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HOW CAN DIGITAL ECONOMY DEVELOPMENT EMPOWER HIGH-QUALITY ECONOMIC DEVELOPMENT?

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Abstract. The role of the digital economy in economic transformation is increasingly prominent. This paper empirically examines how the digital economy affects TFP and its mechanism using Chinese provincial panel data. The results show that the impact of the digital economy on regional TFP is U-shaped. Further studies show that digital economy development may improve regional TFP through two channels: stimulating innovation and promoting entrepreneurship. In addition, we also discuss the role of active government, effective market, and high-level judicial protection in digital economic policies improving economic growth. Based on our research results, we put forward some policy recommendations.

Keywords: digital economy, TFP, innovation and entrepreneurship, active government, effective market, judicial protection.

JEL Classification: O33, O47, O38.

Introduction

In recent years, the traditional extensive economic growth mode has been challenging to sustain in China, and the digital economy has become a fresh engine of economic growth (Jing & Sun, 2019). As early as September 2016, the "G20 Digital Economy Development and Cooperation Initiative" adopted by the Hangzhou G20 Summit explored the path for the

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digitalization of the economy to help achieve inclusive growth and sustainable development. In the "Osaka Declaration on Digital Economy" released by the G20 in 2020, digitalization is believed to have played a key role in realizing an inclusive, sustainable, safe, credible, and innovative society. Over the past few years, the digital economy has become an increasingly significant driver of economic growth in countries around the world. Millions of new jobs have been created, making it the most energetic and prospective economic innovation and development in the world recently (Sutherland, 2018). Recently, China has vigorously developed the digital economy and regarded it as the main driving force to promote economic transformation and upgrading. Since 2014, the Chinese government has issued a number of policies, including "Internet Plus", which has extensively promoted China's transformation from a traditional economy to a digital economy and accelerated the process of digitalization in various industries. By the end of 2019, the added value of China's digital economy had risen to 35.8 trillion yuan, making it the second largest of all economies in the world[1]. Due to the increasing attention of the Chinese government, its overall scale still has great room for growth.

The digital economy provides a novel carrier for promoting innovation and entrepreneurship and improves the overall efficiency of the economic system. An extensive literature has examined the impact of the digital economy on economic growth (Bulturbayevich & Jurayevich, 2020), the financial market (Chen, 2022; Chen et al., 2022b), and firm innovation (Wen et al., 2022). However, little literature discusses the impact of the digital economy on regional total factor productivity (hereafter, TFP). How does the growth of the digital economy affect TFP? This empirical exploration is of great significance for guiding other countries to enable the growth of the digital economy.

We find that the digital economy has a U-shaped impact on TFP. The early stages of the digital economy help inefficient enterprises cope with the adverse effects of costs and inhibit the improvement of resource allocation (Chen, 2022; Yu & Li, 2019). Only when the digital economy develops to a particular stage can it promote competition between enterprises (Eisdorfer & Hsu, 2011; Mihardjo et al., 2019) and benefit regional TFP. Given that "Internet Plus" has provided a broad stage for "Mass Entrepreneurship and Innovation" in China, we investigate the channels through which the digital economy encourages regional TFP, focusing on innovation and entrepreneurship. The empirical tests clarify the internal logic of "Internet Plus" for stimulating innovation and entrepreneurship and thereby facilitating high-quality economic development. In addition, we comprehensively discuss how to strengthen the role of digital economy development in promoting regional TFP.

1. Literature review and hypotheses

1.1. Literature review

Digital transformation penetrates every aspect of the economy and finance, reshaping the virtual environment of the financial market and economic operation. Most literature believes that developing the digital economy helps maintain and accelerate economic growth (Jing & Sun, 2019; Huang et al., 2019; Zhao et al., 2020).

[1] See "China Internet Development Report (2020)".

On the one hand, digital economy development promotes financing efficiency by accelerating information integration and breaking the information island. Thanks to the application of technologies, the digital economy has solved many problems in information acquisition and integration, refining the demand and supply management of products and services and improving marginal efficiency in production (Zhang et al., 2019). Relevant studies have shown that, as an essential tool for production activities, the integration and use of information have become critical support for the effective operation of the market (Jensen, 2007), and data in the form of production factors have become a significant economic development driver (Jones & Tonetti, 2020). Manufacturers can discover consumers' hidden needs through big data to better allocate social and economic resources (Wen et al., 2019). The need to address the distortion of financing constraints is an important reason why enterprises take digital transformation (Chen, 2022). Moreover, digital technology can facilitate financial institutions to connect more clients, evaluate their information, improve business operations, and innovate financial services, which ultimately promotes the leap-forward development of financial technology (Chen et al., 2022b).

On the other hand, developing the digital economy boosts economic development by accelerating technological innovation and promoting industrial upgrading. In terms of fostering technological innovation, Yang (2020) pointed out that technological development has dramatically liberated human manual labor, making social production activities more innovation-oriented. The ease of use of technology and extensive technological empowerment make innovation activities more flexible, and the production and innovation process is no longer an assembly line chain (Wang & Zhang, 2020). In terms of promoting industrial upgrading, Liu and Ma (2020) conducted in-depth research based on the "Broadband China" pilot policy and found that network infrastructure upgrades industrial structures and alleviates resource mismatches between different industries. In addition, Ma (2020) pointed out that digital transformation has changed traditional consumption habits and production logic, which will help reduce the consumption disparity between urban and rural residents, improve consumption levels, and make consumption upgrading an essential engine for industrial upgrading.

For the past few years, the expansion of the digital economy has been crucial to a country's economic progress (Niyazbekova et al., 2021), and one dimension of its influence on economic growth may be the improvement of the economy's TFP. However, some literature notes that technological progress brought by digital economy development does not necessarily improve TFP from the perspective of appropriate technology. Antonelli and Quatratro (2010) pointed out that blind technological progress harms TFP. Only by choosing technological progress that matches the factors of production can the efficient improvement of TFP be achieved. Yuan and Ouyang (2018) indicated that appropriate technological advancement plays a vital role in encouraging TFP, while technological progress unsuitable for current economic production may cause a decrease in the efficiency of resource allocation. Therefore, the effects of the growth of the digital economy on TFP may be nonlinear and need further empirical testing.

We studied how the digital economy affects TFP and its mechanism and then discussed improving its positive impact on TFP. In comparison with existing research, the contributions are mainly reflected in both theoretical and practical aspects:

Theoretically, we develop a comprehensive index to measure digital economy development and provide theoretical insights into its impact on regional TFP. Most studies examine the level of development of Internet or information and communication technology (ICT), such as internet coverage, to describe the digital economy (Meng, 2021; Liu et al., 2019a). However, the traditional ICT level or some synthetic indicators designed based on conventional ICT subdivision indicators cannot fully characterize the digital economy growth because the digital transformation that has a disruptive influence on the economy today relies more on artificial intelligence, blockchain, cloud, and big data (ABCD). In this paper, the digital economy index covers the development of ABCD and the market value level of digital economy enterprises. It can more accurately measure the development level of the digital economy in China's provincial areas so that we can study the impact of the digital economy on TFP.

This paper also extends the literature on the mechanism behind the effects of the digital economy on TFP. Since the "Internet Plus" strategy was put forward in 2015, the digital economy has given a fresh lease of life to innovation and entrepreneurship. The existing literature not only studies the impact of innovation or entrepreneurship on TFP (Liu & Ma, 2020) but also studies how the digital economy affects innovation or entrepreneurship (Zhao et al., 2020; Wu & Zhang, 2021). However, there is still a lack of in-depth research on how the digital economy can promote economic development from the perspective of innovation and entrepreneurship. There is no discussion on strengthening the digital economy's effect in facilitating high-quality economic growth based on the two paths.

Practically, from the three dimensions of "government", "market", and "justice", we comprehensively give policy suggestions for how to improve the function of digital economy development in increasing TFP. Especially in the dimension of "government", based on the policy guidance role of the local government's annual working report (Andrews et al., 2020), this paper uses the frequency of the words "innovation" and "entrepreneurship" in the provincial government working report to design local entrepreneurship and innovation policy support-oriented indicators. After discussing the role of local governments in moderating the impact of digital economy development on TFP, we further study the guiding part of the central "Demonstration Base for Innovation and Entrepreneurship" policy and provide insights into the complementarity of the actions of central government and the local governments.

1.2. Hypotheses

The improvement of the TFP of an economy lies in both the promotion of resources among enterprises (Chen et al., 2015) and the increase in microeconomic entities' productivity (Yu, 2017). The value of the digital economy in its early stages is primarily to stimulate the growth of corporate informatization. The innovation value of simple ICT applications to the economy is far less than the change during the Industrial Revolution. The potential and effect of digital technology have not been fully manifested. According to the "IT Productivity Paradox" (David, 1990; Yang et al., 2020), although information technology investment can quickly form scale effects and marketing advantages in a short period, this does not necessarily result in a rapid return on investment. In addition, in the initial stage of digital economy

development, a large amount of additional investment in intangible assets by enterprises will not help enterprises to improve the availability of funds but may instead increase the financing constraints of enterprises. Therefore, micro-enterprises may experience a decline in productivity in the early stages of digital economy development, which is an "adaptation period" for digital economy development. In addition, the inclusiveness of early digital economy development will enable inefficient enterprises to hedge against the cost pressure caused by rising real estate prices and labor wages in China, which reduces the policy effect of increasing operation costs that force low-efficiency enterprises to exit (Yu & Li, 2019). As the resource optimization effect brought about by moderate cost increases is weakened, the growth of the digital economy will diminish the improvement in resource allocation from low-efficiency to high-efficiency companies, which will harm the progress of regional TFP. As Chen (2022) pointed out, responding to the negative impact of costs constitutes an essential incentive for enterprises' digital transformation, especially for inefficient enterprises with more prominent cost pressures.

As the digital economy develops to a certain stage, the digital economy dominated by ABCD breaks through the bottleneck of development and brings about continuous productivity changes. Micro-agents' capabilities and incentives to adopt digital technology contribute significantly to the policy effect of digital technology innovation (Nicoletti et al., 2020). Exposed to accelerated technological progress, enterprises must compete to innovate to survive (Eisdorfer & Hsu, 2011). This technology competition effect is more prominent in the digital era (Mihardjo et al., 2019). High-efficiency enterprises applying advanced technologies such as ABCD will gradually play a dominant role in the market, extensively promoting regional TFP. This stage is the "cruise period" of digital economy development. Meanwhile, with the overall improvement of the digitalization level, the digital transformation of low-efficiency enterprises will still face more severe market competition. Compared with high-efficiency enterprises, they cannot make more in-depth digital investments. Further development may exacerbate the exit of low-efficiency enterprises and improve resource allocation efficiency, thereby contributing to the improvement of regional TFP.

Thus, we propose Hypothesis 1:

Hypothesis 1: The digital economy has a U-shaped impact on regional TFP; that is, the improvement of the development level of the digital economy will first lead to a decline in regional TFP, and when the digital economy develops to a certain extent, TFP will increase with it.

As a novel economic format, the digital economy represents a powerful engine to promote productivity and provides a fresh channel and carrier for innovation and entrepreneurship in society. Li and Liu (2020) pointed out that both enterprise innovation and entrepreneurship may contribute to regional TFP. In November 2019, Chinese Premier Li Keqiang pointed out in a symposium with economic experts and entrepreneurs, "we must persist in promoting reform and opening up, strengthening scientific and technological innovation, continuing to support "Mass Entrepreneurship and Innovation" and "Internet Plus", and enhancing the support force of fresh kinetic energy for the economy". Based on the era background of the mutual integration of "Internet Plus" and "Mass Entrepreneurship and Innovation", this paper

will discuss the channel of the digital economy impacting regional TFP from the two dimensions of innovation and entrepreneurship.

The growth of the digital economy benefits innovation. First, the digital economy brings about a more transparent market, creating evolutionary pressure on firms to innovate to survive and thrive in the upgraded market environment (Eisdorfer & Hsu, 2011). Second, it provides better conditions for firms to engage in innovative activities (Wen et al., 2022). For example, digital economy development can ease financing constraints for innovation and boost intellectual property patent protection, improving the external environment for regional innovation (Wu & Zhang, 2021). Third, cross-enterprise innovation cooperation is easier to execute in the digital age. The findings of Lozada et al. (2019) suggest a positive relationship between better Big Data Analytics Capabilities and more agile processes of co-creation in products and services.

The improvement in the innovation of enterprises can solve the problem of inefficient production from the root cause, thereby improving TFP (Liu & Ma, 2020). Enterprises can enhance microeconomic vitality through technology research and development and mitigate the problem of low resource allocation efficiency, thereby promoting regional TFP (Zhang, 2018). In particular, Liu et al. (2019b) found that countries with a higher innovation driving force have significantly higher TFP than others.

Thus, we propose Hypothesis 2a:

Hypothesis 2a: The digital economy improves regional TFP by stimulating innovation.

The digital economy can support entrepreneurship. First, the expansion of the digital economy encourages more traditional entrepreneurial prospects by affecting market size, knowledge spillover, and factor mix, enriching entrepreneurial resources by speeding up information exchange and facilitating the transmission of ideas (Sahut et al., 2021). Second, the growth of the digital economy considerably improves the chance of household entrepreneurship by making people take more risks, building new social networks, and offering alternative borrowing channels (Yin et al., 2019). Third, there are an increasing number of new modes of entrepreneurship in the digital era. For example, new entrepreneurs acquiring, processing, and distributing digital information to create digital value are emerging (Sahut et al., 2019).

Entrepreneurship is a meaningful way to transform advanced technology into real productivity (Wang & Du, 2021). Due to the increase in entrepreneurial activity, the digital economy has promoted the conversion of old and new kinetic energy and the upgrading of the economic structure, which helps to expand employment, improve people's livelihood, and achieve fair opportunities and vertical social mobility (Zhao et al., 2020). Stimulating the vitality of entrepreneurship can realize the survival of the fittest in existing enterprises and transform social resources from old enterprises lacking productivity to new ones with high productivity, promoting regional TFP.

Thus, we propose Hypothesis 2b:

Hypothesis 2b: The digital economy can improve regional TFP by promoting entrepreneurship.

Since "Mass Entrepreneurship and Innovation" was first proposed in 2014, the Chinese government's emphasis on innovation and entrepreneurship has gradually deepened. In

March 2015, the term "Mass Entrepreneurship and Innovation" was written into the State Council's government working report for the first time. As "Mass Entrepreneurship and Innovation" received policy support from the central policy maker, many local governments issued corresponding measures to stimulate regional innovation and entrepreneurship. The "Mass Entrepreneurship and Innovation" policy directly affects both the entrepreneurship and innovation levels of the economy (Zhao et al., 2022) and thus affects regional TFP. However, as we focus on how digital economy development affects regional TFP, it is interesting to discuss the moderating effect of the government's entrepreneurship and innovation policy support on the interaction between the digital economy and regional TFP. This discussion will bring insights into the improvement of the policy effect of the digital economy in stimulating TFP.

Many positive and negative factors will impact economies' TFP improvement or technological progress. The positive actions of the government can strengthen the promotion effect of positive factors (Xie & Teo, 2022) and weaken the inhibition effect of negative factors (Chen et al., 2022a). As an important support for innovation and entrepreneurship, government policy can reduce the cost of innovation and entrepreneurship, and the environment allows more enterprises to support "Internet Plus" to bring out the energy of innovation and entrepreneurship. Therefore, it can enhance the policy impact of the digital economy to encourage innovation and entrepreneurship. Additionally, the government's direction on innovation and entrepreneurship can boost their quality by encouraging them to lower input factors per unit output and increase productivity, which will strengthen their support for TFP.

Thus, we propose Hypothesis 3a:

Hypothesis 3a: The government's supportive policy of entrepreneurship and innovation can strengthen the digital economy's effect on regional TFP.

After continuous market-oriented reforms, China has shifted from a planned economy to a market economy, and the fundamental role of the market in resource allocation has been clarified and strengthened. Fang (2006) found that the increasing marketization level has promoted the gradual transfer of capital from inefficient to high-efficiency industries and thus significantly promoted regional TFP. In addition, the empirical research of Ye and Liu (2020) found that the marketization process profoundly affects the manufacturing industry's technological progress and high-quality development.

We focus on the moderating effect of marketization on the relationship between digital economy development and regional TFP and give insights into how to increase the influence of the digital economy on TFP from the perspective of the marketization level. On the one hand, with the continual improvement of the level of marketization, the allocation of elements and resources required for innovation and entrepreneurship in the economy is more efficient, strengthening the supporting role of digital economy development for innovation and entrepreneurship in the economy. On the other hand, the promotion of marketization has intensified the survival of the fittest among microeconomic entities in the economy, improved the quality of innovation and entrepreneurship in the economy, and strengthened the promotion of innovation and entrepreneurship for TFP.

Thus, we propose Hypothesis 3b:

Hypothesis 3b: The improvement of marketization strengthens the digital economy's influence on regional TFP.

Patent protection is both a driving factor and a boosting force for technological research and development. Since the digital economy is a knowledge-intensive economy, strong judicial protection of patents is a powerful engine for bringing out the innovation energy of the digital economy. Zhuang et al. (2020) pointed out that judicial protection of intellectual property rights leads to an increase in enterprise innovation. Intellectual property protection in China is currently at the "optimal intellectual property theory" stage of effective innovation incentives. Li (2016) believed that improving patent protection intensity will help improve the profitability of patent-intensive industries, and intellectual property-intensive industries are the primary engine for China's future economic development. Zhang and Yu (2020) empirically found that regional intellectual property protection has a positive moderating effect on digital investment's global value chain climbing effect.

We examine the moderating impact of judicial protection on the relationship between digital economy growth and regional TFP and offer suggestions for strengthening the digital economy's improvement effect on TFP from the standpoint of judicial protection. On the one hand, enhanced judicial protection will ensure the benefits of innovation and entrepreneurship of microeconomic entities and strengthen the supporting role of digital economy development for innovation and entrepreneurship of economies. On the other hand, increased judicial protection has decreased market free-riding, promoted economic cooperation and coordination of innovation and entrepreneurship, and strengthened TFP's encouragement of innovation and entrepreneurship.

Thus, we propose Hypothesis 3c:

Hypothesis 3c: Enhanced judicial protection of patents can strengthen the promotion effect of the digital economy on regional TFP.

2. Measurement of explained variables and key explanatory variables

2.1. Calculation of TFP

We draw on the method of Kumbhakar and Lovell (2000) and use stochastic frontier analysis in terms of the translog production function to measure provincial TFP. The transcendental logarithmic form of the production function is:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 t + \frac{1}{2}\beta_4 \left(\ln K_{it}\right)^2 + \frac{1}{2}\beta_5 \left(\ln L_{it}\right)^2 + \frac{1}{2}\beta_6 t^2 +$$
$$\beta_7 \ln K_{it} \times \ln L_{it} + \beta_8 t \times \ln L_{it} + \beta_9 t \times \ln K_{it} + v_{it} - u_{it} + \eta_t,$$

where

$$u_{it} = \left\{\exp\left[\eta\left(t - T\right)\right]\right\} \sim i.i.d.\ N\left(\mu, \sigma_u^2\right).$$

In the above model, Y_{it} is the output level, K_{it} represents the physical capital input, L_{it} represents the labor input, v_{it} is the random interference term, u_{it} is the technical inefficiency term, and η is the time-varying parameter of the technical efficiency level.

Each model indicator is calculated as follows: (1) Output indicator. The output indicator uses each province (city)'s gross domestic product (GDP) from 2012 to 2018 and deflates it to the constant price value in 2000. (2) Input indicators. The labor input in the input indicator adopts the data of the whole society of employees in each province (city). The physical capital stock characterizes the physical capital input in the input index. First, according to the implied deflator of the whole country and each province, the fixed capital formation in the past years is consistently transferred into the constant price value in 2000, using 2000 as the baseline, according to the fixed asset depreciation rate of 10.96% (Shan, 2008). The basic formula for re-inventory is used to calculate capital stock over the years.

2.2. Calculation of the regional digital economy index

So far, there has yet to be an authoritative index for describing the development of the Chinese digital economy. The calculation of the digital economy index in the literature generally includes the "Internet Plus" digital economy index designed by the Tencent Research Institute (Jiang & Sun, 2020) and the self-constructed indices (Liu et al., 2020; Zhao et al., 2020). The "Internet Plus" digital economy index comprehensively covers data from Tencent and other large digital enterprises but can only be used as cross-sectional data. Due to the dynamic adjustment of subdivision indicators and weights yearly, the data over the years are different. Regarding the subdivision indicators of the digital economy growth index constructed by scholars, Liu et al. (2020) selected three-dimensional indicators of the growth of the internet, the development of information technology, and the growth of digital transactions. There also exists literature that does not distinguish between the growth of the digital economy and digital finance (Zhang et al., 2019). Zhao et al. (2020) and Han et al. (2021) introduced the component of digital inclusive finance to the internet development level index developed by Huang et al. (2019) to quantify the total degree of digital economic growth in prefecture-level cities.

Authoritative measures of the level of digital economy development on a global scale include the systems of the Organization for Economic Cooperation and Development (OECD) and the US Bureau of Economic Analysis (BEA) (Chen & Zhang, 2020). The OECD uses four factors, including investment in intelligent infrastructure, the level of ICT's promoting a digital society, the capacity of digital technology innovation and the extent to which ICT's facilitating employment and economic growth (OECD, 2014). The BEA's measurement of the development level covers digital infrastructure, e-commerce, and digital media. Referring to the design of these two international authoritative measurement systems and considering that the growth of the digital economy in China revolves around the two main paths of digital industrialization and industrial digitization, this paper constitutes an index for describing the provincial growth of the digital economy in terms of the availability of provincial-level data. The six dimensions of indicators used to calculate the index are digital infrastructure construction level, ICT's promoting digital society, the capacity of digital technology innovation, the extent to which ICT's facilitating economic growth, the development level of regional digital economy industries, and the digital economy's capitalization level. Because technologies such as ABCD are the digital technology innovations most concerned by the Chinese

government and the market and have the potential to bring about a new productivity revolution, we utilize the quantity of patent applications for these four technologies as a measure of the capacity for innovation in digital technology. We choose e-commerce-related indicators to depict the emerging digital economy industry's state of development since China's emerging digital economy sector best represents the e-commerce industry. Following Mueller et al. (2017)'s measuring the development level of different countries' digital economies, we measure the effectiveness of digital economy growth in various regions from the capital market perspective. With logarithmic processing performed on the composite index values formed by the six dimensions, we obtain the final index (*ldigital*) to calculate the digital development level of each provincial-level economy. Compared with the existing indicators, the digital economy growth index constructed in this paper has expanded both in depth and breadth.

As shown in Table 1, considering the possible obvious correlation between the indicators in the process of synthesizing the secondary indicators into the first-level indicators and synthesizing the first-level indicators into the digital economy growth index, we adopt the CRITIC model to generate indicator weights.[2]

The CRITIC technique, which uses objective weighting, can not only completely take into account the variability and correlation of indicators but also efficiently avoid the randomness introduced by subjective weighting. This method overcomes the problem of other objective weighting methods and gives a more precise design of the weights (Yalcin & Ünlü, 2018; Xu & Chen, 2015; Chen & Wu, 2022; Chen et al., 2023).

In terms of data sources, the data used to calculate the four first-level indicators, including digital infrastructure construction level, ICT's promoting digital society, the capacity of digital technology innovation, and the extent to which ICT's facilitating economic growth, come from the *China Statistical Yearbook*. The secondary indicator data for the development level of regional digital economy industries can be found in the *China Statistical Yearbook* from 2013. The data for 2012 are calculated based on our collected data from the website of the

Table 1. Assessment of digital economy development

Primary indicator	Secondary indicators
Digital infrastructure construction level	The usage of telecommunications services and the penetration of mobile phones.
ICT's promoting the level of digital society	The quantity of domains, the quantity of websites, and the quantity of pages.
The capacity of digital technology innovation	The quantity of patent applications for ABCD.
The extent to which ICT's facilitating economic growth	The social fixed asset investment of information transmission, computer service, software industry, and software business income.
The development level of regional digital economy industries	The quantity of businesses with e-commerce transactions, sales, or purchases.
The digital economy's capitalization level	The listed digital technology enterprises' market value in the Chinese A stock market.

[2] See Chen and Wu (2022) for the details of the design of the weights.

China E-Commerce Center, iResearch's e-commerce-related consulting reports and the reports of provincial departments of commerce, and the year-on-year growth data disclosed in the special reports of the statistical bureaus of each province and the working reports of the provincial governments are compiled and calculated. The important statistics on the digital economy's capitalization level are obtained by summing up the year-end market value of A-share listed companies belonging to related industries in the software, information transmission and information technology service industries in the Wind database. The digital patent data come from the *Zero One Think Tank*, a professional think tank of financial technology, which obtains the original data by crawling international patent application data published on the official website of the World Intellectual Property Organization (WIPO) over the years. Because of the availability of software business revenue data and e-commerce-related data, the sample time point of this paper is 2012–2018.

3. Empirical design

3.1. The benchmark model setting

Based on the U-shaped impact of digital economy growth on regional TFP predicted by Hypothesis 1, we establish the following benchmark regression model:

$$TFP_{i,t} = \alpha_0 + \alpha_1 ldigital_{i,t} + \alpha_2 ldigital_{i,t}^2 + \gamma X_{i,t} + \varepsilon_{i,t}. \quad (1)$$

In the benchmark model, $ldigital_{i,t}$ represents the level of digital economy development, and $ldigital^2{}_{i,t}$ is its square term, which describes the nonlinear relationship between digital economy growth and regional TFP. $X_{i,t}$ is the corresponding control variables. According to Hypothesis 1, we predict $\alpha_2 > 0$.

3.2. The mediating effect model setting

To explore the endogenous transmission mechanism of "digital economy-innovation/entrepreneurship-TFP", referring to Edwards and Lambert (2007), we set the following mediating effect model:

$$chuangxin_{i,t}/chuangye_{i,t} = \varphi_0 + \varphi_1 ldigital_{i,t} + \varphi_2 ldigital_{i,t}^2 + \gamma X_{i,t} + \varepsilon_{i,t}; \quad (2)$$

$$TFP_{i,t} = \alpha_0 + \alpha_1 chuangxin_{i,t}/chuangye_{i,t} + \alpha_2 ldigital_{i,t} + \alpha_3 ldigital_{i,t}^2 + \gamma X_{i,t} + \varepsilon_{i,t}. \quad (3)$$

Models (2), (3) and (1) together constitute an econometric model for the mediating effect test. When the mediating variable is the innovation level ($chuangxin_{i,t}$), this paper predicts that once the digital economy reaches a certain level of development, it will have a beneficial impact in enhancing the level of invention, and increased innovation will have a favorable effect on regional TFP. If φ_2 is significantly positive in model (2) and α_1 is significantly positive in model (3), the mediating effect of innovation is confirmed. If α_2 or α_3 in model (3) is also significant, then the mediating effect is a partial mediating effect; if neither is significant, then the mediating effect is a complete mediating effect. For the level of entrepreneurship ($chuangye_{i,t}$), this paper also predicts that if the digital economy reaches a particular degree of development, it will have a positive role in increasing the level of entrepreneurship, and

increasing entrepreneurship will have a positive effect on regional TFP. If φ_2 is significantly positive in model (2) and α_1 is significantly positive in model (3), then the mediating effect of entrepreneurship is confirmed. If α_2 or α_3 in model (3) is also significant, then the mediating effect is a partial mediating effect; if neither is significant, then the mediating effect is a complete mediating effect.

3.3. Sample selection and variable selection

We obtained the basic data from the *China Statistical Yearbook* from 2012 to 2018. The abovementioned models are utilized to calculate the regional TFP and the digital economy index. Considering the availability of constructing the digital economy index, this paper takes 2012 as the starting time. The explanatory variables in this paper are the regional total productivity (*TFP*), the key explanatory variables are the digital economy growth level (*ldigital*) and its squared value; the mediating variables are the level of innovation (*chuangxin*) and the level of entrepreneurship (*chuangye*); the moderating variables are the local government's supporting policy orientation for entrepreneurship and innovation (*INum*), the central government policy dummy variable (*SC*), the level of marketization (*market*) and the degree of patent judicial protection (*caserate*).

The mediating variables are designed as follows. Given that patent applications are more representative and more objective and authoritative in various R&D data (Li & Zheng, 2016), this paper refers to Lin and Long (2019) and uses the annual growth of patent authorization to describe the innovation level (*chuangxin*). Referring to Chlosta et al. (2012), we use the number of private enterprises and self-employed households to reflect the entrepreneurial activity of an economy. The per capita number of private enterprises and self-employed households is defined as the level of entrepreneurship (*chuangye*).

This paper analyzes the moderating effect from three dimensions, including the government's supportive policy for entrepreneurship and innovation, the level of marketization (*market*) and the degree of patent judicial protection (*caserate*). Regarding the government's support policy for entrepreneurship and innovation, this paper constructs two indicators from the dimensions of the central government and the local government: the implementation policy dummy variable (*SC*) for the implementation of "Demonstration Bases for Mass Entrepreneurship and Innovation" and the government's entrepreneurship and innovation support policy orientation indicator (*INnum*). The dummy variable *SC* is designed as follows: when the year is 2016–2018, the value is 1; when the year is 2012–2015, the value is 0. In May 2016, the State Council General Office released the "Implementation Opinions on Building Demonstration Bases for Mass Entrepreneurship and Innovation", supporting enterprises' transformation and upgrading and stimulating enthusiasm for social innovation. Since the launch of demonstration bases, local governments have made greater efforts to promote entrepreneurship and entrepreneurship policies to obtain the state council's approval of the national bases (Gao & Mu, 2021).

In terms of control variable design, combined with Zhao et al. (2020), Huang et al. (2019) and other studies, this paper selects the level of economic development (*lpergdp*), industrial structure status (*tgdpr*), government financial status (*govrate*), and economic openness

(*firate*) as control variables. The TFP of most countries in the world shows convergence; that is, TFP declines with economic growth, which causes the widespread problem of the "middle-income trap" (Liu et al., 2021). Due to the restraint of the lag of institutional reform and the shrinking of the "learning by doing" effect, the impact of technical development on economic expansion in China has also shown a downward trend (Research Group on China's Economic Growth, 2015). Especially after 2008, the convergence trend of Chinese regional TFP is more obvious (Yu, 2017). To this end, this paper introduces both the primary and quadratic terms of *lpergdp* to reflect the abovementioned convergence of TFP. The details of variable definitions are listed in Table 2.

Table 2. Variable definitions

Symbol	Variables	Interpretation
TFP	total factor productivity (TFP)	Provincial TFP based on the SFA model.
ldigital	Digital economy development level	Referring to the text.
chuangxin	Innovation level	The added value of the number of patents granted this year compared with the previous year (10,000 pieces).
chuangye	Entrepreneurial level	(The number of private enterprises and self-employed households)/The number of permanent residents at the end of the year (per ten thousand people).
lpergdp	The level of economic development	Divide the gross regional product by the total resident population at the end of the year to obtain the per capita gross regional product (10,000 yuan/person), and then take the natural logarithm value.
Tgdpr	Industrial structure status	The tertiary industry's share of GDP.
govrate	government financial status	The ratio of the general budget expenditure of the local government to the regional GDP.
Firate	economic openness	The amount of foreign direct investment actually utilized/fixed assets investment of the whole society (%).
INnum	Local government entrepreneurship and innovation policy support orientation	The proportion of the keyword "innovation" in the total number of the keywords "innovation" and "entrepreneurship" in the provincial government's working report.
SC	Implementation Policy of the Central Innovation and Entrepreneurship Demonstration Base	When *year* ≥ 2016, the value is 1, otherwise 0.
market	marketization level	Marketization index, data from Wang et al. (2019).
caserate	Degree of patent judicial protection	The count of closed patent infringement cases/ the total count of patent applications in the current year.

Table 3 shows the descriptive statistics for all variables in the regressions. The mean of the regional TFP is 0.676, while the minimum and maximum values are 1.032 and 0.357, respectively, which shows that TFP varies greatly in different regions and different years. In addition, as shown in Figure 1, the development levels of the digital economy in different regions of China are quite different. The eastern region has the highest level of digital economy development, while the western region has the lowest level of digital economy development. This statistical result is consistent with the actual situation in China. Provinces or municipalities in the eastern region, such as Beijing, Zhejiang, and Guangdong, are at the forefront of digital economy development in the country, with leading digital economy companies such as Alibaba, Tencent, JD.com, Toutiao, and Baidu. Digital facilities in western provinces are still gradually improving. Because of a scarcity of relevant data in the Tibet region, the sample in this paper does not include the Tibet region. Therefore, there are only 210 observations.

Table 3. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
TFP	210	0.676	0.166	0.357	1.032
ldigital	210	1.907	0.772	0.692	3.920
chuangxin	210	0.693	1.717	-3.961	14.543
chuangye	210	0.054	0.017	0.028	0.101
tgdpr	210	0.467	0.093	0.330	0.802
govrate	210	0.249	0.101	0.121	0.593
firate	210	3.260	3.783	0.032	18.548
lpergdp	210	1.602	0.408	0.794	2.558
INnum	210	0.814	0.086	0.525	0.976
SC	210	0.429	0.496	0	1
market	210	5.755	1.684	1.600	8.830
caserate	210	0.017	0.051	0	0.285

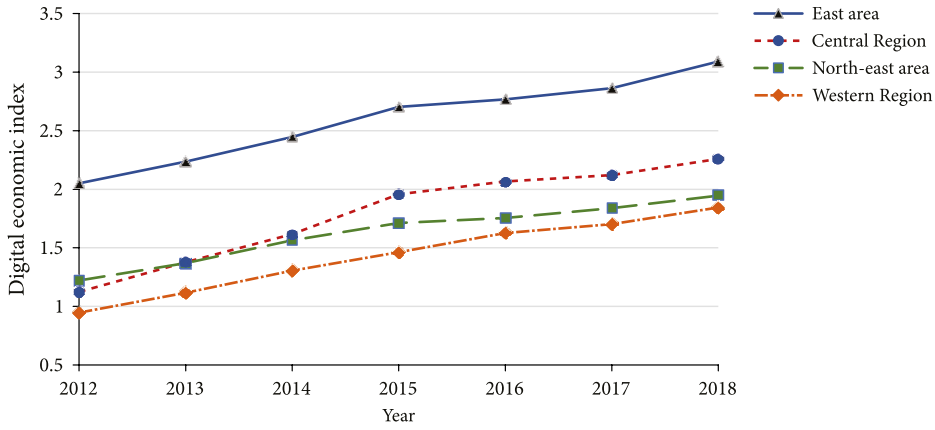

Figure 1. The trend of digital economy growth in different regions

4. Empirical results analysis

4.1. Benchmark model analysis

This paper uses both the random effect model and the fixed effect model to test the impact of the development level of the digital economy on TFP. The results are reported in Table 4. Column (2) reports the result with the province fixed effect, and column (3) reports the result with both the province-year fixed effects. As shown in columns (1)–(3), the first-order terms of *ldigital* are significantly negative at the 1% level, and the squared terms are significantly positive at the 1% level. These results support Hypothesis 1 that digital economy growth has a U-shaped impact on TFP. The Hausman test results show that the double fixed effect model of province and year is suitable for this study. Column (3) suggests that the inflection point value of the U-shaped relationship is 2.08 (0.054/(2×0.013)), which is within the value range of *ldigital* in the sample. As shown in Figure 1, the eastern region of China has been on the right side of the inflection point since 2012, while the central region of China has been basically on the right side of the inflection point since 2015, but as of 2018, the western region and the northeast region as a whole are still on the left side of the inflection point.

Table 4. Benchmark model regressions

	(1) *TFP*	(2) *TFP*	(3) *TFP*
ldigital	–0.054*** (–2.91)	–0.055*** (–3.45)	–0.054*** (–2.87)
$ldigital^2$	0.013*** (3.80)	0.013*** (4.04)	0.013*** (3.77)
tgdpr	0.095** (1.88)	0.092** (2.10)	0.106* (1.85)
govrate	0.087 (0.73)	0.108 (1.44)	0.089 (1.02)
firate	–0.001 (–1.47)	–0.001 (–1.54)	–0.001 (–1.47)
lpergdp	0.169*** (3.82)	0.173*** (3.94)	0.173*** (3.89)
$lpergdp^2$	–0.037*** (–2.88)	–0.038*** (–3.00)	–0.037*** (–2.87)
Province FE	NO	YES	YES
Year FE	NO	NO	YES
R-squared	0.467	0.467	0.472
Obs	210	210	210

Note: t values in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Similarly, hereinafter.

4.2. Mediating effect model

Columns (1) and (2) of Table 5 report the results of tests on the mediating effect of innovation. As shown in column (1), the coefficient of the square term of *ldigital* is significantly positive at the 5% level, indicating that the digital economy will have a positive impact on innovation when it develops to a certain extent. Column (2) suggests that the coefficient of *chuangxin* is significantly positive at the 1% level, indicating that innovation has a positive effect on TFP. Since both the first-order and square-term coefficients of *ldigital* in column (2) are significant, innovation plays a partial mediating effect in the impact of digital economy on TFP. The above empirical results support the prediction of Hypothesis 2a.

Columns (3) and (4) of Table 5 report the results of tests on the mediating effect of entrepreneurship. As shown in column (1), the coefficient of the squared term of *ldigital* is significantly positive at the 1% level, indicating that the digital economy will have a positive impact on entrepreneurship when it develops to a certain extent. Column (4) suggests that the coefficient of *chuangye* is significantly positive at the 10% level, indicating that entrepreneurship has a positive effect on TFP. Since both the first-order term and the square term of *ldigital* in column (3) are significant, entrepreneurship plays a partial mediating effect in the impact of digital economy development on TFP. The above empirical results support the prediction of Hypothesis 2b.

Table 5. Mediating effects

	(1) *chuagnxin*	(2) *TFP*	(3) *chuangye*	(4) *TFP*	(5) *TFP*
ldigital	–3.115* (1.70)	–0.047** (–2.52)	–0.012** (–2.50)	–0.048** (–2.49)	–0.041** (–2.18)
$ldigital^2$	0.688** (2.07)	0.011*** (3.33)	0.002*** (2.75)	0.012*** (3.33)	0.010*** (2.94)
chuagnxin		0.002*** (3.03)			0.002*** (2.95)
chuangye				0.558* (–1.85)	0.512* (1.73)
tgdpr	–4.857 (–0.88)	0.118** (2.10)	–0.025* (–1.74)	0.120** (2.09)	0.130** (2.32)
govrate	9.157 (1.09)	0.067 (0.79)	–0.050** (–2.26)	0.117 (1.33)	0.093 (1.09)
firate	–0.157* (–1.75)	–0.001 (–1.09)	–0.001*** (–2.78)	–0.001 (–1.06)	–0.001 (–0.72)
lpergdp	4.067 (0.94)	0.164*** (3.75)	–0.022* (–1.95)	0.186*** (4.15)	0.175*** (3.99)
$lpergdp^2$	–0.628 (–0.50)	–0.036*** (–2.82)	0.008** (2.29)	–0.042** (–3.17)	–0.040*** (–3.10)
Province FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
R-squared	0.310	0.500	0.936	0.483	0.509
Obs	210	210	210	210	210

The early stage of growth of the digital economy may help to retain low-efficiency firms in the market, which may explain why the digital economy cannot play a beneficial role in boosting innovation and entrepreneurship, which squeezes the required resources for innovation and entrepreneurship of the enterprise sector, making the allocation of resources less efficient. However, as the digital economy matures, it will continue to optimize resource allocation and achieve the synergistic effect of "Internet Plus", "innovation" and "entrepreneurship", thereby promoting regional TFP.

In addition, we find a significant difference between the coefficient of *chuagnxin* in column (2) and that of *chuangye* in column (4), and the absolute values of the coefficients of *ldigital* and $ldigital^2$ in column (2) are significantly smaller than those in column (4), which indicates that compared with entrepreneurship, innovation can contribute more to the improvement of regional TFP. According to Sobel (1982), the Sobel test statistic z was constructed. The z score of "Digital economy-Innovation-TFP" is –1.677, and the p value is 0.094; the z score of "Digital economy-Entrepreneurship-TFP" is –1.838, and the p value is 0.066. Thus, both models above have significant mediating effects.

In addition, we reconstruct the model by introducing both mediating variables, and the regression results of column (5) show that both innovation and entrepreneurship significantly contribute to the improvement of TFP, and they play a partial mediating effect together. As the coefficient of *ldigital* is significantly negative and the coefficient of $ldigital^2$ is significantly positive in column (5), the direct effect of the digital economy on TFP also represents a curvilinear relationship.

5. Further analysis

5.1. The moderating role of policy guidelines

5.1.1. Local government policy guidelines

To explore the role of government policy guidelines in modulating the relationship between digital economy development and TFP, we manually sort out the word frequencies of "innovation" and "entrepreneurship" in the provincial government working report from 2012 to 2018. Local governments have different policy goals for "innovation" and "entrepreneurship". The support policy for "innovation" is to guide the transformation of productivity, promote economic transformation and upgrading, and promote the overall improvement of production efficiency, while for "entrepreneurship", the support policy is more to ensure growth and employment. Some low-productivity production activities that can absorb a large number of jobs are still supported by the entrepreneurship support policy. Governments' supporting "entrepreneurship" does not mean that resources are allocated to new entrants that can truly utilize resources efficiently, which is different from the "start-up" promoted by the spontaneous allocation of market resources. Therefore, the "start-up" encouraged by the local government may have an inhibiting effect on TFP. This paper calculates the number of the keywords "innovation" and "entrepreneur" occurring in the provincial government working report and uses the ratio of the count of "innovation" to the total number (*INnum*) to describe the local government's support policy orientation for innovation. The index *INnum* is used as

a moderating variable to study its moderating effect. Referring to Fan and Liu (2018), the moderating effect model shown below is built:

$$TFP_{i,t} = \alpha_0 + \alpha_1 ldigital_{i,t} + \alpha_2 ldigital_{i,t}^2 + \alpha_3 INnum_{i,t} + \alpha_4 INnum_{i,t} \times ldigital_{i,t} + \gamma X_{i,t} + \varepsilon_{i,t}.$$

Table 6 (1) shows the regression results. The empirical results show that the coefficient of the multiplication term *INnum* × *ldigital* is significantly positive at the 1% level. This shows that the improvement of innovation orientation in the local government's support policy has effectively strengthened the positive effect of digital economy development on TFP, supporting the prediction of Hypothesis 3a.

5.1.2. Central government policy guidelines

The policies issued by local governments in the field of innovation and entrepreneurship and their implementation efficiency are subject to the constraints of the central government assessment. Under the guidance of the implementation of "Demonstration Bases for Mass Entrepreneurship and Innovation" by the central government, local governments will compete to meet the central requirements to show better performance (Wang & Lei, 2021), which greatly impacts the implementation performance of the innovation and entrepreneurship policies of local governments. This section further introduces a dummy variable *SC*. The implementation of the "Demonstration Bases for Innovation and Entrepreneurship" by the Chinese central government in 2016 serves a significant guiding role in promoting the integration of innovation and entrepreneurship in local government policy, which truly represents the transformation toward advanced productivity of "Internet Plus".

In view of the fact that the implementation of the central government's Demonstration Base for Entrepreneurship and Innovation exerts its policy effect by guiding the orientation of the local government's support policy for entrepreneurship and innovation, the interactive variable *SC* × *INnum* × *ldigital* is introduced here to establish a moderating effect model:

$$TFP_{i,t} = \alpha_0 + \alpha_1 ldigital_{i,t} + \alpha_2 ldigital_{i,t}^2 + \alpha_3 INnum_{i,t} + \alpha_4 INnum_{i,t} \times ldigital_{i,t} + \alpha_5 INnum_{i,t} \times ldigital_{i,t} \times SC_{i,t} + \gamma X_{i,t} + \varepsilon_{i,t}.$$

Table 6 (2) lists the regression results, and the coefficient of *SC* × *INnum* × *ldigital* is significantly positive at the 10% level, which shows that implementation of the central government's Demonstration Base for Entrepreneurship and Innovation has a significant moderating effect on the performance of the local government's support policy. The "Demonstration Base for Innovation and Entrepreneurship" launched by the State Council has strengthened the local government's emphasis on innovation and entrepreneurship. The common orientation for high-quality development and the healthy competition between local governments around "Mass Entrepreneurship and Innovation" has further strengthened the significance of the digital economy in boosting TFP. This result also further illustrates the importance of "effective government". The more explicit guidance of the central policy can strengthen the positive effect of local government on the digital economy's promoting TFP.

5.2. The moderating role of marketlization

We use Chinese provinces' marketization scoring data in Wang et al. (2019) to describe the marketization level (*market*). Since the data are updated to 2016, we refer to Yu's et al. (2010) method for interpolation of the data of the remaining years. This paper introduces the interaction term of *market* and *ldigital* and establishes the following moderating effect model:

$$TFP_{i,t} = \alpha_0 + \alpha_1 ldigital_{i,t} + \alpha_2 ldigital_{i,t}^2 + \alpha_3 market_{i,t} + \alpha_4 market_{i,t} \times ldigital_{i,t} + \gamma X_{i,t} + \varepsilon_{i,t}.$$

As shown in Table 6 (3), the coefficient of *market* × *ldigital* is significantly positive at the 1% level, indicating that the increasing marketization level has strengthened the positive impact of digital economy growth on TFP, supporting the prediction of Hypothesis 3b. The logic behind this may be that increased marketization enhances the efficiency with which economic resources are allocated and enables more innovative and entrepreneurial behaviors representing advanced productivity in the digital era.

5.3. The moderating effect of patent judicial protection

Moderate patent protection is important to create innovative value (Deng & Li, 2021). The social value created by the knowledge-intensive digital economy cannot be fully realized without the support of the strong judicial protection of patents. Domestic scholars mostly employ metrics such as "the ratio of lawyers to the total population, the rate of patent litigation closure", and "the ratio of infringement cases to patent grants" to measure the level of judicial protection of patents (He & Dong, 2020). Considering that the intellectual property tribunal of the court system is the only enforcement body for adjudicating national intellectual property disputes and that the number of intellectual property cases can largely characterize the intensity of judicial protection of patents, Mao et al. (2019) used the patent and other civil case closing data issued by the Supreme People's Court as a proxy variable to reflect patent judicial protection. Due to provincial data availability and the differences in the scale of patents in each province, this paper refers to the design method of the administrative protection level of intellectual property by Dai (2014) and uses the ratio of the number of closed cases of patent infringement to the number of patent applications to describe the judicial protection level of patents (*caserate*). The State Intellectual Property Office's website provides the total number of settled patent infringement cases. The interaction term between *caserate* and *ldigital* is included in this study to build the moderating effect model shown below:

$$TFP_{i,t} = \alpha_0 + \alpha_1 ldigital_{i,t} + \alpha_2 ldigital^2{}_{i,t} + \alpha_3 case_{i,t} + \alpha_4 case_{i,t} \times ldigital_{i,t} + \gamma X_{i,t} + \varepsilon_{i,t}.$$

According to Table 6 (4), the coefficient of *case* × *ldigital* is significantly positive at the 1% level. It is evident that the enhanced judicial protection of patents has strengthened the positive effect of the digital economy on TFP, supporting Hypothesis 3c. The logic behind this is that the increasing judicial protection of patents can reduce the free-rider behavior of the corporate sector in innovation during the digital economy era, thereby strengthening the willingness of micro-enterprises to innovate independently and enhancing the enabling effect of the digital economy on TFP.

Table 6 (5) shows the regression coefficients of the model containing all mediating variables. We can see that all of the coefficients of *INum* × *ldigital*, *market* × *ldigital*, and *caserate* × *ldigital* are significantly positive at the 5% level. This further verifies that all the moderating variables mentioned above have significant moderating effects on the policy effect of the digital economy on regional TFP.

Table 6. Moderating effects

	(1) *TFP*	(2) *TFP*	(3) *TFP*	(4) *TFP*	(5) *TFP*
ldigital	–0.077*** (–3.81)	–0.061*** (–2.81)	–0.082*** (–4.11)	–0.034 (–1.59)	0.124*** (2.78)
$ldigital^2$	0.011*** (3.28)	0.007* (1.88)	0.008*** (2.32)	0.008* (1.92)	0.003 (0.79)
INum	–0.048 (–1.60)	–0.042 (–1.43)			–0.040 (–1.34)
INum × *ldigita*l	0.037*** (2.63)	0.030** (2.09)			0.309** (2.19)
SC × *INum* × *ldigital*		0.009* (1.96)			
market			–0.014** (–2.39)		–0.011* (–1.75)
market × *ldigital*			0.007*** (3.49)		0.005** (2.03)
caserate				–0.496*** (–2.68)	–0.381* (–1.90)
caserate × *ldigital*				0.143*** (2.64)	0.116** (2.10)
tgdpr	0.073 (1.26)	0.066 (1.14)	0.116** (2.07)	0.118** (2.08)	0.0886 (1.50)
govrate	0.091 (1.07)	0.123 (1.43)	0.043 (0.50)	0.063 (0.73)	0.047 (0.54)
firate	–0.001 (–1.40)	–0.001 (–1.52)	0.000 (0.37)	–0.001 (–0.74)	0.000 (0.35)
lpergdp	0.156*** (3.54)	0.172*** (3.86)	0.175*** (3.99)	0.143*** (3.05)	0.124*** (2.78)
$lpergdp^2$	–0.035*** (–2.75)	–0.041*** (–3.13)	–0.039*** (–3.04)	–0.029** (–2.09)	–0.025* (–1.96)
Province FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
R-squared	0.499	0.511	0.510	0.494	0.527
Obs	210	210	210	210	210

6. Robustness check and endogenous discussion

The previous empirical results of this paper show that the digital economy's stimulating TFP. However, the improvement of TFP will also provide effective support for the growth of the digital economy, which means that the progress of TFP may, in turn, promote the development level of the digital economy. In other words, there may be a causal relationship between the progress of TFP and that of the digital economy. Consequently, the endogenous problem may emerge between the expansion of the digital economy and TFP. In addition, the impact of TFP will also have an impact on some of the control variables, such as government financial status and economic openness. Endogenous problems will also exist between the explained variables and the control variables. Based on this, this paper lags the key explanatory variables by one period and re-regresses model (1). The results are presented in column (1) of Table 7. In addition, this paper processes the key explanatory variables and all control variables with a lag of one period and re-regresses model (1) in column (2). The significance of the coefficients of *ldigital*^{2} indicates the robustness of the regression results.

This paper's provincial digital economic index is self-synthesized based on sub-indicators from six dimensions. There are also a large number of other digital economic indicators. To illustrate the robustness of the empirical results under the selection of different digital economy indicators, we use the provincial digital economy index data of the "China Digital Economy Development Index" released by CCID Consulting Co., Ltd. over the years as the key explanatory variables to re-regress model (1). As shown in column (3) of Table 7, there is still a significant U-shaped relationship between *ldigital* and TFP, and the empirical results are robust.

Table 7. Endogeneity and robustness analysis

	(1) *TFP*	(2) *TFP*	(3) *TFP*	(4) *TFP*
ldigital			–0.078 (–0.82)	–0.075* (–1.7)
ldigital^2			0.198*** (3.22)	0.016** (2.32)
tgdpr	0.104 (1.53)		0.144*** (2.50)	0.117*** (1.98)
govrate	0.130 (1.26)		0.085 (1.03)	0.075 (0.85)
firate	–0.002 (–1.46)		–0.001 (–0.94)	–0.001 (–1.40)
lpergdp	0.210*** (3.72)		0.189*** (–3.663)	0.204*** (2.82)
lpergdp^2	0.015*** (–2.91)		–0.044*** (–3.66)	–0.046** (–2.19)
L.ldigital	–0.060*** (–2.71)	–0.059** (–2.45)		
L.ldigital^2	0.015*** (3.79)	0.016*** (3.58)		

End of Table 7

	(1) *TFP*	(2) *TFP*	(3) *TFP*	(4) *TFP*
L.tgdpr		0.047 (0.52)		
L.govrate		–0.007 (–0.06)		
L.firate		–0.001 (–1.30)		
L.lpergdp		0.196*** (2.89)		
L.lpergdp^2		–0.050*** (–2.88)		
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
R-squared	0.442	0.406	0.523	0.468
Kleibergen-Paap rk LM statistics				36.530 (0.000)
Kleibergen-Paap rk Wald F statistics				37.575
Obs	180	180	210	210

In addition, we follow Chen (2023) and utilize the setting method of Nunn and Qian (2014), using the interactive item of the mobile phone penetration rate of each province in 2010 (related to the regional difference) and the proportion of China's whole digital sector's total value contributed to its GDP in the calendar years from 2012 to 2018 (related to the time difference) to represent the instrumental variable (*ivdigital*) of the provincial level of digital economic development. Among them, the data on each province's mobile phone penetration rate in 2010 come from the "China Statistical Yearbook", and the added value of China's digital sector comes from the estimated value of Cai and Niu (2021). The results are reported in column (4) of Table 7, and our core findings are confirmed again.

Conclusions and discussion

We empirically test the impact of digital economy development on TFP and its mechanisms. The research shows a U-shaped association between the growth of the digital economy and regional TFP, indicating that when the digital economy reaches a particular degree, it may enhance TFP.

The mediating effect tests indicate that the growth of the digital economy improves TFP by stimulating innovation and promoting entrepreneurship. In addition, we investigate the moderating impacts of the government's entrepreneurship and innovation strategy, the level of marketization, and the degree of judicial patent protection. These conclusions show how to enhance digital economic development's empowering effect on regional TFP.

Based on the empirical data presented in this study, we propose the following recommendations for policy:

First, to help boost TFP, the digital economy should be energetically expanded. According to our empirical results, the IT Productivity Paradox only exists for some time. The growth of the digital economy may damage TFP first, but its further development will eventually improve TFP. On the one hand, the government should provide a good development environment for the digital economy in all aspects and speed up the growth of the digital economy to reach the inflection point of the U-shaped relationship between digital economy development and TFP. On the other hand, the government should minimize the damage to TFP in the early stages of digital economy growth and improve resource allocation efficiency in a variety of ways by further integrating "Internet Plus" and "Mass Entrepreneurship and Innovation", thereby leveraging the digital economy's policy effect to stimulate entrepreneurship and innovation.

Second, the advantages of the Chinese special market system combining "effective government" and "effective market" should be given due attention. Local governments' policy support and guidance can promote the active use of "Internet Plus" in innovation and entrepreneurship in regional economies. The "invisible hand" of the market can also improve enterprises' high-quality creation and entrepreneurship level. According to the calculation of the inflection point value of the U-shaped relationship, within the sample time point, the growth of the digital economy in the western and northeast areas is still on the left side of the inflection point value. Thus, the western and northeastern regions should increase government support and market efficiency.

In particular, we suggest strengthening the central government's leading role in local government policy-making. The entrepreneurship and innovation policies proposed by local governments are more likely to maintain growth rather than promote high-quality economic development. Clear central policy advice is precious in bolstering regional digital economy growth and empowering TFP, promoting local governments' abilities to implement "Internet Plus" to stimulate high-quality innovation and entrepreneurship. Our empirical analysis results show that the launch of the national "Demonstration Bases for Mass Entrepreneurship and Innovation" provides positive effects on the support effect of the local government's entrepreneurship and innovation policy.

Third, the judicial protection of patents should be enhanced. In the digital economy era, the interests of market participants are increasingly complex, and the externalities of innovation and entrepreneurship are more prominent. Patent judicial protection provides an excellent legal system environment for enterprises to innovate independently, reducing the "free rider" problem in the digital era and strengthening the role of digital economy development in promoting innovation.

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References

Andrews, R., Ferry, L., Skelcher, C., & Wegorowski, P. (2020). Corporatization in the public sector: Explaining the growth of local government companies. *Public Administration Review*, *80*(3), 482–493. https://doi.org/10.1111/puar.13052

Antonelli, C., & Quatraro, F. (2010). The effects of biased technological change on total factor productivity: Empirical evidence from a sample of OECD countries. *Journal of Technology Transfer*, *35*(4), 361–383. https://doi.org/10.1007/s10961-009-9134-2

Bulturbayevich, M. B., & Jurayevich, M. B. (2020). The impact of the digital economy on economic growth. *International Journal of Business*, *Law*, *and Education*, *1*(1), 4–7. https://doi.org/10.56442/ijble.v1i1.2

Cai, Y., & Niu, X. (2021). Scale measurement and structural analysis of the value-added of China's digital economy. *Social Sciences in China*, *11*, 4–30.

Chen, B., Jin, X., & Ouyang., D. (2015). Housing prices, resource misallocation and productivity of Chinese industrial enterprises. *The Journal of World Economy*, *38*(4), 77–98.

Chen, M., & Zhang, X. (2020). Analysis on the statistical challenges and accounting ideas of digital economy. *Reform*, *9*, 52–67.

Chen, W. (2022). Can low-carbon development force enterprises to make digital transformation? *Business Strategy and the Environment*, 3189. https://doi.org/10.1002/bse.3189

Chen, W. (2023). Digital economy development, corporate social responsibility and low-carbon innovation. *Corporate Social Responsibility and Environmental Management*, 2443. https://doi.org/10.1002/csr.2443

Chen, W., & Wu, Y. (2022). Does intellectual property protection stimulate digital economy development? *Journal of Applied Economics*, *25*(1), 723–730. https://doi.org/10.1080/15140326.2022.2045846

Chen, W., Zhu, Y., He, Z., & Yang, Y. (2022a). The effect of local government debt on green innovation: Evidence from Chinese listed companies. *Pacific-Basin Finance Journal*, *73*, 101760. https://doi.org/10.1016/j.pacfin.2022.101760

Chen, X., Chen, W., & Lu, K. (2023). Does an imbalance in the population gender ratio affect FinTech innovation? *Technological Forecasting and Social Change*, *188*, 122164. https://doi.org/10.1016/j.techfore.2022.122164

Chen, X., Yan, D., & Chen, W. (2022b). Can the digital economy promote FinTech development? *Growth and Change*, *53*(1), 221–247. https://doi.org/10.1111/grow.12582

Chlosta, S., Patzelt, H., Klein, S. B., & Dormann, C. (2012). Parental role models and the decision to become self-employed: The moderating effect of personality. *Small Business Economics*, *38*(1), 121–138. https://doi.org/10.1007/s11187-010-9270-y

Dai, Z. Q. (2014). Does the intellectual property protection enhance China's export technological sophistication? – An empirical study on panel data of provinces. *Journal of Studies in Science of Science*, *12*, 1846–1858.

David, P. A. (1990). The dynamo and the computer: An historical perspective on the modern productivity paradox. *American Economic Review*, *80*(2), 355–361.

Deng, Y., & Li, L. (2021). Research on influencing factors of patent protection strength from perspective of national innovation system. *Studies in Science of Science*, *39*(07), 1229–1238.

Edwards, J. R., & Lambert, L. S. (2007). Methods for integrating moderation and mediation: A general analytical framework using moderated path analysis. *Psychological Methods*, *12*(1), 1–22. https://doi.org/10.1037/1082-989X.12.1.1

Eisdorfer, A., & Hsu, P. H. (2011). Innovate to survive: The effect of technology competition on corporate bankruptcy. *Financial Management*, *40*(4), 1087–1117. https://doi.org/10.1111/j.1755-053X.2011.01172.x

Fan, J., & Liu, Y. (2018). Comparison of the internationalization-performance relationships between Chinese 500 and Global 500. *Journal of Management Sciences in China*, *21*(6), 110–126.

Fang, J. X. (2006). Evolvement of marketization and improvement of capital allocation efficiency. *Economic Research Journal*, *5*, 50–61.

Gao, J., & Mu, R. (2021). Mass entrepreneurship and mass innovation in China. In X. Fu, B. McKern, & J. Chen (Eds.), *The Oxford Handbook of China Innovation* (pp. 254–271). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190900533.013.15

Han, L., Chen, S., & Liang, L. (2021).Digital economy, innovation environment and urban innovation capabilities. *Science Research Management*, *42*(4), 35–45.

He, N., & Dong, Z. (2020). An empirical study of the quantitative model of patent judicial protection intensity. *Scientific Research Management*, *41*(2), 115–122.

Huang, Q., Yu, Y., & Zhang, S. (2019). Internet development and manufacturing productivity improvement: Internal mechanism and Chinese experience, *China Industrial Economics*, *8*, 5–23.

Jensen, R. (2007). The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector. *The Quarterly Journal of Economics*, *122*(3), 879–924. https://doi.org/10.1162/qjec.122.3.879

Jiang, S., & Sun, Y. (2020). A emprical study on the efct of digital economy on real economy. *Science Research Management*, *41*(5), 32–39.

Jing, W. J., & Sun, B. W. (2019). Digital economy promotes high-quality economic development: A theoretical analysis framework. *Economist*, *2*, 66–73.

Jones, C. I., & Tonetti, C. (2020). Nonrivalry and the economics of data. *American Economic Review*, *110*(9), 2819–2858. https://doi.org/10.1257/aer.20191330

Kumbhakar, S., & Lovell, C. (2000). *Stochastic frontier analysis*. Cambridge University Press. https://doi.org/10.1017/CBO9781139174411

Li, L. (2016). Inverted U-shaped relationship between patent judicial protection and industrial economic development: Measurement and facts. *Studies in Science of Sciences*, *34*(6), 841–849.

Li, W., & Zheng, M. (2016). Is it substantive innovation or strategic innovation? Impact of macroeconomic policies on micro-enterprises' innovation. *Economic Research Journal*, *4*, 60–73.

Li, Z., & Liu, F. (2020). Does entrepreneurship improve the total factor productivity of cities? *Economic Review*, *221*(1), 131–145.

Lin, Z., & Long, X. (2019). Can short-selling threat motivate the innovation of Chinese firms? *The Journal of World Economy*, *42*(9), 126–150.

Liu, C., & Ma, Q. (2020). Research on the influence of network infrastructure construction on total factor productivity growth: A quasi-natural experiment of "Broadband China" pilot policy. *Chinese Journal of Population Science*, *3*, 75–88+127–128.

Liu, H., Fu, L., Li, T., & Sun, B. (2019a). The summary of the 1st forum for internet and digital economy. *Economic Research Journal*, *54*(3), 204–208.

Liu, J., Yang, Y., & Zhang, S. (2020). Research on the measurement and driving factors of China's digital economy. *Shanghai Journal of Economics*, *6*, 81–96.

Liu, J., Zhang, Y., & Wang, Q. (2021). Escaping "middle-income trap": Based on the test of convergence club and the cross-country analysis on the TFP promotion path. *Zhejiang Social Sciences*, *11*, 12–26+156.

Liu, S., Zhang, S., & Zhu, H. (2019b). Study on the measurement and high-quality economy development effect of national innovation driving force. *The Journal of Quantitative & Technical Economics*, *36*(4), 3–23.

Lozada, N., Arias-Pérez, J., & Perdomo-Charry, G. (2019). Big data analytics capability and co-innovation: An empirical study. *Heliyon*, *5*(10), e02541. https://doi.org/10.1016/j.heliyon.2019.e02541

Ma, X. (2020). The change of consumption in the digital economy: Trends, characteristics, mechanisms and model. *Finance & Economics*, *1*, 120–132.

Mao, H., Chen, D., & Yin, Z. (2019). A theoretical inquiry and empirical investigation on the way towards perfection of the "dual track" patent protection system in China. *China Soft Science*, *9*, 1–17.

Meng, Q. (2021). Digital economy and high-quality employment: Theory and empirical research. *Journal of Social Sciences*, *2*, 47–58.

Mihardjo, L.W., Sasmoko, S., Alamsyah, F., & Elidjen, E. (2019). The influence of digital leadership on innovation management based on dynamic capability: Market orientation as a moderator. *Management Science Letters*, *9*(7), 1059–1070. https://doi.org/10.5267/j.msl.2019.3.018

Mueller, S., Bakhirev, A., Böhm, M., Schröer, M., Krcmar, H., & Welpe, I. (2017). Measuring and mapping the emergence of the digital economy: A comparison of the market capitalization in selected countries. *Digital Policy, Regulation and Governance*, *19*(5), 367–382. https://doi.org/10.1108/DPRG-01-2017-0001

Nicoletti, G., von Rueden, C., & Andrews, D. (2020). Digital technology diffusion: A matter of capabilities, incentives or both? *European Economic Review*, *128*, 103513. https://doi.org/10.1016/j.euroecorev.2020.103513

Niyazbekova, S. U., Moldashbayeva, L. P., Zhumatayeva, B. A., Mezentseva, T. M., & Shirshova, L. V. (2021). Digital economy development as an important factor for the country's economic growth. In E. G. Popkova, V. N. Ostrovskaya, & A. V. Bogoviz (Eds.), *Studies in systems, decision and control: Vol. 314. Socio-economic systems: Paradigms for the future* (pp. 361–366). Springer, Cham. https://doi.org/10.1007/978-3-030-56433-9_38

Nunn, N., & Qian, N. (2014). US food aid and civil conflict. *American Economic Review*, *104*(6), 1630–1666. https://doi.org/10.1257/aer.104.6.1630

Organisation for Economic Co-operation and Development. (2014). *Measuring the digital economy: A new perspective*. OECD Publishing.

Research Group on China's Economic Growth. (2015). The new factor-suppy theory, system and choices for breakthrough economic growth slowdow. *Economic Research Journal*, *50*(11), 4–19.

Sahut, J. M., Iandoli, L., & Teulon, F. (2021). The age of digital entrepreneurship. *Small Business Economics*, *56*(3), 1159–1169. https://doi.org/10.1007/s11187-019-00260-8

Shan, H. J. (2008). Reestimating the capital stock of China: 1952–2006. *The Journal of Quantitative & Technical Economics*, *10*(1), 17–31.

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological Methodology*, *13*, 290–312. https://doi.org/10.2307/270723

Sutherland, E. (2018, July 16–20). Trends in regulating the global digital economy. In *Proceedings of the 4th Annual Competition and Economic Regulation Conference*, Johannesburg, South Africa. https://doi.org/10.2139/ssrn.3216772

Wang, J., & Lei, P. (2021). The tournament of Chinese environmental protection: Strong or weak competition? *Ecological Economics*, *181*, 106888. https://doi.org/10.1016/j.ecolecon.2020.106888

Wang, M., & Zhang, X. (2020). Research on the impact mechanism of technological change on the production process in the digital economy era. *Economist*, *1*, 152–158.

Wang, S., & Du, E. (2021). Can technological entrepreneurship promote economic growth? Evidence from the perspective of national high-tech zones. *Study & Exploration*, *313*(8), 130–138.

Wang, X., Fan, G., & Yu, J. (2019). *China provincial marketization index report 2018*. Social Science Literature Publishing House.

Wen, H., Zhong, Q., & Lee, C. C. (2022). Digitalization, competition strategy and corporate innovation: Evidence from Chinese manufacturing listed companies. *International Review of Financial Analysis*, *82*, 102166. https://doi.org/10.1016/j.irfa.2022.102166

Wen, J., Yan, Z., & Cheng, Y. (2019). Digital economy and upgrading regional innovation capacity. *Inquiry into Economic Issues*, *11*, 112–124.

Wu, Y., & Zhang, Y. (2021). Digital economic and regional innovation: From the perspective of financing and intellectual property protection. *South China Journal of Economics*, *9*, 36–51.

Xie, R., & Teo, T. S. H. (2022). Green technology innovation, environmental externality, and the cleaner upgrading of industrial structure in China – Considering the moderating effect of environmental regulation. *Technological Forecasting and Social Change*, *184*, 122020. https://doi.org/10.1016/j.techfore.2022.122020

Xu, D., & Chen, S. (2015). Research on systemic financial risk measurement based on financial stress index. *Economic Perspectives*, *4*, 69–78.

Yalcin, N., & Ünlü, U. (2018). A multi-criteria performance analysis of initial public offering (IPO) firms using CRITIC and VIKOR methods. *Technological and Economic Development of Economy*, *24*(2), 534–560. https://doi.org/10.3846/20294913.2016.1213201

Yang, H. (2020). How artificial intelligence "empowers" high-quality development: Enlightenment in the ICT era and countermeasures in the AI era. *Journal of Humanities*, *5*, 31–42.

Ye, X., & Liu, J. (2020). The impact of government support and market-oriented reforms on manufacturing technology progress. *Economic Research Journal*, *55*(5), 83–98.

Yin, Z., Gong, X., Guo, P., & Wu, T. (2019). What drives entrepreneurship in digital economy? Evidence from China. *Economic Modeling*, *82*, 66–73. https://doi.org/10.1016/j.econmod.2019.09.026

Yu, H., Xu, L., & Chen, B. (2010). The control right of ultimate controlling shareholder and overinvestment of free cash flow. *Economic Research Journal*, *8*, 103–114.

Yu, Y. (2017). Estimation of total factor productivity in China from the perspective of heterogeneity: 1978–2012. *China Economic Quarterly*, *16*(3), 1051–1072.

Yu, Y., & Li, Q. (2019). Urban housing prices and total factor productivity: "Crowding effect" and "screening effect". *Finance & Trade Economics*, *40*(1), 128–143.

Yuan, L., & Ouyang, Y. (2018). The key of the large developing countries to promote total factor productivity. *China Industrial Economics*, *6*, 43–61.

Zhang, H. (2018). A preliminary study on the theory and approach of constructing a modernized economic system. *Journal of Peking University* (*Philosophy and Social Sciences*), *55*(1), 105–116.

Zhang, Q., & Yu, J. (2020). Input digitization and climbing global value chain: Micro evidence from Chinese manufacturing enterprises. *Economic Review*, *6*, 72–89.

Zhang, X. (2019). Research on the evolution of innovation model under the condition of digital economy. *Economist*, *7*, 32–39.

Zhang, X., Wang, G., Zhang, J., & He, Z. (2019). Digital economy, financial inclusion, and inclusive growth. *Economic Research Journal*, *54*(8), 71–86.

Zhao, K., Wu, W., & Ye, J. (2022). The impact of "Mass Entrepreneurship and Innovation" policy on SMEs' innovation: Using quasi natural experiments. *Bulletin of Economic Research*, 12359. https://doi.org/10.1111/boer.12359

Zhao, T., Zhang, Z., & Liang, S. (2020). Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. *Journal of Management World*, *36*(10), 65–76.

Zhuang, J., Wang, H., & Zhang, W. (2020). Does strengthening the juridical protection of Intellectual property contribute to corporate innovation? Evidences from the establishment of courts for intellectual property right Cases. *Contemporary Finance & Economics*, *9*, 16–27.