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THE DIGITAL ECONOMY IS A CATALYST FOR TOTAL FACTOR PRODUCTIVITY GROWTH

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Abstract: Based on data including the provincial TFP calculated using the dual approach and the digital economy index proposed by the principal component analysis in this paper, this study used pooled regression to examine the innovation-driven effects of digital economy on total factor productivity (TFP) in China. The findings suggest that the digital economy index has a positively nonlinear connection with province TFP, demonstrating that the digital economy serves as an innovation catalyst for TFP's broad and long-term development. Nonetheless, there is regional variation in that digital integration promotes high-quality TFP growth in eastern China, but it is substantially inferior in the middle and western areas. The findings serve as helpful reference materials for the departments concerned in their efforts to overcome regional technical information barriers, establish a cooperation program, and build a decentralized infrastructure.

Keywords: Total factor productivity, innovation-driven effects, digital economy, information technology, economic structure improvement.

Introduction

Digital economy, a brand-new economic form recently, originates from networked intelligence, which can be related back to the 1990s (Tapscott, 2014). It is not clearly defined until the G20 leaders' Hangzhou Summit in September 2016 that the digital economy, with information technology as the core and modern network as the carrier, comes from a series of economic activities intending at efficient application in communication technology and economic structure improvement. Currently, global economic governance is entering a new era through digital transformation (Paradise, 2019). Resultant business model innovations have fundamentally altered consumers' expectations and behaviours, pressured traditional firms, and disrupted numerous markets (Peter et al., 2021). As an emergent branch of economies, digital economy requires the building of a scientific knowledge base and represents the pattern transformation of economic growth in China and exerts a significant influence on industrial structure upgrading. Nowadays, China has entered a new phase characterised by medium-to-high growth and oriented towards comprehensive and sustainable development. Digitalisation is in line with the current trend in China's economy, especially high-quality development. As an important concept in economics, total factor productivity (TFP) measures the impact of technological progress on production. It refers to the efficiency of production activities over a certain period of time and is mainly used to indicate the partial contribution of output that cannot be explained by the growth of capital and labour factors. TFP decomposition can be separated into scale economies, technical change, and technical efficiency change, and it is the primary contributor to enhanced Chinese provincial productivity performance. As the digital economy significantly facilitates social productivity through high-tech innovation and application, including mobile networks, artificial intelligence (AI), blockchain, and cloud computing, it is considered an innovation driver for TFP. In this context, we posit that such a correlation discussion is required, finding an effective index that represents the digital economy, calculating the current provincial TFP, and investigating the correlation between digital economy and TFP have considerable theoretical and

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practical significance. The relevant literature mainly includes the following aspects. The qualitative research literature argues that digital economy is multidisciplinary. The driving source of digitalisation essentially is the effective application of information and communications technology (ICT), and digital economy is a new economic form that has emerged with the rapid development of the ICT industry. Technological change and governance adjustments since the Industrial Revolution have closely linked technological production models to organisational governance structures and together constitute the driving force of economic and social development, which is precisely the mechanism inherent in the evolution of the digital economy. In the applied research literature, open market paradigm is proposed with the approach of digital reform, which is the most popular e-business model that can suggest strategic directions for participants. The main trend in integrated production is the creation of digital copies of industrial processes, data platforms, and productive ecosystems to facilitate economic transactions.

The strategic management literature has mostly focused on the impact of the digital economy and the various responses to it. To some extent, the digital economy has not only considerably reduced business frictions, but also created new challenges for market operations. The dramatic reduction in the cost of searching, transmitting, and copying information has pressured traditional firms, and they have been surpassed by innovative fast-growing digital entrants. Institutional regulation, information security, and industrial restructuring are receiving attention from researchers. In addition, the quantitative research literature is concerned about the appropriateness of traditional research approaches and methodologies that attempt to measure the development of the digital economy from different aspects.

According to existing literature around the world, the following shortcomings are found. First, to the best of our knowledge, there has been no scientific index system in the quantitative research literature, and it is important to measure the current state of digital economy development through an appropriate index. Second, the academic literature has so far paid surprisingly little attention to the linkage between TFP and the digital economy,

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which may be an important innovation driver for TFP. Third, many scholars account for TFP under Solow's framework, and the perpetual inventory method is widely used to simulate capital stock, while inherent defects are inevitable. In addition, linear regressions have been widely used in previous studies, whereas we believe that the impact of the digital economy on total factor productivity is quite complicated and there may be non-linear linkages. The contributions of this paper include the following aspects. First, researchers have mainly studied the digital economy from a specific perspective, but the digital economy is a complex covering various hightech industries, and it is very incomplete to measure the development of the digital economy only from the changes in the network or Information and Communication Technology (ICT) industries. We believe this multidisciplinary discussion is needed and study the digital economy from three aspects: infrastructure, industry scale, and spillover value, to comprehensively reflect the development of China's digital economy. Second, the subjective weighting method usually introduces uncertainty in the construction of the indicator system. We use the principal component analysis, which is an objective weighting method to scientifically reflect the contribution of different dimensions of evaluation elements and construct the digital economy index. Third, TFP calculation using the Solow residual method is susceptible to the influence of capital stock estimates (Thijs & Victoria, 2011). Therefore, we use the dual approach that does not require measuring the capital stock, as well as setting up a production function with a constant elasticity of substitution to accurately account for TFP. In addition, linear regressions are mostly employed in panel data analysis, but we argue that there is a nonlinear relationship between China's digital economy index and provincial TFP. Therefore, this paper constructs a nonlinear panel model with square terms and interactive terms, which is more in line with the current situation. In our discussion, we employ a nonlinear model to describe the relationship between the digital economy index and TFP to demonstrate that the digital economy is an innovation driver of TFP growth. We start with the calculation of provincial TFP based on the dual approach and the construction of the digital economy index by principal component method from 2010 to 2018 in China, which provides the panel data for our further analysis. Next, we use pooled

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regressions to deal with nonlinear relationships, examine the regression results for the country as well as the three major economic regions separately, and discuss the influence of digital transformation. We propose that the digital economy is an innovation driver and discuss the economic transformation that results from digitalisation in terms of growth strategies, organisational structure, and regional balance. To conclude our discussion, we make some suggestions for digital transformation.

TFP refers to the contribution of technological progress to economic growth except for factors input. It is the part which cannot be explained by the input growth of factors (capital and labour). In the past century, scholars have generally used the Solow residual method to calculate economic growth, which usually requires accurate data of production factors and output elasticity coefficients. Two assumptions are essential. First, investment keeps constant returns to scale. Second, a perfectly competitive market is satisfactory. However, it is quite difficult to meet such conditions. This paper measures TFP by using the dual approach: from the perspective of income, output is equal to the sum of factor income.

$$Y = \gamma K + \omega L$$

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where Y is the total output, K is the capital, γ is the capital price (capital use rent), L is the labour, and ω is the labour price (labourer's salary). Taking logarithms and functions is derived as:

$$g_Y - S_K g_K - S_L g_L = TFP = S_K g_\gamma + S_L g_\omega \quad (2)$$

where $g_Y = dY/Ydt$, $g_\gamma = d\gamma/\gamma dt$, $g_K = dK/Kdt$, $g_\omega = d\omega/\omega dt$, $g_L = dL/Ldt$, $S_K = \gamma K/Y$, $S_L = \omega L/Y$, and $S_K + S_L = 1$. The left side of equation (2) is calculated by Solow residual method, which mainly calculates the part of output growth that cannot be explained by the increase of production factors. The right side of equation (2) is the formula for the dual approach. It allows to calculate a weighted average of the growth rates of production factors based on their price ratios. The calculation results are the same for both methods, but the dual approach does not require capital stock data, and the assumption that the elasticity of substitution between production factors remains constant:

$$TFP = S_K g_\gamma + S_L g_\omega \quad (3)$$

The economic significance of equation (3) is very clear. The dual approach mainly measures TFP through three specific indicators: real rental prices, real wage levels, and the share of capital and labour. This paper accounts for real wage levels based on labour compensation provided by the National Bureau of Statistics from 2010 to 2018 and calculates the labour share S_L by the share of labour compensation in GDP. The capital share S_K is also determined at this time. The price of rent is the price of capital, and we calculate the real rent price of capital in China based on the standard rent formula proposed by Griliches and Jorgenson (1962):

$$\gamma = \frac{p_\gamma}{p_Y}(i - \pi_\gamma - \delta) \quad (4)$$

In equation (4), pγ denotes the investment deflator, pY is the price index, i is the nominal interest rate, πγ is the inflation rate, and δ is the depreciation rate. It indicates that the real rent is equal to the relative price of capital multiplied by the real interest rate. In this paper, we mainly use total fixed capital formation to calculate its relative price and estimate the effective interest rate through the provincial depreciation rate, then we finally obtain the real rental price of capital.

The purpose of this research is to study the impact of the digital economy on TFP. Therefore, it is necessary to measure the development level of digital economies scientifically to maintain the reliability and accuracy of data and indicators. Referring to the digital economic index system issued by the Organization for Economic Cooperation and Development, China Information and Communication Research Institute, and National

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Bureau of Statistics, and considering the continuity and long-term observation of available statistical data, we determine three primary indicators: infrastructure, industrial scale, and spillover value to define the main characteristics of digital economy. Therefore, the digital economic index constructed in this paper consists of three parts: infrastructure, industrial scale, and spillover value. After a great deal of literary research and practical investigation, we choose the following secondary indicators representatively connected with the three basic indicators. Among primary indices, infrastructure includes five secondary indices: internet port access, internet penetration rate, mobile phone penetration rate (Brandt & Thun, 2011), CN number of domain names, and IPv4 quantity; industrial scale includes number of R&D institutions in high-tech industries, and internal expenditure of R&D funds in high-tech industries and number of R&D personnel in high-tech industries. Spillover value includes added value of tertiary industry. The digital economic index system is established as shown in Table 1. Most scholars often used the simple average method to synthesise indicators in previous studies. This paper considers that it is difficult to reflect the true level of the digital economic development index by giving each index an average weight subjectively. Therefore, this study adopts objective weighted principal component analysis to transform multiple indicators with correlation into a few comprehensive indicators by dimension reduction. The quantitative results of the digital economy index can be obtained by extracting principal components, and the formed weight structure can fully reflect the contribution rate of the basic indicators to the digital economy index in each dimension.

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Suppose there are n observation objects, and each observation object is described byp indicators $x_1, x_2, \cdots, x_p$, then the original data is:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{pmatrix} = (x_1, x_2, \cdots, x_p), x_j = \begin{pmatrix} x_{1j} \\ x_{2j} \\ \vdots \\ x_{nj} \end{pmatrix}, (j = 1, 2, \cdots, p) \quad (5)$$

The steps of calculating comprehensive index by principal component method are as follows.

First, standardise the original data according to the following formula.

$$Z_i = \left(x_i - \overline{x}_i\right) / s_i \quad (6)$$

$\overline{x}_i$ and s_i are the average value and standard deviations of every indicator. After standardisation, the mean value of each index is 0, and the

Analysis and results of empirical research

This study calculates the provincial TFP in China using the dual approach, and Fig. 1 shows China's TFP in different years and regions. According to Fig. 1, TFP in China's eastern, central, and western regions shows an overall upward trend from 2010 to 2018, which reflects China's technological innovation and high-tech industrial development, indicating that China's high-tech development strategy is effective. However, TFP in the eastern region is significantly higher than that of other regions. Eastern TFP growth is stable, while the development of central and western TFP is relatively slow, which even declines in some years. According to the statistical survey, the proportion of production factors in different provinces is similar, fluctuating around 45–50%, but the growth rates of per-capita wage and real rent are discrepant. We suppose that high-tech progress leads to significant growth in regional TFP, that is, it determines economic development. The following are the specific results for each region. First, TFP growth rates in eastern region, including Beijing, Shanghai, Guangzhou, Zhejiang, Jiangsu, and other provinces with strong economic strength, have generally risen from 2010 to 2018. It is speculated that funds used at low cost before 2012 might lead to a substantial increase in inefficiency. After that, all the localities attach great importance to digital economy development. China's high-tech industries are widely distributed in coastal areas, hence eastern

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provinces have significant advantages in infrastructure, investment, high-tech talent, and many aspects. It has been successfully transformed from traditional growth of capital and labour input to digital economic development with high-tech industry, and scientific research and technological application are the essential factors of rapid economic growth in eastern region. Through comprehensive integration of networks, artificial intelligence, high-tech industries, and substantial economy, TFP in eastern China has achieved rapid economic growth, far exceeding other regions in 2016 to 2018. Second, TFP growth rate in central China, including Hunan, Hubei, Henan, Anhui, Jiangxi, and provinces with traditional agriculture, shows a tortuous trend, but it is increasing slowly from 2010 to 2018. Around 2010, China's TFP in central region is relatively low; it is supposed that central provinces mainly depended on productive inputs of capital and labour during the past periods rather than high-tech industries. However, central provinces experienced a period of economic transition since 2012, and TFP in central China has increased significantly. It shows that central provinces begin to accelerate investment in digital infrastructure projects and focus on the development of high-tech industries. Third, compared with eastern and central regions, TFP in Yunnan, Gansu, Qinghai, Ningxia, Xinjiang, and western provinces has been lagging behind, even though a certain trend is upward in 2010 to 2018. According to TFP accounting results, we suppose that China's western development is highly affected by natural environment and strategic deployment, which are greatly inferior to eastern and central conditions. Traditional patterns in economic development have gradually changed with rapid progress of high-tech industry; however, digital infrastructures and high-tech talent in western provinces are still scarce, which means that western development confronts serious problems.

Research conclusions This paper calculates TFP of 30 provinces in 2010 to 2018 based on the dual approach and scientifically constructs the digital economy index through principal component analysis. Finally, we employ the pooled regression to empirically study the impact of digital economy on TFP. The results show that the development of digital industry is the most important innovation driver of TFP growth. It can improve the efficiency of digital reform and accelerate the structural

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transformation of the economy. According to the results of the nonlinear square regression, the relationship between the digital economy index and TFP is consistent with the parabolic function characteristics, and TFP increases significantly with the growth of the digital economy after reaching the inflection point. However, the regional regression results show that the development of digital economy still faces unbalanced and insufficient problems. The digital industry in eastern China has advanced infrastructure, as well as abundant material resources and talent reserves. Guangdong, Shanghai, Zhejiang, and other provinces have always maintained a national lead in the field of digitalisation and have a large number of strong digital enterprises, which can effectively contribute to TFP development in the eastern region. In contrast, the digital economy in the central and western regions still lags behind, and not fully transformed from a traditional crude development to a digital model. It cannot function effectively as an innovation driver. The innovation inputs and outputs of ICT are also not closely linked to the development of the digital economy, indicating that China's digital economy is still unbalanced. 5. Research countermeasures The development of China's digital economy faces unbalanced and insufficient problems, and there are great differences in the regional development of digital economy, which indicate that the decentralised infrastructure is still primitive. This paper makes some suggestions to address the existing problems. The current regression results for the three major economic regions confirm that China's economic transformation requires a new pattern of information industry, as some regions are not yet fully adapted to the demands of the digital economy. In some regions, digital businesses in education, tourism, health services, and finance need to be licensed and qualified under the same standards as traditional businesses, raising the barrier to entry. In addition, the current taxation is not compatible with the integration of resources across regional digital enterprises. We suggest that there is an urgent need for local governments to change the current management approach. Preferential policies for digital enterprises should be appropriately improved, and measures should be taken to support the sustainable development of micro and small enterprises, such as data sharing platforms that

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provide free credit or financial services. Localities should continue to improve economic integration through digital technologies, such as fifth-generation mobile networks, blockchain, cloud computing, and artificial intelligence. Supply-side reforms are also crucial. Local governments should break down the regional barriers that exist in the flow of technology information and actively encourage cross-provincial investment, as well as bidding projects to address the problem of excessive competition. Interaction item results show that China's high-tech investment does not interact with digital economy significantly and has a limited contribution to TFP. This may be because irrational application of funds has the potential to lead to a large increase in inefficient investments. Therefore, interventions are important to address structural challenges. The government needs to establish an appropriate market regulatory system and formulate property protection policies to improve market performance for the development of a modern digital economy and promote high-tech investments. At the same time, relevant authorities.

Conclusion

Based on the pooled regression, this study takes TFP as the explanatory variable and digital economy index as the main explanatory variable and draws the key conclusion that digital economy can significantly promote TFP growth. However, there are still some limitations: (1) In this paper, uncertain factors are not considered enough, such as policy changes, trade frictions, economic crisis, and even the current COVID-19 epidemic, which may affect TFP significantly. (2) This study is based on the nonlinear pooled regression, but whether there is a more reasonable model for the impact of digital economy on TFP remains to be solved. Therefore, further research could focus on variable adjustment, including exploring other factors that significantly affect TFP or exploring a more scientific and reasonable nonlinear model.

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