure optimization.

3.2.2. Consumption upgrading driving effect

The emergence of digital trade, a novel form of commerce, not only facilitates the transformation and reshaping of consumers' consumption patterns but also drives product innovation and enhances product quality (Huang & Song, 2019; Zhang & Duan, 2023). In this process, an increasing number of development-enjoyment consumption services such as information services and digital entertainment continue to emerge, effectively meeting the escalating demand for high-quality consumption among residents while promoting improvements in their consumption habits from the supply side (Luo et al., 2022). With the widespread application of digital technologies like big data and artificial intelligence in commodity circulation, previously existing barriers related to information access and distribution can be eliminated within residents' consumption landscape. Consequently, commodities can be more accurately matched with consumer demands (Peltier et al., 2020; Wang & Li, 2024). Furthermore, the high-frequency interaction between supply and demand sides in data resources enables businesses or enterprises to effectively tap into consumers' latent needs and analyze their genuine preferences. This not only facilitates the unleashing of consumption potential but also presents valuable opportunities for businesses to develop high-quality products and continuously drive consumption upgrading. From the perspective of the impact of consumption upgrading on regional economic resilience, residents' upgraded consumption compels domestic industries to adapt to consumer choices, while micro-enterprises must align with market demands in order to enhance product quality and value-added features. This process fosters the advancement of high-end manufacturing and premium services across various regions, elevating the proportion of high-productivity industry added value. Consequently, it achieves a driving effect on economic resilience through consumption upgrading. Based on this analysis, this paper proposes research hypothesis H3.

H3: Digital trade can enhance regional economic resilience through the consumption upgrading driven effect.

4. Research design

4.1. Model specification

4.1.1. Baseline regression model

Drawing upon existing literature, this study employs a two-way fixed effect model to examine the impact of digital trade on economic resilience. The econometric model established is presented in equation (1):

$$ER_{it} = \alpha_0 + \alpha_1 DT_{it} + \alpha_c Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{1}$$

Where, i and t stand for province and year respectively; ER_{it} represents the level of economic resilience of each province; DT_{it} stands for the level of digital trade development; $Controls_{it}$ denotes the set of control variables; μ_i and δ_t represent the fixed effects of control province and time, respectively; ε_{it} is the random error term.

4.1.2. Mechanism test model

To examine the channels through which the development level of digital trade influences economic resilience, this study selects resource allocation efficiency, industrial structure upgrading, and consumption upgrading as intermediary variables for regional digital trade development and economic resilience based on previous analysis. Following Baron and Kenny (1986) research methodology, we construct the subsequent model on the foundation of equation (1).

$$MV_{it} = \beta_0 + \beta_1 DT_{it} + \beta_c Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{2}$$

$$ER_{it} = \gamma_0 + \gamma_1 DT_{it} + \gamma_2 MV_{it} + \gamma_c Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{3}$$

Where, MV_{it} represents the various mediating variables mentioned above, while the meaning of other parameters remains unchanged.

4.2. Description of variables

4.2.1. Dependent variable: regional economic resilience (ER).

In the existing literature, economic resilience is commonly measured through three main approaches: the single sensitivity index method (Tian & Guo, 2023b), comprehensive index evaluation method (Man et al., 2021; Wu, 2023), and counterfactual estimation method (Doran & Fingleton, 2017; Xu & Zhang, 2019). However, the single index method and counterfactual estimation method primarily focus on the economy's ability to recover from shocks, neglecting its capacity to withstand risks before a shock occurs and adapt and transform after a shock. Consequently, they fail to capture the holistic concept of economic resilience. To address this gap, this study adopts an integrated evaluation index system inspired by Wu (2023) to assess regional economic resilience comprehensively. Considering data availability and comparability factors, we commence by considering three dimensions of resilience and recovery ability, adaptation and adjustment ability, as well as innovation and transformation ability (Martin & Sunley, 2014). Subsequently, a regional economic resilience index evaluation system is constructed using 15 selected sub-indicators (refer to Table 1). The entropy weighting method is then employed to assign weights to each indicator in order to calculate the economic resilience level (er) for each province. This approach not only ensures objective weight assignment without subjective bias but also effectively avoids the loss of key information caused by principal component analysis. The specific measurement steps are outlined as follows:

(1) Perform standardization processing

$$\text{Positive indicators:} \quad X_{ij}' = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{4}$$

$$\text{Negative indicators:} \quad X_{ij}' = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \tag{5}$$

In the formula, X_{ij} represents the observed value of the i-th indicator in province j, and X_{ij}' is the dimensionless value.

(2) Calculate indicator weights

$$P_{ij} = \frac{X_{ij}'}{\sum_{i=1}^{n} X_{ij}'} \tag{6}$$

The variable P_{ij} in the equation represents the proportion of province j within index i.

(3) Calculate the entropy value of the indicator

$$e_j = \frac{1}{\ln(n)} \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \tag{7}$$

(4) Calculate the information entropy redundancy and weight

$$g_j = 1 - e_j \tag{8}$$

$$w_j = \frac{g_j}{\sum_j g_j} \tag{9}$$

(5) Calculate the economic resilience score of each province

$$ER_{it} = \sum_j w_j X_{ij}{}' \tag{10}$$

Table 1. Evaluation system of regional economic resilience

	First-level indicators	Second-level indicators	Indicator attributes
Regional economic resilience evaluation system	Resistance and recovery ability	Per capita disposal income	+
		Per capita regional GDP	+
		The proportion of social security expenditures in the fiscal expenditure	+
		The end-of-year deposit balance of financial institutions as a percentage of GDP	+
		Level of human capital (represented by average years of education)	
	Adaptation and adjustment ability	Total fiscal expenditure as a percentage of GDP	+
		Fiscal self-sufficiency level (revenue/expenditure)	+
		Per capita consumption expenditure of residents	+
		Urban survey unemployment rate	-
		Gross fixed asset formation	
	Innovation and transformation ability	The proportion of fiscal spending on science and technology	+
		The proportion of fiscal education expenditure in total expenditure	+
		Urbanization rate	+
		The ratio of R&D expenditures to GDP	+
		Number of patent applications per 100,000 population in high-tech industries	+

4.2.2. Core explanatory variable: digital trade development (DT)

There is currently no consensus among scholars regarding the measurement of digital trade development. In this paper, we adopt the research concepts proposed by Wang et al. (2023) and Wan et al. (2024) to construct a comprehensive evaluation system for the development of digital trade. This system encompasses five dimensions: digital infrastructure, level of digital technology, degree of integration between digital industry sectors, potential for digital trade growth, and logistics environment (refer to Table 2). Furthermore, we employ the entropy weight method to calculate the digital trade development index (*DT*) for each region.

Table 2. Measurement of digital trade development

	Primary index	Secondary index
Digital trade development level	*Digital infrastructure development*	*The penetration rate of mobile phones*
		Length of optical cable lines
		Internet broadband access ports
		Number of domains
	Digital technology	*The number of domestic patent applications accepted*
		Employed personnel in urban units of information transmission, computer services and software industry
		Fiscal expenditure on science and technology
		R&D expenditure of industrial enterprises above designated size
	Digital and industrial integration degree	*E-commerce sales volume*
		The proportion of enterprises engaged in e-commerce transactions
		Number of internet broadband users
		Software business revenue
		Total volume of telecommunications services
	Digital trade potential	*Total export-import volume*
		Total retail sales of consumer goods
		Trade openness
	Logistics carrying capacity	*Length of postal routes*
		Volume of express deliveries
		Express revenue

4.2.3. Control variables

To mitigate the potential impact of omitted variables on the regression outcomes, this study incorporates the following control variables based on existing relevant literature: cultural soft power (*CULTURE*), measured by per capita public library holdings (Cooke & Lazzeretti, 2018); economic openness (*OPEN*) (Wang & Wei, 2021), represented by the ratio of foreign direct investment to GDP; healthcare conditions (*MEDICAL*), indicated by the number of health institutions per 100,000 individuals (Laker et al., 2024); tax burden level (*TAX*), quantified by the ratio of tax revenue to GDP (Gjerde et al., 2019); and energy consumption intensity (*EC*), assessed through unit GDP electricity consumption (Wang et al., 2020).

4.2.4. Moderating Variables

(1) Industrial structure upgrading (*IS*). While many studies employ the ratio of tertiary industry output value to secondary industry output value as an indicator, this measurement method often overlooks the upgrading of the primary industry. To address this limitation, this paper adopts the approach proposed by Wu et al. (2021), introducing the industrial structure hierarchical coefficient for measuring industrial structure upgrading.

$$IS_{it} = \sum_{j=1}^{3} \frac{Y_{it,j}}{Y_{it}} \times j \tag{11}$$

Where IS_{it} represents the upgrading of the industrial structure, Y_{it} represents the GDP of the region, and $Y_{it,j}$ represents the added value of the *j*-th industry. A higher value of IS_{it} indicates a higher level of industrial structure upgrading.

(2) Resource allocation efficiency (RM). To assess the resource allocation efficiency of each region, we adopt the capital mismatch index (τ_{Ki}) and labor mismatch index (τ_{Li}) as measurement tools, following the research design of Hsieh and Klenow (2009). The specific calculation method is as follows:

$$\tau_{Ki} = \frac{1}{\gamma_{Ki}} - 1, \tau_{Li} = \frac{1}{\gamma_{Li}} - 1 \tag{12}$$

Among them, γ_{Ki} and γ_{Li} are the absolute distortion coefficients of factor prices, which are replaced by relative distortion coefficients in actual measurement:

$$\hat{\gamma}_{Ki} = \left(\frac{K_i}{K}\right) / \left(\frac{s_i \beta_{Ki}}{\beta_K}\right), \hat{\gamma}_{Li} = \left(\frac{L_i}{L}\right) / \left(\frac{s_i \beta_{Li}}{\beta_L}\right) \tag{13}$$

Specifically, $\frac{K_i}{K}$ and $\frac{L_i}{L}$ represent the proportion of capital used by each province out of the total capital, and the proportion of labor used out of the total labor force, respectively. s_i represents the share of output produced by *i*-th province in the total economic output, while $\frac{s_i\beta_{Ki}}{\beta_K}$ and $\frac{s_i\beta_{Li}}{\beta_L}$ actually measure the proportion of capital used and the proportion of labor used when the capital and labor resources are effectively allocated in each region, reflecting the degree of deviation between the actual use of factors and the effective allocation of factors. B_{Ki} and β_{Li} are the capital output elasticity and labor output elasticity for each region, respectively. Following the method used by Zhao et al. (2006), the Solow residual method is used to estimate them. The measurement process is as follows:

Suppose the production function is a C-D production function with constant returns to scale:

$$Y_{it} = AK_{it}\beta^{Ki} L_{it}^{1-\beta_{Li}} \tag{14}$$

After taking the natural logarithm of both sides of the aforementioned equation and incorporating the individual effect (μ_i) and time effect (λ_t), we can derive:

$$\ln(\frac{Y_{it}}{L_{it}}) = \ln(A) + \beta_{Ki}\ln(\frac{K_{it}}{L_{it}}) + \mu_i + \lambda_t + \varepsilon_{it} \tag{15}$$

Specifically, the output variable Y_{it} is represented by the actual GDP of each province; L_{it} represents the labor input, measured by the total number of employed people in each province; and K_{it} represents the capital input, measured by the fixed capital stock of each province, calculated using the perpetual inventory method (Zhang et al., 2022).

Considering the variations in economic conditions and disparities in factor market development across Chinese provinces, differences exist in the capital and output elasticities. Therefore, this study employs the least squares dummy variable (LSDV) method proposed by Bai and Liu (2018) to estimate the capital and output elasticities for each province and calculate the index of capital and labor misallocation. As resource misallocation can occur due to both insufficient ($\tau<0$) and excessive ($\tau>0$) resource allocation, this paper follows Ji et al. (2016)'s practice by taking the absolute value of the index of capital and labor misallocation, summing them up, and obtaining a resource misallocation index (*RM*) for each province. This index is used to represent the efficiency of resource allocation in each region. The measurement process reveals that smaller values indicate higher resource allocation efficiency in each region.

(3) Consumption upgrade (*CU*). Following the approach taken by Zhou (2024), we measure the upgrading of resident consumption by the proportion of development and enjoyment-oriented consumption expenditures in total consumption. Development and enjoyment-oriented consumption includes consumption categories such as transportation and communication, health care, culture and education, household facilities and services.

4.3. Sample selection and data Description

Considering the availability of data, the research sample selected for this paper is the panel data of 30 provinces, autonomous regions, municipalities, and directly administered municipalities (excluding Tibet and Hong Kong, Macau, and Taiwan) in China from 2013 to 2021. The data used in the study comes from statistical yearbooks and the CNRDS database. The descriptive statistics of each variable are shown in Table 3. During the sample period, there are obvious differences in the levels of economic resilience and digital trade development among Chinese provinces. The average level of regional economic resilience is 0.262, with a maximum of 0.687 and a minimum of 0.113. The average level of digital trade development is 0.129, with a maximum of 0.838 and a minimum of only 0.006.

Table 3. Descriptive statistical results of each variable

Types of variables	Variables	N	Mean	SD	Min	Max
Dependent variable	ER	270	0.262	0.123	0.113	0.687
Independent variable	DT	270	0.129	0.133	0.006	0.838
Mediating variable	IS	270	2.412	0.118	2.132	2.834
	RM	270	0.611	0.499	0.059	2.414
	CU	270	0.879	0.098	0.457	0.98
Control variable	MEDICAL	270	72.156	24.419	20.135	121.054
	EC	270	0.098	0.064	0.031	0.319
	OPEN	270	0.113	0.52	0.008	6.992
	TAX	270	0.082	0.029	0.044	0.2
	CULTURE	270	0.764	0.54	0.24	3.32

5. Empirical analysis

5.1. Baseline regression analysis

To test the hypothesis, a Hausman test was initially conducted to determine whether fixed effects or random effects should be employed in the model. The results provided support for utilizing a fixed effects model. The benchmark regression outcomes are presented in Table 4, where columns (1) and (2) represent the regression results without controlling for control variables and without considering fixed effects, while column (3) includes both individual and time fixed effects. Subsequently, columns (3) and (4) present the regression results with control variables incorporated but without controlling for fixed effects, as well as with both control variables and fixed effects controlled. Across all four regression models, it is consistently observed that the coefficient of the core explanatory variable digital trade exhibits a positive sign and passes significance tests at the 1% level. This finding suggests that advancements in digital trade contribute to enhancing resilience levels of regional economies, thus confirming Hypothesis 1.

From the estimated results of the control variables, energy consumption intensity (*EC*) has a significant negative impact on economic resilience. A higher energy consumption intensity may indicate a stronger regional economy's dependence on energy resources. This dependence may make the economy more vulnerable to fluctuations in energy prices and supply disruptions. The estimated coefficient of openness (*OPEN*) to the economy is -0.002, which is statistically significant at the 1% level. This result may be attributed to the fact that highly open regions tend to have a greater dependence on foreign markets and resources, making them more vulnerable to external economic and financial shocks, thereby reducing regional economic resilience. Additionally, the regression results indicate that cultural soft power (*CULTURE*) can enhance regional economic resilience primarily because strong cultural soft power can boost international recognition and attractiveness of regional brands, attract foreign investment, and promote exports. Moreover, cultural soft power can also strengthen social cohesion and trust, contributing to maintaining social stability and fostering cooperation during economic crises.

Table 4. Baseline regression results

Variables	(1)	(2)	(3)	(4)
	ER	ER	ER	ER
DT	0.498***	0.498***	0.589***	0.468***
	(0.025)	(0.025)	(0.034)	(0.025)
MEDICAL			-0.000	-0.000
			(0.000)	(0.000)
EC			-0.287***	-0.154**
			(0.038)	(0.066)
OPEN			-0.003	-0.002***
			(0.002)	(0.001)
TAX			0.598***	-0.059
			(0.227)	(0.118)
CULTURE			0.061***	0.031*
			(0.011)	(0.017)
Constant	0.197***	0.197***	0.131***	0.200***
	(0.003)	(0.003)	(0.020)	(0.017)
Controls	NO	NO	YES	YES
Province FEs	NO	YES	NO	YES
Year FEs	NO	YES	NO	YES
N	270	270	270	270
Adj. R^2	0.988	0.988	0.868	0.989

Note: Standard errors clustered at the city level are reported in parenthesis;
***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

5.2. Endogenous problem

Considering the potential reverse causality between digital trade development and economic resilience, this study employs an instrumental variable approach to address endogeneity concerns. Following the methodologies of Nunn and Qian (2014)and Huang et al. (2019), we construct an interaction term by multiplying each province's internet broadband access ports from the previous year with the number of fixed phones in 1984 as an instrumental variable for digital trade development. On one hand, the establishment of communication infrastructure is a crucial prerequisite for the advancement of digital trade, exerting a profound influence on its development and aligning with the pertinent correlation requirements of instrumental variables. On the other hand, due to scientific and technological advancements, there has been a gradual decline in the utilization of conventional communication tools such as fixed telephones; however, their impact on economic resilience remains negligible, thereby satisfying the exogenous criterion.

The regression results in column (1) of Table 5 indicate that the Kleibergen-Paaprk LM statistic rejects the null hypothesis of *Underidentification test* at a significance level of 5%. Additionally, the Cragg-Donald Wald F statistic exceeds the critical value for the Stock-Yogo weak recognition test at the 10% level. These findings suggest an absence of weak instrumental variable problems Staiger and Stock (1997). The estimated coefficient of digital trade development (*DT*) remains significantly positive at the 1% level, indicating that even after employing the instrumental variable method to mitigate endogeneity concerns, the impact of digital trade on regional economic resilience continues to be statistically significant.

5.3. Robustness test

(1) Lag explanatory variables

To further alleviate the potential endogeneity issues in the model, all explanatory variables are lagged by one period in this study. The regression results presented in Table 5, Column (2) demonstrate that the estimated coefficient of the core explanatory variable *L.DT* is 0.484, which exhibits statistical significance at the 1% level, thereby reinforcing the robustness of the benchmark regression findings.

(2) Replace the variable measurement method.

The variables economic resilience (*ER*) and digital trade (*DT*) in the benchmark regression are measured using the entropy weighting method. To mitigate potential biases arising from different measurement methods, we adopt the approach proposed by Pan et al. (2022) and employ principal component analysis (*PCA*) to reevaluate the economic resilience (*ER*) and digital trade development (*DT*) for each region. As shown in Table 5, Column (3), the coefficient estimates of the digital trade development index (*DT_pca*) obtained through PCA remain significantly positive, indicating that our benchmark regression model is robust against variations in variable measurement methods, thereby validating the conclusions drawn from this study.

(3) Remove special samples

To mitigate the influence of location advantages and policy benefits, which are more pronounced in the four municipalities directly under the central government compared to other regions, we excluded samples from these municipalities and conducted a regression analysis as presented in Table 5, Column (4). Following this adjustment, the coefficient direction and significance of digital trade development level (*DT*) remain consistent with the benchmark regression results, providing further support for Hypothesis 1.

(4) Tobit model regression

Considering that both the dependent and independent variables in this article are measured by the entropy weighting method, with a value range of [0,1] and a truncation feature, in order to avoid the defects of traditional OLS model regression, this article further uses the panel Tobit model for regression. The LR test result shows that the P value is less than 0.01, so the final selected model is the random effect Tobit model. Column (5) shows that the coefficient of the core explanatory variable (*DT*) is still significantly positive, indicating that after considering the sample data characteristics and changing the model, the robust conclusion obtained from the benchmark regression is still valid.

Table 5. Endogenous treatment and robustness test results

Variables	(1)	(2)	(3)	(4)	(5)
	ER	ER	ER_pca	ER	ER
DT	0.410***			0.469***	0.522***
	(0.045)			(0.029)	(0.027)
L.DT		0.484***			
		(0.041)			
DT_pca			0.165***		
			(0.027)		
Controls	YES	YES	YES	YES	
Province FEs	YES	YES	YES	YES	
Year FEs	YES	YES	YES	YES	
Kleibergen-Paap rk LM statistic	5.023				
	(0.025)				
Cragg-Donald Wald F statistic	216.133				
Constant		0.213***	-0.404***	0.181***	0.150***
		(0.021)	(0.087)	(0.018)	(0.022)
N	240	240	270	234	
Adj. R^2	0.679	0.990	0.993	0.982	LR=418.76***

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

5.4. Mechanism test

Using the mediating effect model, we investigated the mechanism through which digital trade impacts economic resilience. The results of the mediating effect test are presented in Table 6. In columns (1) and (5), both regression coefficients of digital trade (*DT*) exhibit significant positive values, indicating that the advancement of digital trade not only facilitates the optimization and upgrading of regional industrial structure but also positively stimulates residents' consumption upgrades. Notably, column (3) reveals a negative coefficient for *DT* which surpasses the 1% significance level, indicating that digital trade plays a crucial role in alleviating distortions in regional factor allocation while enhancing overall resource allocation efficiency. Based on this, we take the core explanatory variable (*DT*) and the mediating variables (*IS*, *RM*, *CU*) as independent variables and the economic resilience (*ER*) as the dependent variable to include in the regression equation. The results in column 2, column 4, and column 6 show that the regression coefficient of the core explanatory variable digital trade (*DT*) is significantly positive. Among the mediating variables, only industrial structure (*IS*) and factor allocation efficiency (*RM*) pass the significance test, while the coefficient of consumption upgrading (*CU*) is negative and not significant.

The above findings preliminarily validate the mediating role of optimizing industrial structure and improving factor allocation efficiency in enhancing regional economic resilience through digital trade. To further ensure the robustness of these results, this study subsequently conducts supplementary verification using the Bootstrap method. After conducting 1,000 bootstrap random samplings, the results indicate that the 95% confidence intervals of both mediating variables, namely industrial structure (*IS*) and factor allocation efficiency (*RM*), do not encompass zero. However, the 95% confidence interval of consumption upgrading (*CU*) does include zero. This finding is consistent with the results obtained from the three-step method test. Therefore, based on mediation effect testing, Hypothesis H2 is confirmed to be true while Hypothesis H3 is not supported; thus, indicating that digital trade can enhance regional economic resilience through its impact on optimizing industrial structure and improving factor allocation efficiency, but there is currently no evidence to demonstrate a driving effect of consumption upgrading. The reason for this result may be that while consumption upgrading can drive domestic manufacturing and service industries upgrading, on the other hand, consumption upgrading may also lead to unstable consumption demand, thereby increasing economic uncertainty and negatively impacting economic resilience. Furthermore, since consumption upgrading mainly manifests as a higher proportion of development-enjoyment consumption with high income elasticity of demand, when the economy is hit by negative shocks, a larger reduction in consumer income will lead to a more significant reduction in demand for development-enjoyment consumption goods, which may exacerbate economic fragility (Loxton et al., 2020).

Table 6. Mediation effect test

Variables	(1) IS	(2) ER	(3) RM	(4) ER	(5) CU	(6) ER
DT	0.132***	0.441***	-0.612***	0.446***	0.065***	0.473***
	(0.040)	(0.024)	(0.172)	(0.026)	(0.021)	(0.026)
IS		0.204***				
		(0.058)				
RM				-0.036***		
				(0.008)		
CU						-0.073
						(0.081)
Constant	2.406***	-0.292**	0.547***	0.219***	0.488***	0.235***
	(0.031)	(0.143)	(0.167)	(0.020)	(0.017)	(0.043)
N	270	270	270	270	270	270
Adj. R^2	0.978	0.989	0.951	0.990	0.897	0.989
Controls	YES	YES	YES	YES	YES	YES
Province FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES
95% CI	[0.0059635, 0.0480983]		[0.0033757, 0. 0404086]		[-0.151926, 0.0056523]	

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

6. Further analysis

6.1. Moderating effect analysis

Previous studies have demonstrated that the development and enhancement of transportation infrastructure play a crucial role in optimizing resource allocation efficiency, improving logistics transportation efficiency, facilitating trade liberalization, and promoting trade growth (de Soyres et al., 2020; Han & Li, 2022; Xu & Yang, 2021). Moreover, transport infrastructure serves as an essential prerequisite for economic resilience by not only supporting digital trade but also ensuring its effectiveness. In regions with inadequate transportation facilities, characterized by underdeveloped areas or poor connectivity, labor, goods, raw materials, and products face challenges in swift circulation due to the absence of corresponding transport conditions, thereby limiting the full exploitation of digital trade advantages. However, with the strategic development and enhancement of transportation networks, closer connections are established among relevant enterprises. This not only reduces transportation costs for foreign trade companies and promotes international economic division of labor (Chen & Li, 2021), but also fosters knowledge spillover effects and technology diffusion resulting from industrial agglomeration and talent concentration. Consequently, the role of digital trade in enhancing regional economic resilience is expected to be further unleashed. Building upon this analysis, we further investigate whether transportation infrastructure can enhance the role of digital trade in bolstering regional economic resilience. The subsequent establishment of a moderating effect model is as follows:

$$ER_{it} = \varphi_0 + \varphi_1 DT_{it} + \varphi_2 DT \times INF + \varphi_3 INF + \varphi_c Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (16)$$

Among them, *INF* represents transportation infrastructure, quantified by the average per capita railway and highway mileage for each province, sourced from the CNRDS database.

The regression results in Table 7 reveal a significant positive regression coefficient at the 1% level for the interaction term between digital trade and transportation infrastructure construction. This finding suggests that as transportation infrastructure improves across different regions, the role of digital trade in enhancing regional economic resilience becomes more pronounced.

Table 7. Regression results for moderating effects

Variables	(1) ER
INF×DT	53.023***
	(20.063)
INF	5.708
	(3.822)
DT	0.602***
	(0.054)
Constant	0.150***
	(0.026)
Controls	YES
Province FEs	YES
Year FEs	YES
N	270
Adj. R^2	0.989

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

6.2. Heterogeneity analysis

6.2.1. Regional heterogeneity

Considering the substantial disparities in resource endowments and levels of economic development across different regions in China, this study categorizes the sample of 30 provinces into Eastern, Central, and Western regions for analyzing regional heterogeneity. Table 8 presents the outcomes of the regional heterogeneity test on the impact of digital trade on economic resilience. The regression results reveal that, after controlling for two-way fixed effects, the coefficients indicating returns from digital trade development in China's Eastern, Central, and Western regions are all significantly positive at a 1% significance level. Among them, the Central region exhibits the most pronounced effect on enhancing economic resilience through digital trade development followed by the Western region; whereas such effect is relatively weaker in the Eastern region. The reason for this result may be that the eastern region already has good transportation and logistics conditions, its digital trade development is relatively mature, and the space for enhancing economic resilience through digital trade is shrinking, so its marginal effect is weak. In contrast, the marginal effect of digital trade in the central and western regions is currently in the process of being released as their digital infrastructure and transportation infrastructure are becoming increasingly complete. It is worth noting that compared to the western region, the industrial system in the central region is more complete, and its digitalization and intelligence level is higher, which can fully release the development potential of digital trade, so the impact of digital trade on economic resilience in the central region is the strongest.

6.2.2. Heterogeneity based on the level of marketization

The level of marketization is a crucial factor that influences the efficiency of resource allocation. Regions with higher levels of marketization generally possess more comprehensive legal systems, experience less market intervention, and employ more efficient mechanisms for resource allocation. These factors contribute to the rapid adoption of digital technologies and the development of digital trade, thereby enhancing the economy's adaptability, innovation capacity, and resilience. To investigate the differential impact of digital trade on economic resilience under varying degrees of marketization, this study employs Fan Gang et al.'s marketization index as a grouping variable. The entire sample is divided into two groups based on each province's median level of marketization:

low-marketization group and high-marketization group. Regression analyses are conducted separately for these groups. Results from columns (4) to (5) in Table 8 reveal that in regions characterized by greater market openness, the coefficient indicating the impact of digital trade on economic resilience is 0.684—significantly higher than the coefficient value of 0.371 observed in regions with lower levels of market openness. This outcome can be attributed to the fact that regions with higher levels of market openness typically exhibit more efficient resource allocation through their functioning market mechanisms which allocate capital, technology, talent, and other production factors more effectively. As an emerging form of trade that can swiftly integrate into such a conducive marketplace environment, digital trade promotes efficient resource utilization and consequently enhances both adaptability and resilience within economies.

Table 8. Heterogeneity analysis

Variables	Eastern (1) ER	Central (2) ER	Western (3) ER	High-marketization (4) ER	Low-marketization (5) ER
DT	0.419***	1.073***	0.490***	0.684***	0.371***
	(0.032)	(0.118)	(0.088)	(0.103)	(0.030)
Constant	0.246***	0.090**	0.109***	0.128***	0.290***
	(0.056)	(0.042)	(0.028)	(0.021)	(0.041)
Controls	YES	YES	YES	YES	YES
Province FEs	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES
N	99	72	99	133	132
Adj. R^2	0.992	0.977	0.951	0.934	0.990

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

6.3. Spatial regression analysis

Previous studies have indicated that digital trade can facilitate the flow of large amounts of data and information and overcome the barriers to circulation caused by information or technological disparities, thus accelerating the flow of information and technology across regions and generating spatial spillover effects. In order to examine the possible spillover effects of digital trade in reducing carbon emissions, this paper first calculates the global Moran's I index for each province of China from 2013 to 2021 based on spatial weight matrices (including spatial geographic distance matrix and spatial economic distance matrix). The larger the index, the stronger the spatial correlation, and the formula for calculation is as follows:

$$Moran's\ I = \frac{\sum_{ij} w_{ij}\left(Y_i - \bar{Y}\right)\left(Y_j - \bar{Y}\right)}{S^2 \sum_i \sum_j w_{ij}} \tag{17}$$

$$S^2 = \frac{1}{n}\sum_i \left(Y_i - \bar{Y}\right), \bar{Y} = \frac{1}{n}\sum_i Y_i \tag{18}$$

The global Moran's I index of digital trade development level and economic resilience in 30 provinces of China from 2013 to 2021 is shown in Table 9. Under three weighting matrices, the global Moran's I index is positive, and all of them pass the spatial autocorrelation test at the level of at least 10%. This result preliminarily indicates that there is a significant spatial positive correlation between digital trade and economic resilience across the entire region.

Table 9. Moran's I index calculation results

	Geographic distance matrix		Economic distance matrix	
Year	DT	RX	DT	RX
2013	0.188***	0.110***	0.242***	0.395***
2014	0.193***	0.115***	0.247***	0.401***
2015	0.181***	0.111***	0.245***	0.394***
2016	0.177***	0.110***	0.263***	0.370***
2017	0.169***	0.111***	0.289***	0.363***
2018	0.143**	0.102***	0.253***	0.332***
2019	0.120**	0.099***	0.215**	0.309***
2020	0.105**	0.109***	0.153**	0.310***
2021	0.130**	0.116***	0.195**	0.304***

Note: ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

To examine the local characteristics of digital trade and economic resilience across different provinces in China, we employed Moran scatter plots based on a spatial geographic distance matrix to visualize the development of digital trade and economic resilience in China for 2015 and 2020. As depicted in Figure 1-4, the provinces in China predominantly cluster within the first and third quadrants, indicating high-high (HH) agglomeration and low-low (L-L) agglomeration patterns in terms of both digital trade development levels and economic resilience. Moreover, the Moran's I index for digital trade and economic resilience in 2015 and 2020 exhibited a statistically significant positive correlation, indicating considerable local spatial autocorrelation regarding both digital trade and economic resilience.

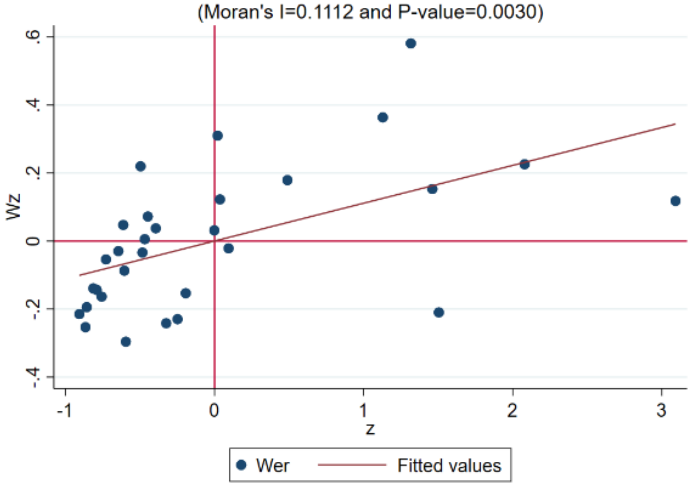

Figure 1. Moran scatter plot, source: (ER, 2015)

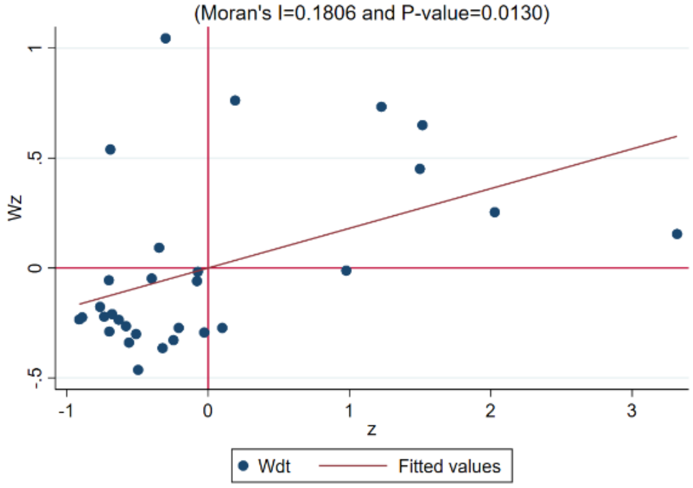

Figure 2. Moran scatter plot, source: (DT, 2015)

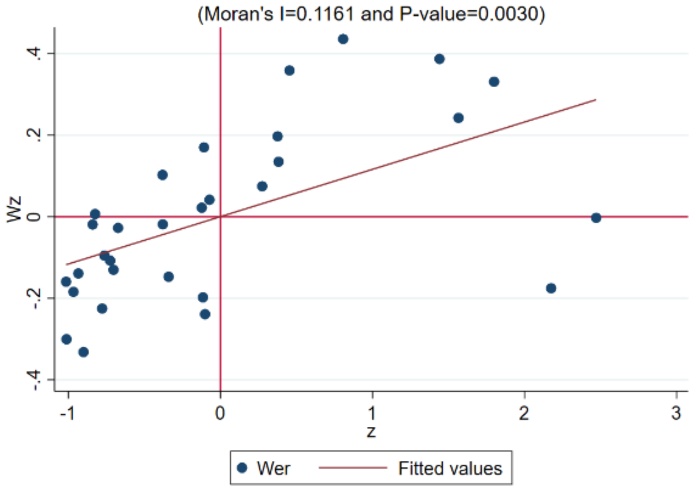

Figure 3. Moran scatter plot, source: (ER, 2020)

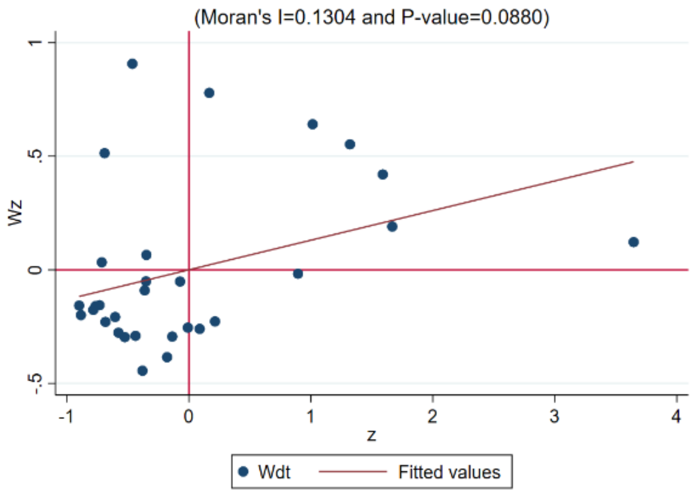

Figure 4. Moran scatter plot, source: (DT, 2020)

Based on the aforementioned analysis, this paper further develops a spatial panel model for examination. In terms of model selection, considering that the spatial Durbin model (SDM) accounts for both the spatial effects of the dependent variable and the error term, it is capable of providing more accurate estimation of the spatial spillover effect generated by individual entities. Therefore, in this study, we opt for employing the spatial Durbin model to conduct regression analysis. Additionally, we also perform a Hausman test to determine the ultimate model choice. Consequently, our final selected model is a spatial Durbin model with fixed effects in both directions as illustrated below:

$$ER_{it} = K_1 W \times ER_{it} + \theta_1 dt_{it} + K_2 W \times DT_{it} + \theta_c Controls_{it} + K_3 W \times Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (19)$$

Specifically, W is a weight matrix for the n-dimensional space, and the other parameters have the same meaning as before.

Considering the robustness of the regression results, this study employs two types of spatial weight matrices to examine the spatial Durbin model: a spatial geographic distance matrix and a spatial economic distance matrix. Furthermore, to provide a more intuitive analysis of spatial effects, we adopt the partial differential processing method proposed by LeSage and Pace (2009) to obtain direct and indirect effects.

As shown in Table 10, both the direct and indirect effects of digital trade on economic resilience are significantly positive under two types of weight matrices. This indicates that the development of digital trade can enhance the local economic resilience of the region while effectively breaking down barriers to the flow of talent, capital, and knowledge, and accelerating the diffusion of information technology and digital technology to promote knowledge spillovers within and outside the region, thereby boosting the economic resilience level of surrounding areas.

Table 10. Decomposition results of spatial effects

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Geographic distance matrix			Economic distance matrix		
	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
DT	0.484***	0.081**	0.565***	0.524***	0.206***	0.730***
	(0.028)	(0.038)	(0.054)	(0.028)	(0.055)	(0.072)
MEDICAL	-0.000	-0.001***	-0.001***	0.000	0.000	0.000
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
EC	0.042	0.629***	0.671***	-0.121	-0.097	-0.217
	(0.091)	(0.174)	(0.240)	(0.078)	(0.213)	(0.229)
OPEN	-0.006***	-0.031***	-0.037***	-0.004**	-0.017*	-0.021**
	(0.002)	(0.012)	(0.013)	(0.002)	(0.009)	(0.010)
CULTURE	0.008	0.062*	0.071*	0.008	-0.195***	-0.187***
	(0.016)	(0.035)	(0.039)	(0.017)	(0.061)	(0.065)
TAX	-0.163	-0.923***	-1.086***	0.003	-0.536	-0.532
	(0.109)	(0.295)	(0.361)	(0.103)	(0.365)	(0.402)
Year FE	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES
Spatial:rho	0.234***			0.228***		
	(0.085)			(0.085)		
Adj.R^2	0.067			0.067		

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively.

Conclusions and policy implications

Faced with a complex and dynamic internal and external environment, the imperative of fostering stable and robust national economies necessitates the identification of strategies to bolster economic resilience amidst shifting patterns of economic growth. Based on panel data from Chinese provinces from 2013 to 2021, this paper systematically investigates the influence of digital trade development on regional economic resilience as well as its underlying mechanisms, which is in compliance with stainable development concept. This study reveals that: (1) Digital trade plays a significant role in enhancing regional economic resilience, which is strongly supported by both the endogeneity test and robustness test. (2) Digital trade primarily impacts economic resilience through industrial upgrading and resource allocation effects at the production end, while the consumption-driven effect on consumption upgrading has yet to be demonstrated. (3) As transport infrastructure progresses, it becomes a crucial enabler for digital trade development and significantly amplifies its impact on economic resilience. (4) Regionally, digital trade has the greatest impact on improving economic resilience in the central region, followed by the western region; however, its influence is weakest in the eastern region. Moreover, compared to areas with lower marketization levels, regions with higher marketization levels experience a stronger enhancement of economic resilience through digital trade. (5) The regression results obtained from the spatial Dubin model demonstrate that the advancement of digital trade enhances the economic resilience of neighboring regions.

Based on the research findings, the following policy recommendations are put forward: (1) Harnessing digital technology innovation to bolster the impetus of digital trade development. As a novel form of trade, the advancement of digital trade necessitates heightened demands for digital infrastructure. China should strive to augment its autonomous capacity for innovative breakthroughs in digital technologies and information and communication technologies, expedite the establishment of digital industries, and propel the high-quality progression of digital trade through digitization. Furthermore, drawing from the experience gained in constructing free trade zones, it can explore pilot initiatives within digital trade demonstration zones to facilitate harmonization between international standards and both digital standards and trading norms. This will create an enabling institutional environment that fully unlocks the potential for advancing digital trade while continuously enhancing China's economic resilience. (2) Optimize the allocation of regional resources and facilitate industrial upgrading. From a production perspective, resource allocation and industrial structure play a crucial role in mediating the impact of digital trade on economic resilience. Therefore, China should formulate relevant legislation and policies to eliminate restrictions on factor mobility and administrative barriers, enhance marketization, and guide the rational and effective allocation of data, talent, capital, and other production factors. Additionally, efforts should be made to assist export-oriented enterprises in transitioning into digitalized and intelligent entities while promoting coordinated development between industrial digitization and digital industrialization. This will facilitate the transformation and optimization of the overall industrial structure. (3) Enhance infrastructure development to unlock the potential of digital trade. As evidenced by research findings, robust infrastructure is a crucial prerequisite for effectively harnessing the driving forces behind digital trade. Therefore, regions should prioritize the improvement of transportation and digital infrastructure, with particular attention to bridging the *digital divide* and addressing the *infrastructure gap*. Additionally, it is imperative to eliminate barriers impeding the flow of factors and goods between regions in order to ensure unobstructed pathways towards enhancing economic resilience. (4) Strengthen inter-regional and inter-industry exchanges and cooperation to further promote the coordinated development of digital trade across regions. It is essential to leverage the exemplary role of the eastern regions in the development of digital trade while gradually narrowing the digital infrastructure gap between the central and western regions and the east. Tailored measures should be formulated to assist provinces with weaker digital foundations in bridging the digital divide, ensuring that the benefits of digitalization permeate widely across all regions and sectors. Concurrently, a robust mechanism for the transfer and reception of industries should be established to mitigate market segmentation and attract innovative elements to flow towards the central and western regions, where there is greater potential for the growth of digital trade. This approach will achieve coordinated regional development and an overall enhancement of economic resilience.

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Data availability

Data will be made available on request.

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