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The Impact of the Digital Economy on High-quality Economic Development under the Dual-Circulation Perspective

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Abstract

This paper aims to explore the impact of the digital economy on high-quality economic development, particularly the roles of digital infrastructure, digital industries, and digital integration in promoting regional total factor productivity (TFP). Within the framework of the relationship between the digital economy and high-quality economic development, this study constructs an econometric model that incorporates mediating effects to verify whether technological progress acts as a bridge between the digital economy and high-quality economic development. By collecting panel data from 30 provinces and cities in China from 2017 to 2021, we measure the digital economy development index and link it to regional TFP.

Keywords

Digital Economy; Total Factor Productivity (TFP); Technological Progress; Mediating Effect; Spatial Spillover Effects.

1. Introduction

China's "14th Five-Year Plan" proposes to construct a new pattern of dual circulation, domestic and international, with the digital economy at its core to promote high-quality development. The digital economy accounts for 4.5% to 15.5% of the global GDP, with the United States and China together accounting for 40% of the global value added in information and communication technology. The proportion of China's digital economy in GDP has increased from 14.2% in 2005 to 38.6% in 2020, indicating a broad scope for research.

The concept of the digital economy was first articulated in 1996 by Tapscott in his influential report "The Digital Economy: Promise and Peril in the Age of Networked Intelligence," which emphasized the digital flow and transmission of information in cyberspace, marking the preliminary formation of digital economy theory. Tapscott's theoretical contribution not only laid the foundation for subsequent academic discussions but also provided a key perspective for understanding new models of economic activity in the digital age [1]. In 1998, the U.S. Department of Commerce first introduced the concept of the "digital economy" in its report "The Emerging Digital Economy," which gained global recognition. Research on the digital economy has rapidly evolved, with its connotations and frameworks continuously deepening. In a narrow sense, the digital economy encompasses information and communication technology services, manufacturing, as well as retail, platform, and sharing economies, providing an accurate framework for policy-making and academic research.Maglio proposed that the digital economy encompasses four core components: Internet infrastructure, e-commerce, digital distribution of goods and services, and retail sales of tangible goods. Meisenberg emphasizes e-business infrastructure, e-business activities, and their expansion. Bukht divides the digital economy into three levels: the core layer (IT/ICT domain), which includes hardware manufacturing, software and IT consulting, information services, and telecommunications; the narrow digital economy, encompassing e-commerce, digital services,

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and platform economy; and the broad digital economy, including e-commerce, Industry 4.0, precision agriculture, and the algorithm economy, providing a comprehensive framework for policy and research [2]. The rapid development of digital technology and the emergence of new industries continuously expand the connotations of the digital economy. As a historical category, the digital economy is formed through the interaction of technology, organizational structure, and institutions within the economic system, based on efficient collaboration in economic activities and new modes of production organization shaped by such highly coordinated economic activities and technology-based interactions, manifesting as a highly coordinated macroeconomic phenomenon. This reflects the central role of digital technology in the modern economy and reveals new trends and characteristics in the digital transformation of economic activities [3-4].

In the context of supply-side reforms, digital technology is driving changes in the economic sector. China's digital economy is divided into digital industrialization and industrial digitization. The study focuses on China's position in the global digital economy, and explores the integration of digital technology with traditional industries with the following goals. Achieve green and rapid GDP development [5-6]. Realize the transformation of consumption structure [7]. Improve the quality of human capital [8-9]. promote the transformation of the industrial economy from labor-intensive to technology-intensive; Consolidate infrastructure construction [10-12]. Make the most of your data resources [13-14]. In order to promote the high-quality development of the digital economy, China needs to strengthen technological innovation, expand digital applications, and build a digital industrial chain. In the face of challenges such as unbalanced development and cyber security, it is necessary to coordinate policies in a precise manner, narrow the digital divide, and achieve balanced regional development [15]. At present, China's economy is in a period of transformation and slow growth, and economic development depends more on the quality and efficiency of economic growth than on quantity and speed [16]. Economic growth indicators such as GDP and national income are no longer the sole focus of governments, and policymakers are shifting to focus on the quality of growth to promote efficient use of resources and environmental sustainability,and to promote resource-saving and environmentally-friendly social development [17]. The focus of economic growth theory shifts from scale to quality, and the Moran index and spatial econometric model reveal the spatial spillover effect of China's economic growth, emphasize the importance of economic growth quality, and provide a new perspective of regional economic interaction [18]. Scholars use a variety of econometric models to explore the impact of education, political instability, FDI, human capital, banking globalization, and information and communication technology on economic growth, aiming to construct an indicator system of high-quality economic development and provide accurate analysis tools [19-21]. Qi constructs a system for measuring the quality of economic growth that encompasses scale, performance, structure, and coordination [22]. Based on the matrix method, Frolov constructs a regional economic growth quality evaluation system that combines average annual productivity growth and per capita development index [23]. Regarding the research on the relationship between digital economy and high-quality economic development, more scholars have studied the impact of digital economy on high-quality economic development from the perspectives of big data empowerment [24], integration of digital economy and real economy [25], sharing economy [26], digital finance [27], and policy supply system [28].

The digital economy is in line with the new development concept, and has become China's strategic development direction to promote high-quality economic development. Scholars have conducted extensive research, but there is a lack of empirical research, especially a lack of in-depth discussion on the development of China's digital economy. This paper selects key dimensions to evaluate the development of China's inter-provincial digital economy from 2017

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to 2021, constructs a model to explore the impact of digital economy on high-quality economic development, and introduces technological progress as a mediating variable to analyze the heterogeneity of digital economy and regional development.This study analyzes the impact of the digital economy on high-quality development, especially under the dual circulation pattern. Through the intermediary effect of technological progress, this paper explores how the digital economy can improve total factor productivity and promote high-quality development, and examines regional heterogeneity, so as to provide reference for China's digital economy policy and promote the optimization of economic structure and efficiency.

2. Theoretical Analysis and Research Hypotheses

This study analyzes the direct impact of the digital economy on high-quality development from both macro and micro perspectives. At the macro level, the digital economy enhances total factor productivity by improving the input of production factors, optimizing the efficiency of allocation, and promoting technological progress and spillover [29]. For developing countries, digitalization is considered to be the main driver of economic growth. It increases capital and labor productivity, lowers transaction costs, and facilitates national integration into the global market system [30-31]. For developed countries, the impact of the digital economy on the quality of economic development is mainly reflected in the promotion of sustainable development [32]. and the improvement of enterprise agility [8]. The digital economy was the main driver of economic growth in the United States between 2004 and 2012 [33]. Independent R&D investment and technological progress in the production sector have a significant positive impact on total factor productivity (TFP) growth [34]. Informatization has played an important role in driving TFP growth in 12 major OECD countries [35]. Data from 2009 to 2018 from the EU's 15 advanced economies show that national and sectoral digital policies can significantly boost economic growth[8].In addition, the increase in the productivity of digital assets has led to a sharp decline in employment in mass production systems [36], which has also had a long-term and stable effect on the development of technological innovation [37]. From a micro perspective, digital manufacturing technologies have improved the competitiveness of enterprises and improved their performance [38], effectively promoted the development of e-government [39], and helped enterprises realize the business model of circular economy [40]. In general, despite the rapid development of information technology and digital technology, the role of the digital economy, represented by information data and cloud computing, in economic development has not yet been brought into full play [41]. In the era of digital economy, based on the theory of comparative advantage and first-mover advantage, the technology-intensive and fast-growing digital economy relies on platform construction, intelligence, and ecosystem improvement to promote regional growth and technological progress. Regions with perfect infrastructure and thriving digital economy have the comparative advantages of agglomeration effect, depth of technology application and ecosystem maturity, as well as first-mover advantages of digital infrastructure optimization and human capital accumulation, to jointly promote high-quality regional economic growth.Based on this, the following research hypotheses are proposed:

H1: The development of the digital economy has a positive effect on improving total factor productivity and can directly promote high-quality economic development. Compared with regions with a low level of digital economic development, those regions with a solid foundation in the digital economy will be more able to benefit from the development of the digital economy.

Total factor productivity (TFP) refers to the part of value that remains in the process of economic growth after removing the contribution of all quantifiable factors of production (such as capital and labor). Technological progress is a key component of this surplus value, with information technology constituting a core feature of the digital economy. According to the

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endogenous growth theory, spontaneous R&D activities and innovative behaviors are the fundamental driving forces for economic growth and technological progress[42]. The development of digital technology has not only broadened the boundaries of production, but also expanded the frontier of innovation, thereby promoting the improvement of total factor productivity. In the wave of digital economy, the cost structure of enterprises has undergone significant changes, showing the characteristics of high fixed costs and low marginal costs. The network externality effect further reduces the average cost of enterprises and promotes the formation of economies of scale. At the same time, enterprises pay more attention to the diversification of products and services, accumulate user data through multilateral platforms, reduce operating costs, and realize user drainage between different products. The digital economy has also given rise to the parallel development of multiple business models, enabling economies of scope. The efficient integration ability of information technology optimizes market supply and demand information, improves matching efficiency, reduces information redundancy, reduces market transaction costs, and improves the operational efficiency of the economic system. A new generation of information technology, such as big data, cloud computing, and artificial intelligence, is reshaping traditional industries, making data a core factor of production. The digital division of labor promotes knowledge sharing and factor coordination, and greatly improves the development efficiency of traditional industries.

Therefore, this paper proposes the hypothesis that the development of H2:

H2: digital economy can indirectly have a positive impact on total factor productivity by promoting technological progress.

3. Measurement of China's Digital Economy

3.1. Measurement Index of China's Inter-provincial Digital Economy

The digital economy, as a product of the fifth technological revolution driven by information and communication technology (ICT), has three significant characteristics: first, data has become the core factor of production, efficient allocation of resources, penetration into all fields of economy and society, and embodiment of integrated development; Second, digital infrastructure such as big data, artificial intelligence, mobile Internet, and cloud computing have become the cornerstones of economic development, pushing the digital economy into a new era of flexibility, sharing, and high performance [43]. In addition, infrastructure including communication infrastructure, IoT terminals, cloud computing resources, etc., has adapted to technological development and entered a rapid development track. Third, the digital economy has become the main driving force for economic development in this era. With the advantages of special netizens, China will gradually unleash its economic growth momentum, and its contribution to economic growth will steadily increase [44]. Based on the analysis of the essential attributes and characteristics of the digital economy, with reference to the digital economy reports and white papers published by authoritative research institutions in China, and following the principles of timeliness, representativeness, comparability and data availability [45], this paper argues that the development of the digital economy refers to the use of a new generation of information technology and information infrastructure to penetrate into all aspects of economic and social development. In addition, it also involves carrying out a series of activities to promote the development of traditional industries and the optimization of the economic structure. Therefore, this paper constructs an index system to measure the development of China's inter-provincial digital economy from three dimensions: digital infrastructure, digital industry, and digital convergence effect.

As shown in Table 1, in order to measure the development of the digital economy, this paper designs an index system, including 3 second-level indicators and 12 third-level indicators, and evaluates the development level of China's inter-provincial digital economy. In order to make

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statistical indicators in different regions comparable in time series, proportional indices are used as much as possible. In addition, the development effect of digital economy integration is affected by many factors and cannot be measured by a single indicator. Therefore, this paper draws on the online government index and the digital life index in China's inter-provincial information society index released by the Ministry of Industry and Information Technology and the State Information Center. All three indicators are constructed based on secondary data, and the others are based on information from the National Bureau of Statistics and provincial and municipal statistical yearbooks.

(1) Digital economy infrastructure sub-index. This part of the index is mainly used to measure the development level of inter-provincial digital economy infrastructure, which is an important prerequisite for the development of regional digital economy. This article examines two main aspects: mobile Internet and Internet ports. The level of mobile Internet development is characterized by mobile phone penetration rate and per capita mobile Internet access traffic. The level of Internet port development is explained by the number of Internet bandwidth access ports and the number of websites owned by the business.

Table 1. Digital economy measurement index system and its weight.

First-level inde	Second-level index	Third-level index	Unit	Weight
Digital economy development index	Digital economic infrastructure sub-index.(0.4152)	Internet broadband access port	10000/10000 people	0.0908
		Mobile Internet access traffic per capita	10000 GB/10000 people	0.0836
		Mobile phone penetration rate	Per hundred people	0.1137
		Number of websites per 100 enterprises	Per 100 enterprises	0.1271
	Digital economic industrial developmentsub-index (0.2984)	Value added for information transmission, software and information technology services/GDP	Percentage	0.0996
		Value added for computer, communications and otherelectronic equipment manufacturing/GDP	Percentage	0.0796
		Number of enterprises related to digital economy	Number	0.0645
		ICT investment level proportion of regional digital investment	Percentage	0.0547
	Digital economy integration and application sub-index. (0.2864)	Regional e-commerce procurement and sales/regional GDP	Percentage	0.0399
		Industrialization information integration index	Third-party data	0.0903
		Online government index	Third-party data	0.0797
		Digital life index	Third-party data	0.0765

(2) Digital economy industry development sub-index. This part of the index is mainly used to measure the industrial scale, enterprise and investment development of the inter-provincial

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digital economy; The scale of the core industries of the digital economy is explained by the added value of the information technology service industry and the electronic equipment manufacturing industry; The number of enterprises in the regional economy is used to explain the level of development of enterprises related to the regional economy; Investments in the regional digital economy are explained through investments in information and communication technology (ICT).

(3) Digital economy integration and application sub-index. This part of the index is mainly used to measure the development level of inter-provincial digital economy integration. China's consumer internet is a core component of the digital economy; Therefore, regional e-commerce sales are used to measure the development of regional "digital economy + service industry". The level of digitalization of industrialization cannot be measured by a single indicator; Therefore, this paper draws on the integrated development potential index of the Ministry of Industry and Information Technology to measure. In addition, "digital economy + government affairs" and "digital economy + people's livelihood" are two important aspects of the development of the digital economy. Therefore, in order to measure the level of development of digital economy integration, we draw on the online government index and the digital life index in the information society index released by the State Information Center.

3.2. The Pattern of China's Inter-provincial Digital Economy

Table 2. Comprehensive index of the interprovincial digital economy in China.

Area		Composite index in 2015	composite index in 2019	index movement (%)	Regional average index in 2019
Eastern	Beijing	75.99	89.44	13.45	73.58
	Tianjin	47.03	61.87	14.84	
	Hebei	36.06	59.04	22.98	
	Shanghai	73.32	83.55	10.23	
	Jiangsu	65.51	80.90	15.39	
	Zhejiang	65.79	77.65	11.86	
	Fujian	55.73	66.15	10.42	
	Shandong	46.43	66.20	19.77	
	Guangdong	73.73	87.88	14.15	
	Hainan	47.98	63.15	15.17	
Northeast	Liaoning	44.46	55.81	11.35	52.18
	Jilin	34.58	52.18	17.60	
	Heilongjiang	33.17	48.54	15.37	
Central	Shanxi	33.29	46.22	12.93	50.68
	Jiangxi	37.57	48.88	11.31	
	Anhui	43.04	56.05	13.01	
	Henan	34.23	49.16	14.93	
	Hubei	40.24	55.79	15.55	
	Hunan	37.83	47.99	10.16	
western	Mongolia	32.89	58.21	25.32	54.19
	Guangxi	26.97	48.75	21.78	
	Chongqing	41.04	63.43	22.39	
	Sichuan	44.95	62.27	17.32	
	Guizhou	25.30	51.93	26.63	
	Yunnan	28.92	40.56	11.64	
	Shanxi	42.36	57.15	14.79	
	Gansu	30.05	47.06	17.01	
	Qinghai	39.32	54.62	15.30	
	Ningxia	35.93	56.93	21.00	
	Xinjiang	28.07	42.05	13.98	

As can be seen from Table 2, in the development of China's digital economy, the eastern region has performed strongly, while the non-eastern region has lagged behind. In 2021, the average value of China's Digital Economy Composite Index was 59.31, of which 11 provinces and cities exceeded this average, mainly in the eastern provinces and cities, as well as Chongqing and Sichuan, while the rest of the provinces and cities were below the average. The variance of the digital economy development index has been decreasing year by year, indicating that the "digital economy gap" between provinces is narrowing, reflecting the support of national policies for regional balanced development. The development of the digital economy in the eastern region is relatively good, but the internal "digital divide" is obvious, especially in Beijing, Shanghai and Guangzhou, and other provinces and cities have a much higher level of digital economy development than other regions. In the future, replicating and disseminating the experience of digital economy development in developed regions to other regions is one of the effective ways to solve the "digital economy gap" between provinces.

4. Model Building

4.1. Variable Definitions

4.1.1. Dependent Variable

At present, the academic community has not developed a unified accounting framework and system for high-quality economic development, and the methods can be summarized as multi-index and single-index measurement methods, most of which are guided by the "five development concepts" to comprehensively and systematically describe the quality of economic development, that is, high-quality economic development in a broad sense. The single-indicator method focuses more on the economic development efficiency in the connotation of high-quality economic development, that is, high-quality economic development in a narrow sense. The purpose of this paper is to study the impact of digital economy on the efficiency of economic development, so a single indicator of total factor productivity is used to describe high-quality economic development [46-47]. This approach is also in line with the view of most scholars that the key to achieving high-quality economic development is to improve economic efficiency. Among the methods used to measure total factor productivity, the Solow residual method is the most common [48]. The Cobb-Douglas production function can be expressed as:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{1-\alpha} \quad 0 < \alpha < 1; \quad A_{it} = \frac{Y_{it}}{K_{it}^{\alpha} L_{it}^{1-\alpha}} \tag{1}$$

Among them, capital investment K is to estimate the physical capital stock of each province and city during the sample period by using the internationally recognized perpetual inventory method. The specific formula is:

$$K_t = I_t + (1-\delta) K_{t-1} \tag{2}$$

The stock of physical capital at the beginning of the period is estimated as:

$$K_0 = \frac{I_0}{g+\delta} \tag{3}$$

Considering that the base period is set earlier, the initial capital stock estimation has little impact on the later capital stock estimation. The base period is set at 2010. It is the amount of

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investment in year t, expressed as the total investment in fixed assets of the whole society, and converted to RMB at constant prices in 2010 according to the price index; δ is the rate of depreciation of fixed assets. Referring to the practice of most scholars, this paper calculates the capital stock of each province and city in the country, and sets δ = 9.6%. In the calculation of total factor productivity, there are some differences in the calculation value of the elastic α of capital output in different literatures. When calculating the total factor productivity of each province and city, this paper studies the value of the elastic α of capital output as 0.6 [49]. A statistical description of the measured data is shown in Table 3 (TFP). In addition, for the sake of robustness testing, the capital output elasticity α is set at 0.5 and 0.7.

Table 3. Classification of China's interprovincial digital economy development level clubs in 2019.

Highly developed areas	Beijing Guangdong Shanghai Jiangsu Zhejiang
Moderately developed areas	Fujian Shandong Hainan Tianjin Chongqing Sichuan
Low developed areas	Shanxi (western) Hebei Liaoning Anhui Hubei Henan Ningxia Qinghai
Underdeveloped areas	Jilin Shanxi (Central) Jiangxi Heilongjiang Hunan Guangxi Guizhou Gansu Xinjiang Yunnan

4.1.2. Argument

The core independent variable, the Digital Economy Index, is calculated based on 12 indicators across three dimensions: Infrastructure Sub-index, Digital Industry Sub-index, and Digital Integration Sub-index. The indicators reflecting the level of technological progress in Chinese provinces are synthesized from two metrics: the volume of regional patent applications authorized and the transaction volume of regional technology markets, with data sourced from the National Bureau of Statistics.

Table 4. Variable definition.

Variable	Symbol	Basic meaning	Measure
Dependent variable	*TFP*	Total factor productionefficiency	The C-D function is used to measure Inter-provincial Total Factor Productivity
Independent variable	*DEI*	Digital economy development index	The digital economy index consists of three dimensions: the basic sub-index (INF), the industrial sub-index (DIND) and the integration sub-index (FUSE).
Intermediary variable	*TP*	Technological progress	Combination of regional patent application authorization and technology market turnover
Control variable	*TD*	Level of technology development	R&D investment of industrial enterprises/ regional GDP
	FD	Level of financial development	Total deposits and the loan balance of financial institutions/regional GDP
	IS	Level of industrial structure	Service industry value added/regional GDP
	OPEN	Level of opening up	Total imports and exports/regional GDP
	RD	Level of financial R&Dinvestment	Government financial R&D expenditure/general budget expenditure of local finance

As the process of index standardization and weighting is analogous to that of measuring the Digital Economy Index, it will not be reiterated here. The definitions of the relevant variables are presented in Table 4, and the descriptive statistics of the variables are shown in Table 5.

ISSN: 2710-0723

Table 5. Statistical description of standardized data.

Variable	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
TFP	150	52.4840	11.2899	34.8840	77.6635
DEI	150	51.1314	14.6046	25.2996	89.4383
TP	150	49.9420	14.2785	36.2121	100.3963
TD	150	47.9432	28.7876	5.8856	99.9783
FD	150	48.0834	28.3672	3.2096	99.2884
IS	150	45.3988	21.5884	8.7335	100.0000
OPEN	150	45.3853	20.8818	23.9121	99.4366
RD	150	49.3396	22.2278	24.2445	108.8159

4.2. Research Methods:

4.2.1. Direct Effect Model

A multiple linear regression model was constructed to explore the direct impact of the digital economy on high-quality economic development (total factor productivity). The model looks like this:

$$TFP_{it} = b_0 + b_1 DEI_{it} + Controls + \mu_{it} \tag{4}$$

In model (4), TFP_{it} represents the total factor productivity of provinces, DEI_{it} represents the level of development of the digital economy, and the indicator data comes from the previous measurement of the digital economy index. According to previous analysis, the digital economy can increase total factor productivity by promoting technological progress. As for the control variables, it is consistent with the existing research practice [50], and the level of technological progress (TP), technological development (TD), financial development (FD), industrial structure (IS), openness (OPEN), and fiscal R&D investment (RD) have been added. i represents the province, t represents the year, β_0 represents the intercept term, and μ_{it} represents the random error term. Using a general benchmark model, this paper tests the impact of the three dimensions of the digital economy index, namely the basic sub-index (INF), the industry sub-index (DIND), and the convergence sub-index (FUSE), on total factor productivity. The model setup is similar to model (4).

4.2.2. Mediator Effect Model

This paper introduces the mediating effect model to study whether the digital economy can increase total factor productivity by promoting technological progress, and when technological progress is used as a mediating variable, so as to promote the high-quality development of China's economy. The specific mediating effect model is set as follows:

$$TFP_{it} = C + \alpha DEI_{it} + Controls + \mu_{it} \tag{5}$$

Compared to the control variables in model (4), the control variables in this model do not include indicators of technological progress, and the other variables are defined in the same way as in model (4). The second step is to verify the impact of the digital economy on promoting technological progress. First, we test the impact of the digital economy on technological progress with technological progress as the dependent variable and the digital economy index as the independent variable, and build a panel model:

$$TFP_{it} = C + ZDEI_{it} + Controls + \mu_{it} \tag{6}$$

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The third step is to test whether the mediating effect of technological progress is complete, that is, whether the digital economy can directly affect total factor productivity. In this article, the following panel model is built:

$$TFP_{it} = C + \gamma DEI_{it} + \lambda TP_{it} + Controls + \mu_{it} \quad (7)$$

In the above model, technological progress is the mediating variable. The coefficient α in model (5) is the total effect of the digital economy in improving total factor productivity, and the coefficient η in model (6) is the influence of the digital economy on the mediating variables. After controlling for the development of the digital economy with the coefficient λ in Model (7), we determined the impact of the digital economy on the intermediate variables, and then studied the influence of these intermediate variables on Total Factor Productivity (TFP); θ represents the direct effect of the digital economy on improving TFP, and the mediating effect is ηλ, which has the following relationship with the total effect α and the direct effect θ.

$$\alpha = \theta + \eta\lambda \quad (8)$$

To determine the presence and extent of mediation effects, the process of mediation analysis is as follows: If the coefficient α is significant and both η and λ are significant, the mediating effect is significant; if the coefficient α is not significant or neither η nor λ is significant, there is no mediating effect. If the coefficient α is significant, both η and λ are significant, and the coefficient θ is less than α, then technological progress is part of the mediating variable, and in this case, the mediation effect is considered as ηλ / α. If the coefficient α is significant, η and λ are both significant, but θ is not significant, then there is a full mediating effect; that is, the effect of the digital economy on improving Total Factor Productivity (TFP) must be fully realized through the mediation effect.

5. Results & Discussion

5.1. Directly Impact the Test

This study utilizes panel data from 30 Chinese provinces and cities from 2017 to 2021. FGLS was employed to address heteroscedasticity and autocorrelation, with OLS and GEE methods for robustness checks. The digital economy significantly boosts TFP, with a coefficient of 0.4551, while technological progress has a lesser impact, with a coefficient of 0.1527. Other variables influencing TFP include openness, financial development, technology development, industrial structure, and fiscal subsidies, with the latter having a negative effect. The study suggests that fiscal subsidies need to be more targeted towards efficient R&D to optimize resource allocation. The GEE and OLS results confirm the significant role of the digital economy and technological progress in enhancing TFP. The impact of sub-indices-infrastructure, industry, and integration-on TFP is evident, with integration having the most significant effect, highlighting the rapid development of China's consumer internet and e-commerce and the need for high-quality development of the digital industry to drive future TFP growth.

Table 6. The regression results of the digital economy index and its infrastructure sub-index, industry sub-index, and integration sub-index.

variable	Dependent variable: total factor productivity (TFP)					
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	FGLS				GEE	OLS
DEI	0.4551***(10.88)				0.2933***(12.64)	0.4551***(10.58)
INF		0.2452***(10.13)				
DIND			0.0773**(1.23)			
FUSE				0.3458***(7.88)		
TP	0.1527***	0.2306***	0.3678***	0.2377***	0.3132***	0.1527***
	(3.55)	(5.60)	(6.68)	(5.17)	(8.20)	(3.45)
TD	0.0456***	0.0553***	0.0492**	0.01857**	0.0159*	0.0456**
	(3.11)	(3.65)	(2.51)	(1.10)	(1.04)	(3.02)
FD	0.0565***	0.0712***	0.0504**	0.0129*	0.0226**	0.0565***
	(3.34)	(4.05)	(2.24)	(0.66)	(2.03)	(3.25)
IS	0.0379**	-0.0359**	0.0454**	-0.0249**	0.0276*	0.0379**
	(-2.20)	(-2.02)	(2.18)	(-1.28)	(1.73)	(2.14)
OPEN	0.1195***	0.1909***	0.1976***	0.1619***	0.0668**	0.1195***
	(3.78)	(6.14)	(4.18)	(4.66)	(2.44)	(3.68)
RD	-0.0910***	-0.0986***	-0.1067***	-0.0791***	-0.0634***	-0.0910***
	(-3.69)	(-3.88)	(-3.26)	(-2.83)	(-2.68)	(-3.59)
constant	17.4683***	19.8441***	19.7913***	18.9658***	21.3497***	17.4683***
	(15.13)	(17.26)	(11.51)	(14.89)	(12.50)	(14.72)
Wald	1748.93	1638.11	922.44	1351.01	914.74	-
R^2	-	-	-	-	-	0.9171
N	150	150	150	150	150	150

5.2. Mediator Effect Test

The analysis confirms that the Digital Economy Index and its sub-indices play a significant role in enhancing Total Factor Productivity (TFP). Consistent with prior theoretical analyses, technological progress is a crucial foundation for maximizing the role of the digital economy in boosting TFP, and the continuous improvement of the digital economy also exerts a certain impact on technological advancement. Therefore, it is essential to identify the internal mechanisms through which digital economic development enhances TFP from the perspective of technological progress. A stepwise regression estimation method was employed to delve into these issues. When testing the comprehensive effect of the digital economy on TFP, technological progress was excluded as a mediating variable, indicating that technological progress has a certain mediating effect between the digital economy and TFP.

5.3. Analysis of Regional Heterogeneity

The existing academic studies and related reports point out that the development level of digital economy in the eastern region is significantly higher than that in the central and western regions, but there is no practical explanation for the impact of regional heterogeneity on high-quality economic development. Therefore, in order to study whether there is a significant difference in the impact of digital economy on high-quality economic development between the eastern region and the non-eastern region, this paper first adds the inter-provincial digital economy development index and the interaction term $DEI_{it} \times dum$ between the eastern region and the non-eastern region through equation (9), where dum=1 represents the eastern region and dum=0 represents the non-eastern region (according to the standard of the National Bureau of Statistics of China, the eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan 10 provinces and cities, the rest of the northeastern, central and western regions are divided into non-eastern regions), and the parameters are estimated.

$$TFP_{it} = b_0 + b_1 DEI_{it} + b_2 DEI_{it} \times dum + Controls + \mu_{it} \tag{9}$$

Table 7. Regression results of the digital economy index and its three sub-indexes and regional interaction items.

Variable	Dependent variable: total factor productivity (TFP)					
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	FGLS				GEE	OLS
DEI	0.4609***				0.2706***	0.4609***
	(10.29)				(11.98)	(9.95)
INF		0.2215***				
		(8.13)				
DIND			0.2251***			
			(3.37)			
FUSE				0.3744***		
				(8.51)		
DEI*DUM	0.0968***				0.0619***	0.0968***
	(1.27)				(1.90)	(1.22)
INF*DUM		0.0677***				
		(1.36)				
DIND*DUM			-0.4376***			
			(-4.75)			
FUSE*DUM				-0.2336***		
				(-3.64)		
TP	0.1815***	0.0631***	0.4583***	0.2748***	0.2647***	0.1815***
	(3.85)	(3.49)	(8.53)	(6.16)	(6.29)	(3.72)
TD	0.0305**	0.0688***	0.0135*	0.0034*	0.0118**	0.0305**
	(1.75)	(3.96)	(0.71)	(0.20)	(0.79)	(1.69)
FD	0.0557***	0.0600***	0.0389***	0.0457***	0.01407**	0.0562***
	(3.30)	(3.47)	(1.88)	(2.56)	(1.32)	(3.23)
IS	0.0377**	0.1578**	0.0246**	0.0416**	0.0177**	0.0368**
	(2.20)	(4.49)	(1.28)	(2.37)	(1.16)	(2.09)
OPEN	0.1060***	0.1230***	0.2692***	0.1924***	0.0093*	0.1305***
	(3.13)	(3.07)	(5.18)	(4.90)	(0.31)	(3.25)
RD	-0.0852***	-0.0941***	-0.0905***	-0.0600***	-0.0566**	-0.0823***
	(-3.39)	(-3.65)	(-2.96)	(-2.21)	(-2.50)	(-3.17)
constant	15.6321***	22.2824***	8.5929**	14.4529***	24.8301***	15.6321***
	(6.78)	(12.52)	(2.67)	(7.15)	(12.99)	(6.55)
Wald	1784.56	1683.83	1144.91	1521.54	1037.92	-
R^2	-	-	-	-	-	0.9175
N	150	150	150	150	150	150

In addition to examining the impact of the Digital Economy Composite Index, this paper further investigates the interactive effects between the three sub-dimensions of digital infrastructure, digital industry, and digital integration with regions. The empirical model settings are similar to those previously mentioned, and thus will not be repeated here. Columns (1), (5), and (6) of Table 7 estimate the interaction terms between the Digital Economy Index and regions, with the FGLS, GEE, and OLS methods yielding impact coefficients of 0.0968, 0.0619, and 0.0968, respectively, all of which are significant at the 1% level. These results are robust, indicating that the role of the digital economy in promoting Total Factor Productivity (TFP) is more pronounced in the eastern regions. Based on the three sub-indices of the Digital Economy Index, the regression results for the interaction terms of infrastructure sub-index, industry sub-index, and integration sub-index with regions are 0.0677, -0.4376, and -0.2336, respectively. This paper refers to these interaction terms as the "Digital Access Gap," "Digital Industry Gap," and

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"Digital Application Gap." The Digital Access Gap has the largest impact coefficient, followed by the Digital Application Gap, with the Digital Industry Gap being the smallest. On one hand, digital applications in China do not have strict regional boundaries. Since internet platform products or services are available nationwide, enterprises and individuals from all regions can access digital application products or services. On the other hand, digital transformation enterprises, represented by individual cases and certain regions, are mostly concentrated in non-eastern regions, leading to a significant "Digital Industry Gap" between the eastern and non-eastern regions. The analysis indicates that the impact of digital economy development on improving TFP in eastern regions is more significant than in non-eastern regions.

From another perspective, this suggests that central and western regions, which are at a medium level of digital economy development, place greater importance on improving technological progress in the process of achieving high-quality economic development through the development of the digital economy. In the future, addressing the issue of regional economic development imbalances exacerbated by the "Digital Economy Gap" is essential for achieving balanced economic development in China.

6. Conclusion

As China's economy enters the new normal, the digital economy has become a key way to promote high-quality economic development. Although the academic community has not yet comprehensively explored the impact of digital economy on high-quality economic development and its mechanism, this study empirically examines the impact of digital economy on high-quality economic development and reveals its transmission mechanism from the perspective of technological progress. The study finds that from 2017 to 2021, the level of China's digital economy has increased year by year, and the digital infrastructure sub-index has grown significantly, while the growth of the digital industry has been relatively slow, highlighting the necessity of developing the digital industry. It is necessary to strengthen the construction of digital infrastructure, promote the deep integration of new infrastructure such as 5G and big data, and support the digital transformation of traditional enterprises. At the same time, China needs to deepen the development of the industrial Internet, build a modern industrial system, break down industrial, regional and operational barriers, and promote cooperation between physical enterprises and Internet enterprises

The level of digital economy development in the eastern region is higher than that in the non-eastern region, and the marginal contribution rate of digital economy development to the improvement of total factor productivity is significantly higher in the eastern region than that in the non-eastern region, which is closely related to the first-mover advantage and comparative advantage of the eastern region. From the perspective of sub-dimensions, the digital infrastructure sub-index has the largest impact coefficient, followed by the industry sub-index, and finally the convergence sub-index, indicating that there is an obvious "digital access gap". In order to narrow the "digital economy gap" between regions, while expanding the scale of the digital economy, each region should develop the digital economy industry according to local conditions and highlight its comparative advantages.

The empirical results show that fiscal R&D subsidies have no significant positive impact on improving technological progress and the development of digital economy, and may even affect the market competition mechanism, resulting in low efficiency. Therefore, it is necessary to clarify the government's position in leading the development of the digital economy, formulate a negative control list for fiscal R&D investment, and accurately subsidize basic and non-market R&D. The composite index, digital infrastructure sub-index, digital industry sub-index and digital convergence sub-index of digital economy all have a significant positive impact on regional total factor productivity, which confirms the importance of developing digital economy to achieve high-quality economic development. Technological progress plays an important role in the influencing mechanism of the digital economy on high-quality economic development, and its mediating effect can explain about 1/3 of the total effect.

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