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The Impact of the Digital Economy on the Total Factor Productivity of Enterprises

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Abstract
The digital economy centered on digital technology brings high-end digital service elements, empowers the new development of total factor productivity, and becomes the new driving force to promote the high quality of the economy at present. In this context, this paper conducts an empirical research on the relationship between digital economy and enterprise total factor productivity based on the matching data of A-share listed enterprises in Shanghai and Shenzhen and the development of digital economy in cities from 2011 to 2021. The results of the study show that, firstly, the digital economy has a significant contributing effect on enhancing enterprise total factor productivity, and the results still hold after a series of robustness tests. Second, the heterogeneity analysis found that the digital economy has different degrees of influence on enterprise total factor productivity in different regions, especially in the eastern region, this effect is stronger. On this basis, the theoretical content of promoting the construction of digital economy is enriched, and policy recommendations for integrating the development of digital economy and total factor productivity are put forward.

Keywords: Digital economy, total factor productivity, regional heterogeneity

1. Introduction

In recent years, with the rapid development of the digital economy, the trend is accelerating global industrial development and the adjustment of industrial layout, and countries have rushed to develop the digital economy to improve their position in the world. Since 2020, the country has been vigorously promoting the construction of infrastructure with the digital economy as the main body, enhancing the depth and breadth of the integration of the digital economy and the real economy, and thus realizing the goal of the change in the power of economic development.2023, the scale of China's digital economy has reached 56.1 trillion yuan, an increase of about 11.75% year-on-year, and accounted for the proportion of the national economy to reach more than 40%, which has brought a strong macroeconomic development. Power. The digital economy is supported by digital technology, and the application of digital technology has brought a series of new modes of industry and new forms of business, broken the limitations of technical barriers, reshaped the production system and production process of the manufacturing industry, promoted the inclusive development of production and enterprises, and facilitated the aggregation of resources and the sharing of information among enterprises.

Total factor productivity is "the additional production efficiency achieved under the conditions of the established levels of various factor inputs", which is an important indicator for measuring the quality development of the economy, and in the context of China's economy having moved from the stage of high-speed growth to the stage of high-quality development, a high-efficiency mode of production is an important support for the construction of a modernized economic system (Gao Peiyong *et al*.,2019) [1], but for a long time, China has mainly relied on the expansion of factors of production to promote economic growth, and the technological transformation rate is at a low level as well as the level of utilization of economic production capacity is not high, which leads to a slower increase in enterprise productivity, and even falls into the development dilemma of not rising but falling (Du Chuan zhong and Yuan Zhang,2021) [2], so how to further promote the total factor productivity and consolidate the enterprise competitiveness has become a top priority to crack the dilemma of high-quality development.

In the above context, exploring the impact of the development of digital economy on enterprise total factor productivity, will it be able to promote enterprise total factor productivity? And will whether it generates heterogeneity depending on enterprise regions? Sorting out the relationship between the two is of strategic significance for enriching the research related to the digital economy and leading the high-quality development of the economy.

2. Literature review

2.1 Research on the digital economy and its metrics

Combing through the research of domestic and foreign scholars, it is found that Bukht and Heeks (2017) [3] took the lead in proposing a three-scale conceptual framework for the digital economy, including the core digital economy, the digital economy, and the digitized economy, and this definition has been most used as a recognized concept of the digital economy. At present, the measurement of the digital economy is mainly divided into two ways, the first is to measure by constructing indicators, domestic scholars from digital infrastructure, industrial digitization and digital industrialization and other different dimensions to build China's provincial digital economy comprehensive development index (Chen Jingjing and Tian Gui xian,2024;Wang Jiating *et al*.,2024) [4, 5], the entropy method or principal component analysis method for measurement, a more comprehensive analysis of regional digital economy. and comprehensive to analyze the development of regional digital economy; the other is measurement through statistics, which refers to the use of ICT industry definitions and the International Standard Industrial Classification (ISIC) to determine the scope of the core digital economy, and then calculate its added value.Barefoot *et al*.(2018) [6]obtained the U.S. digital economy from the economic sectors that produce digital products and services size, yielding that the value added from the digital economy grew at a rate of 5.6% from 2006-2016, which is higher than the average figure in the U.S. economy. In addition research on the digital economy focuses on the macro and meso levels, Wang Zhe *et al*.(2024) [7] based on panel data of 41 cities in the Yangtze River Delta (YRD) region from 2006-2021 concluded that the digital economy in YRD promotes the level of high-quality development, and the degree of spatial correlation of the digital economy has deepened year by year; Bai Bing *et al*.(2024) [8]found that the digital economy can significantly promote the development of new quality productivity, and at the same time, there is a nonlinear threshold effect of "marginal increment" in the impact of the digital economy on new quality productivity. Zhang Li *et al*.(2024) [9]concluded that the positive impact of the digital economy on the resilience of the manufacturing industry chain is a nonlinear characteristic of the "marginal effect" of increasing, in which the digital industrialization of the digital technology to promote the deepening of the value chain of the data, the digitization of the industry to strengthen the basic capacity of the traditional industry, and jointly drive the modernization and upgrading of the manufacturing industry chain. Modernization and upgrading. Some scholars have also explored the impact of the digital economy on the technological innovation of microenterprises and the efficiency of enterprise management (Dong Xiangshu *et al*.,2022; Zhou Bingjun and He Jinjun,2024) [10, 11], which extends the research perspective to the micro field and refines the impact of the digital economy.

2.2 Research on total factor productivity of enterprises

The research results for the total factor productivity of enterprises have been relatively abundant, in terms of measurement, Lu *et al*.(2012) [12]utilized the data of Chinese industrial enterprises from 1999 to 2007, and applied parametric and semiparametric methods such as the least squares method, the fixed-effects method, the OP method, and the LP method to account for the TFP of China's major industrial enterprises, which was a level total factor productivity estimation is revised. Existing literature mainly centers on the external environment and the internal environment of enterprises to study total factor productivity, as far as the external environment is concerned, public data openness can significantly promote the growth of enterprise total factor productivity, in which public data openness is conducive to improving the regional business environment, enhancing the efficiency of resource allocation as well as lowering the cost of sales and management of enterprises to have an impact on the total factor productivity of enterprises (Yang Xiuyun and Han Qi,2023) [13], The improvement of external business environment will also enhance enterprise total factor productivity by improving enterprise capital allocation efficiency, incentivizing enterprise technological progress, reducing institutional transaction costs and increasing economic openness(Liu Xinzhi *et al*.,2023) [14].However, Yu Changlin *et al*.(2023) [15]based on the panel data of China's manufacturing industries from 1999-2018 concluded that the terms of trade significantly inhibit the improvement of total factor productivity in the manufacturing industry, and that the improvement of the terms of trade before the financial crisis has a significant inhibitory effect on the growth of comprehensive technical efficiency, and that the improvement of the terms of trade after the financial crisis has a significant The improvement of terms of trade after the financial crisis has a significant role in promoting the growth of comprehensive technical efficiency. As far as the internal environment of enterprises is concerned, CSR fulfillment can promote total factor productivity, but environmental uncertainty weakens the positive impact of CSR fulfillment on total factor productivity (Ma Jianwei *et al*.,2024) [16]. Luo Jia *et al*.(2023) [17]based on the data of listed companies in the manufacturing industry from 2008-2019 argued that digital technology innovation significantly promotes the improvement of enterprise total factor productivity, and with the growth of the scale of digital technology innovation, the stronger the enhancement effect, and the level of digitization of the industry plays a positive moderating role.R&D investment also significantly promotes the total factor productivity of the manufacturing industry, but the effect has a lagging effect will be weakened with the passage of time(Zhang Guangsheng and Meng Maoyuan,2020) [18].

2.3 Research on total factor productivity of enterprises in the digital economy

Research on the economic effects of the digital economy on the total factor productivity of enterprises can be divided into three main areas. The first is the technological progress effect. In the era of digital economy, the most significant phenomenon is the rapid influx of digital resources, digital intermediate elements due to the qualities of the digital itself can be more rapid, not subject to time and space constraints, thus shortening the front and back-end connection time, especially for the front-end in the data collection, analysis and response to consumers. Enterprises can build a network

collaborative innovation platform with the help of digital technology to enhance the efficiency of matching market supply and demand, reduce the mismatch between resources, lower the marginal cost and risk of technological innovation, mobilize innovation enthusiasm, and then enhance enterprise productivity. On the other hand, digitalization breaks the market-oriented segmentation, making enterprises form a structure with high fixed costs and low marginal costs, further expanding the sales scale generating a scale effect, and making products and technologies develop towards standardization and high level (Wan Xiaoyu *et al*.,2022) [19]. The second is the industrial structure upgrading effect. Distinguished from the traditional industrial ecological model, the digital economy builds an open and collaborative industrial ecology, emphasizes inter-industrial collaboration and resource sharing, and promotes the optimization and upgrading of the industrial structure with. On the one hand, the digital economy promotes the cross-border integration and innovative development of data and traditional factors of production, forming a more efficient and intelligent mode of production, making the industrial boundaries more blurred, extending the scope of labor objects, promoting the optimization and integration of the industrial chain, and accelerating the pace of the transformation of the traditional industries; on the other hand, with the continuous application and development of digital technology, new industries based on digital technology and traditional industries are integrated and developed, giving rise to new industries. integration and development, giving rise to new business forms and new models, the industrial pattern will be more diversified and complex (Yang Huimei and Jiang Lu,2021) [20]. The third is the resource allocation effect. Relying on digital technology, the digital economy realizes the unified transformation of diverse and complex information into digital signals, and uses digital platforms to realize the rapid, extensive and low-cost transmission and sharing of this information. Enterprises can more accurately grasp market demand and consumer behavior, so as to optimize product design, production and sales strategies, greatly alleviating the problem of information asymmetry, improving the efficiency of resource utilization, and promoting the process of resource allocation to be more reasonable and efficient (Li Zongxian *et al*.,2021) [21]; on the other hand, the development of the digital economy has intensified the market competition, and broken the mismatch of resources due to the existence of market distortion in reality. The digital economy development intensifies market competition, breaking the situation of resource mismatch caused by the existence of market distortion in reality, forcing enterprises with low factors of production to withdraw from the market, and then the factors of production flow to enterprises with high productivity, and promoting the improvement of enterprise productivity.

3.Research design

3.1 Modeling

To test the impact of the digital economy on total factor productivity, this paper draws on Zheng Yu (2022) to construct the following benchmark model:

$$TFP_{pet} = \alpha_0 + \alpha_1 Dig_{pt} + \alpha_2 controls + \eta_j + \varphi_t + \delta_e + \varepsilon_{pet} \quad (1)$$

where subscripts p, e and t denote province, enterprise, and year, respectively, TFP denotes total factor productivity of the enterprise, Dig denotes the level of digital economy development of the province where the enterprise is located, Controls denotes the control variables, η_j、φ_t、$\delta_e$denotes industry, time, and province fixed effects, respectively, and ε_{pet} denotes a randomized perturbation term.

3.2 Description of variables

3.2.1 Firms' Total Factor Productivity (TFP)

Levinsohn and Petrin (2003) pointed out that there are adjustment costs for firms, so many firms have zero investment, and using the OP method to measure firms' TFP requires that firms' real investment must be greater than 0, and this restriction will lead to the loss of many firms' samples in the estimation process. The LP method solves the problem of sample loss by substituting the variables on the basis of the OP method. Based on this, this paper will use LP, a semiparametric method, to portray TFP, with labor L, capital K, and intermediate inputs M measured by the number of employees in listed firms, the net value of fixed assets, and cash paid for purchasing goods and accepting services, respectively, and the output variable Y, which is measured by the main business revenue of listed firms. In addition, the OLS method is used in this paper for robustness testing.

3.2.2 level of development of the digital economy (Dig)

This paper refers to the construction system of digital economy by Zhao Tao *et al*. (2020) [22], and takes interconnected development as the core and combines with the availability of regional data, and mainly measures from the three dimensions of digital infrastructure, digital industrialization, and digital financial inclusion, which are calculated as shown in Table 1, and measures the digital economy of each region by entropy method. The entropy method is used to measure the digital economy of each region, and the linear interpolation method is used to fill in the missing data.

Table 1: Digital economy development measurement system

Primary indicators	Secondary indicators	Tertiary indicators
Level of development of the digital economy	Digital infrastructure	Number of Internet broadband access ports (10,000/km^2) Length of fiber-optic cable per unit area (km/km^2) Number of domain names (10,000) Cell phone penetration rate (units/100 population)
	Digital industrialization	Revenue from software operations (billions of dollars) E-commerce sales (billions of dollars) Share of enterprises with e-commerce trading activities (%) Number of websites per 100 enterprises (number)
	Digital Inclusive Finance	China Digital Inclusive Finance Index

3.2.3 Control variables

Drawing on Wang Dong mei and Sun Yangyang (2023) [23], this paper introduces firm- and city-level control variables into the model. At the firm level: gearing ratio (Lev), measured by the ratio of total liabilities to total assets, moderate liabilities may also reflect the firm's strong financing ability; return on assets (ROA), measured by the ratio of net profit to the balance of total assets, reflecting the firm's profitability; firm's growth capacity (Gro), measured by the growth rate of total assets, reflecting the firm's expansion of the total assets scale speed, age of the enterprise (Age), the difference between the current year and the year of the company's establishment plus 1 logarithmic value, reflecting the development stage of the enterprise and market experience. At the city level: the degree of government intervention (Gov), measured by the ratio of fiscal expenditure to GDP; the level of financial development (Fin), measured by the ratio of the loan balance of financial institutions to GDP; and the level of industrial structure (Stru), measured by the ratio of tertiary industry output to secondary industry output.

3.3 Data sources

This paper selects A-share listed companies in Shanghai and Shenzhen from 2011 to 2021 as the research sample, and refers to the practice of related literature to make the following treatments to the company-level data: (1) excluding non-financial listed companies; (2) excluding companies with operating anomalies, i.e., those marked with ST or *ST status, during the sample period; and (3) shrinking the tails of the continuous variables at the 1% and 99% levels to eliminate the extreme of the outliers' impact. Subsequently, we matched the data on the development level of regional digital economy with the cities to which the enterprises belonged, and obtained a total of 14,207 research samples. The data related to listed companies are mainly from the CSMAR database, and the data related to the level of digital economy development are mainly from the official website of the National Bureau of Statistics, the China Urban Statistical Yearbook and the Digital Inclusive Finance Index of Peking University.

4.Empirical results and analysis

4.1 Benchmark regression

Table 2 presents the results of the benchmark regression on the impact of the digital economy on firms' total factor productivity. Among them, column (1) verifies the relationship between the digital economy and enterprise total factor productivity without adding control variables, and the regression results show that the estimated coefficient of the core explanatory variable Digital Economy (Dig) is significantly positive at the 1% level, which indicates that the digital economy has a facilitating effect on the improvement of enterprise total factor productivity. The control variables at the enterprise level and city level are added sequentially in (2) and (3), respectively, to conclude that the digital economy still has a significant promoting effect on enterprise total factor productivity. At the same time, the digital economy with the help of perfect digital infrastructure to create a multi-mode digital platform, on the one hand, enterprises can faster and more accurate access to market-related information and customer demand and feedback, to create differentiated and personalized services, and timely adjustment of the path and direction of enterprise development, so as to improve the competitiveness of the market; on the other hand, for the enterprise, the digital economy promotes the close integration of new elements and traditional elements On the other hand, for enterprises, the digital economy promotes the close integration of new factors and traditional factors, realizes efficient resource allocation, improves internal operation efficiency, optimizes the synergy and optimization between upstream and downstream supply chains, reduces operation costs, and promotes the enhancement of the total factor productivity of enterprises.

Table 2: Benchmark regression results

	(1)	(2)	(3)
	TFP_LP	TFP_LP	TFP_LP
Dig	0.298***	0.180*	0.213**
	(2.93)	(1.88)	(2.21)
Lev		1.110***	1.113***
		(22.55)	(22.63)
ROA		2.368***	2.358***
		(18.80)	(18.74)
Gro		0.0586***	0.0585***
		(3.62)	(3.61)
Age		0.312***	0.307***
		(5.80)	(5.73)
Gov			0.0491
			(0.18)
Stru			-0.0694***
			(-2.83)
Fin			-0.0796*
			(-1.90)
_cons	8.588***	7.111***	7.327***
	(360.15)	(46.41)	(44.67)
Industry Fixed	Yes	Yes	Yes
Time Fixed	Yes	Yes	Yes
Province Fixed	Yes	Yes	Yes
N	14207	14207	14207
R^2	0.899	0.912	0.913

Note: t statistics in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

4.2 Heterogeneity analysis

The development of digital economy is of great practical significance for the improvement of total factor productivity of enterprises. Considering the vast territory of China and the large regional development differences between different regions, this paper divide the enterprises into two categories of eastern and central and western enterprises according to their geographical locations, and conducts a regional heterogeneity test to explore in depth the differential impact of total factor productivity that may be caused by geographic factors, and the regression results are shown in Table 3.As shown in Table 3, the eastern region's level of digital economy development has a stronger effect on promoting the total factor productivity of enterprises, while the impact coefficient in the central and western regions is insignificant, reflecting the obvious difference between the impact of the eastern and central and western regions. On the one hand, this may be due to the fact that the eastern region vigorously develops the digital economy based on the advantages of perfect digital infrastructure and digital business environment, and thus enterprises in the eastern region can obtain, utilize and transform the dividends brought about by the digital economy more quickly. At the same time, the industrial structure of the eastern region is relatively optimized, and the high-tech industries and innovative industries with strong innovation ability and willingness to digital transformation can be more proactive to take advantage of a series of data, information and other elements brought by the digital economy to reduce the information cost and transaction cost of enterprises, improve the level of human capital and spread professional knowledge through the spillover effect on enterprises to bring about a positive externality effect to stimulate the driving effect on the total factor productivity of enterprises. The driving effect on the total factor productivity of enterprises is stimulated.

Table 3: Analysis of regional heterogeneity

	(1)	**(2)**
	Eastern part	Central and Western region
Dig	0.207*	0.0337
	(1.70)	(0.06)
_cons	7.098***	7.506***
	(36.43)	(20.28)
N	9621	4501
R^2	0.918	0.915
Control variable	Yes	Yes
Fixed effect	Yes	Yes

4.3 Robustness Tests

In order to enhance the solidity and credibility of the empirical model and its test results, this paper further conducts the following tests:(1) Replacement of explanatory variables. This paper utilizes the OLS method to recalculate the total factor productivity of enterprises (TFP_OLS), and the regression results after re-measurement are presented in column (1) of Table 4. (2) Excluding municipalities directly under the central government. The level of economic development and market size of municipalities directly under the central government is usually higher than that of ordinary prefecture-level cities, and this difference gives enterprises in municipalities many advantages and opportunities in terms of innovation and absorptive capacity. Excluding municipalities can improve improve the comparability between the samples. The regression results are shown in column (2) of Table 4. (3) Change the estimation sample. This paper draws on the practice of Wang Dongmei *et al*.(2023) [24], because the information technology-related industry itself has a high level of digitization and intelligence, referring to the "Guidelines for Industry Classification of Listed Companies" (2012 edition of the Securities and Exchange Commission), the "information transmission, software and information technology services" is excluded, and reconstruction of the construction sample and regression, to avoid the impact of this type of industry on the estimation of the sample and to avoid the impact of this type of industry on the estimation of the sample. The sample is reconstructed and regressed to avoid the influence of this type of industry on the estimation results. The regression results are shown in column (3) of Table 4. After the above three tests, the results are still consistent with the benchmark regression results, and the development of digital economy can significantly promote the total factor productivity of enterprises.

Benchmark regression although it has been concluded that the development of digital economy has a facilitating effect on the total factor productivity enhancement of enterprises, but in order to alleviate the endogeneity problem arising from certain omitted variables and autocorrelation problems, etc., this paper selects the lagged one period of the explanatory variables as the instrumental variables for the two-stage least squares estimation to solve the endogeneity problem existing in the model. The results of the test show that the P-value of under-identification (Anderson canon. corr. LM statistic) in column (4) of Table 4 is 0. The F-statistic of the weak instrumental variable test (Cragg-Donald Wald F statistic) also shows the rejection of the original hypothesis, both of which indicate that the selection of this instrumental variable is justified, while the IV two-stage results show that the estimated coefficient on trade openness in digital services is significantly positive at 1%. After exploring endogeneity in the model, the core conclusions drawn in this paper remain robust and reliable.

Table 4: Robustness test results

	(1) Substitution of explanatory variables	(2) Excluding municipalities	(3) Changing the estimation sample	(4) IV-2SLS
Dig	0.293***	0.447***	0.173*	
	(2.82)	(4.14)	(1.75)	
L.Dig				1.0606***
				(732.34)
_cons	9.544***	7.102***	7.276***	0.0348***
	(54.82)	(38.57)	(44.24)	(26.57)
N	14207	11425	13486	12960
R^2	0.932	0.913	0.917	0.976
Control variable	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes
Anderson canon. corr. LM statistic				1.3e+0.4
Cragg-Donald Wald statistic				5.3e+0.5

5.Conclusions and policy recommendations

Taking the A-share listed enterprises in Shanghai and Shenzhen from 2011 to 2021 as samples, this paper uses the entropy value method to measure the level of digital economy development at the city level and match it with the total factor productivity at the enterprise level to further examine the effect of digital economy on the total factor productivity of enterprises. The results of the study are as follows: First, from the overall level, the digital economy development can significantly promote the enterprise total factor productivity, and under the influence of control variables, for every 1 unit of digital economy development, the enterprise total factor productivity will increase by 0.213 units. Secondly, from the analysis of regional heterogeneity of enterprises, due to the different levels of regional economic development between the east and the central and western regions, the digging of the digital economy, the different degree of development will also have a different impact on the total factor productivity of enterprises. Compared with the central and western regions, the promotion effect of digital economy on enterprises in the eastern region is more prominent. Thirdly, in terms of robustness results, by replacing the explained variables, eliminating municipalities, and changing the estimated samples for verification and endogeneity test, the direction of the estimated coefficients is consistent with the previous estimation results, indicating that the conclusions in this paper are relatively robust.Based on these conclusions, this paper offers corresponding policy implications:

First, the Government should keep pace with the rapid development of the digital economy, take the initiative to seize the opportunities brought about by the digital economy, actively bring into play the positive effects of the digital economy on the total factor productivity of enterprises, and create a favourable environment for the development of the digital economy. In promoting the transformation of enterprises to digitalization, the government needs to prevent industrial monopoly through legislative means, avoid excessive concentration of data resources in large enterprises, and at the same time solve the problem of insufficient and unreasonable utilization of digital technology. The Government should ensure that the digital economy plays a positive role in resource allocation, information optimization and knowledge dissemination, thereby enhancing the total factor productivity of enterprises.

Second, strengthening the construction of digital infrastructure, improving the digital business environment, and laying a solid network foundation for the development of the digital economy. Not only to promote the development of a new round of digital technology such as cloud computing, but also to achieve extensive data sharing for the deep integration of the digital economy and the real economy, promote the sharing of generic technologies among enterprises, promote information exchange and R&D cooperation, and add value to knowledge in sharing and optimize resources in collaboration. In this way, it can not only enhance the total factor productivity of enterprises, but also drive the innovative development of the whole industry through the knowledge spillover effect.

Last but not least, precise and differentiated development measures should be implemented for enterprises in different regions, focusing on the balanced development of the digital economy between regions. While vigorously developing the digital economy in the eastern region, the central and western regions should formulate new ways and modes of digital economy construction according to local conditions, and the government should also increase financial and policy support, strengthen network coverage, enhance digital processing capacity, and capture the local capacity to utilize and transform new elements such as digital and information. Enterprises oriented to central and western China should also enhance their awareness of digital transformation, accelerate the application of digital technology, enhance their innovation capabilities, and thus improve their total factor productivity.

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