

Digital Transformation and Enterprise Total Factor Productivity - Empirical Evidence from Chinese Listed Companies

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ABSTRACT

Accelerating the promotion of digital transformation of enterprises is the only way to achieve high-quality economic development in China. This paper uses the method of machine learning to measure the digitalization level of enterprises, and uses the A - share data of listed companies from 2011 to 2018 to examine the impact of digital transformation on the total factor productivity of enterprises and its mechanism. The study found that digital transformation significantly improved the total factor productivity of enterprises, and after passing instrumental variables and a series of robustness tests, the basic conclusions remained robust. The results of the mechanism analysis show that digital transformation mainly improves the total factor productivity of enterprises through the effect of cost saving and technological innovation. The research in this paper not only reveals the impact mechanism of digital transformation on the total factor productivity of enterprises, but also provides micro-evidence for the integrated development of the digital economy and the real economy. The research conclusions have important policies for the formulation of digitalization-related policies and high-quality economic development revelation.

Keywords: *Digital transformation, Total factor productivity, Cost saving effect, Technological innovation effect.*

1. INTRODUCTION

Since the beginning of the new century, the widespread application of a new generation of digital technologies based on the Internet has played an important role in the transformation and upgrading of China's economic structure. According to the report "White Paper on the Development of China's Digital Economy (2021)", the scale of China's digital economy in 2020 will reach 39.2 trillion yuan, accounting for more than one-third of GDP. At the same time, the "14th Five-Year Plan" clearly pointed out that promoting the deep integration of digital technology and the real economy, enabling the transformation and upgrading of traditional industries, and strengthening the new engine of economic development, further highlighted the importance of digital transformation in the stage of high-quality economic development. However, the fact that cannot be ignored is that, on the one hand, the digital transformation of the real economy is not achieved overnight. Although many companies embrace digital technology, they have not met

expectations (Chen Dongmei et al., 2020). As the micro-subject of digital transformation, the digital transformation of enterprises has become an innovative sign of enterprises moving from traditional production systems to digital systems. On the other hand, the quality of China's economic growth has been questioned by some scholars. The reason is that the total factor productivity of China's economy is low, especially since it entered the new normal, the traditional factor-driven growth model has been underpowered (Tian Youchun et al., 2021). It can be seen that improving total factor productivity is still a practical problem that needs to be solved urgently. In this context, whether digital transformation can become a growth driver in the new development stage and thus promote high-quality economic development has become an important research topic.

There is no doubt that digitalization as a new development model will affect all aspects of the economic system. At the same time, the economic effects of digital transformation have received extensive attention from the academic community, and related

research can be summarized from high-quality economic development (Zhao Tao et al., 2020), inclusive growth (Zhang Xun et al., 2019), wage gap (Acemoglu & Restrepo, 2017) Enterprise division of labor (Yuan Chun et al., 2021). Compared with the existing literature, the possible innovations of this paper are as follows. First, in terms of research methods, this paper uses machine learning to measure the level of digitalization of enterprises, which is a useful supplement to the existing research at the micro level. Second, in terms of research mechanism, this paper mainly analyzes how the digital transformation of enterprises affects the total factor productivity of enterprises from the perspective of cost saving effect and technological innovation effect, and enriches the impact mechanism of digital transformation on the total factor productivity of enterprises. Based on this, in-depth discussion of the impact of digital transformation on the total factor productivity of enterprises and the theoretical mechanism behind it is of great significance for high-quality economic development.

2. THE RESEARCH HYPOTHESIS

This paper discusses the theoretical mechanism of how digital transformation affects the total factor productivity of enterprises from the perspectives of cost saving effect and technological innovation effect. The specific theoretical analysis is as follows:

(1) Digital transformation can improve the total factor productivity of enterprises through cost saving effects. In the process of rapid development of the digital economy, the trend of enterprise disintermediation is obvious (Tan Songtao et al., 2016). Specifically, on the one hand, enterprises can empower more digital technologies in production, sales, services, etc, and affiliated enterprises can form an effective connection, sharing, and open ecosystem, which can reduce the cost of information exchange to a certain extent. On the other hand, the extensive application of digital technology has changed the traditional way of information technology interconnection, and then efficiently integrated information flow, technology flow, capital flow and material flow, enabling enterprises to develop collaboratively through digital platforms and reduce business operating costs (Xiao Xu and Qi Yudong, 2019). In addition, digital transformation can optimize and upgrade traditional production tools and improve production efficiency.

(2) Digital transformation improves the total factor productivity of enterprises through the effect of technological innovation. First, digital transformation can improve the external financing environment of enterprises through the allocation effect of innovative elements. From the perspective of government-enterprise interaction, the establishment of digital platforms reduces the problem of information

asymmetry between the two parties, and the government can identify substantive innovative enterprises through digital technology and alleviate the mismatch of innovation subsidies. Second, digital transformation has changed the way companies innovate. Digital technology can build an open digital innovation system, which helps to transform the enterprise innovation model from a traditional closed model to an open innovation model with extensive participation of all departments and even the entire industry chain and consumers, so as to achieve integrated and networked innovation and improve the innovation ability of enterprises (Du Chuansong and Zhang Yuan, 2021). Finally, digital transformation is conducive to enterprises to exert the technology spillover effect, improve the level of innovation of enterprises, and then improve the total factor productivity of enterprises.

Therefore, from a comprehensive perspective, digital transformation can promote technological innovation by improving the external financing environment of enterprises, innovative models, and exerting technological spillover effects, thereby improving the total factor productivity of enterprises.

Based on the above analysis, this paper proposes the following hypotheses:

Hypothesis 1: Digital transformation can improve the total factor productivity of enterprises.

Hypothesis 2: Digital transformation can improve the total factor productivity of enterprises through cost-saving effects.

Hypothesis 3: Digital transformation can improve the total factor productivity of enterprises through the effect of technological innovation.

3. RESEARCH DESIGN AND DATA

3.1. Model setting

The main purpose of this study is to scientifically evaluate the impact of digital transformation on the total factor productivity of enterprises. According to the previous theory, this paper sets the following benchmark regression model:

$$TFP_{it} = \beta_0 + \beta_1 digital_{it} + \sum controls + \sum province + \sum industry + \sum firm + \sum year + \varepsilon_{it} \quad (1)$$

Among them, TFP_{it} represents the total factor productivity of the enterprise, the benchmark regression is measured by the OP method, and the LP method is used for the robustness test; $digital_{it}$ is the core explanatory variable of this paper, indicating the digitalization level of the enterprise. $\sum controls$ is Enterprise size (size), enterprise age (age), asset-liability ratio (lev), cash holding ratio (cash), return on total assets (roa), asset intensity (capital), market-to-book ratio (mb), economic Development level (gdp), Internet

development level (Internet) and marketization level(market).provincial fixed effects (\sum province), industry fixed effects (\sum industry), firm fixed effects (\sum firm), and year fixed effects (\sum year) were added.

3.2. Variable measurement and data description

3.2.1. Core explanatory variable-enterprise digitalization level

This paper mainly refers to the method of Yuan Chun et al. (2021). First, a vocabulary of professional terminology about enterprise digitization is constructed by using python word segmentation technology. Second, analyze the text of the annual report of the listed company, expand the vocabulary of enterprise digitalization terminology to the "jieba" Chinese word segmentation library of the python software package, and use the method of machine learning to analyze the text of the annual report of the listed company, and finally get the relevant enterprise digitalization. The frequency of appearance of technical terms in the annual report. Finally, by summarizing the frequency of each listed company's digital terminology appearing in the annual report, and taking into account the difference in the text length of the "Management Discussion and Analysis" section of each company's annual report, this paper summarizes the appearance of each company's digital terminology. The ratio of the frequency to the length of each company's annual report "Management Discussion and Analysis" and multiplied by 100 as a proxy variable for the level of digitization of the firm.

3.2.2. Data source and description

The sample of this paper is China's Shanghai and Shenzhen A-share listed companies, and the time span is 2011-2018. Relevant data comes from the CSMAR database Wind database, regional data mainly comes from the "China Urban Statistical Yearbook" over the years, and the marketization level of the province where the enterprise is located comes from Wang Xiaolu et al. (2019).

4. EMPIRICAL RESULTS AND ANALYSIS

4.1. Benchmark regression analysis

Table 1 reports empirical results on the impact of digital transformation on firm TFP. Each of these columns includes firm, industry, province, and year fixed effects. Column (2), on this basis, the control variables at the enterprise and regional levels are added, which are all in this paper at the same time. The results show that the coefficients of the core explanatory variables are all significantly positive at the 5% level, indicating that the higher the level of digitalization of

enterprises, the higher the level of total factor productivity of enterprises. Specifically, for every 1 percentage point increase in the level of digitalization of enterprises, the total factor productivity of enterprises will increase by 0.0533%, indicating that Hypothesis 1 is established.

Table 1. Benchmark regression results

variable	(1) TFP_OP	(2) TFP_OP
digital	0.2455*** (6.1169)	0.0533** (2.0596)
control variable	NO	YES
fixed effects	YES	YES
sample size	11955	11955
adjustedR ²	0.102	0.517

Note: The t-statistics clustered to the firm level in parentheses, *, ** and *** are significant at the 10%, 5% and 1% levels, respectively.

4.2. Endogenous problems

Although the benchmark results show that enterprise digitization can significantly improve the total factor productivity of enterprises, there may be endogeneity problems in the regression results. First, there may be interference of missing variables on the estimated results. The method adopted in this paper is to control the variables at the two levels of enterprises and regions at the same time, and control the fixed effects of enterprises, industries, provinces and years at the same time, and further eliminate the interference of macro-level variables on the results. The second is reverse causality. Enterprises with higher total factor productivity have certain advantages in technology, management, and capital, and are more likely to choose digital transformation. The method adopted in this paper uses instrumental variables to test. The first instrumental variable is based on the practice of Yuan Chun et al. (2021), taking the interaction between the number of post and telecommunications in each city in 1984 and the number of Internet users in the country with a lag period as the first instrumental variable of this paper.

In addition, this paper further refers to the research of Guo Jiatang and Luo Pinliang (2016), using the Internet penetration rate of the province from 2001 to 2009 as the second instrument variable of this paper. The empirical results in Table 2 show that the coefficient of the core explanatory variable digital is significantly positive, and the problem of insufficient identification of instrumental variables and weak instrumental variables is rejected, indicating that the results of this paper are robust.

Table 2. Endogenous test results

variable	(1) TFP_OP	(2) TFP_OP
digital	0.0541** (2.0794)	0.0533** (2.0596)
control variable	YES	YES
fixed effects	YES	YES
sample size	11955	11955
Kleibergen-Paap rk LM statistic	8.9765***	10.2680***
Cragg-Donald Wald F statistic	34.1580 [20.80]	35.2790 [25.87]

4.3. Robustness test

To further illustrate the robustness of our results, we use four methods for testing. The first is to change the measurement method of the explained variables, specifically using the LP method to measure the total factor productivity of enterprises. The second is to exclude samples with a digital level of 0, in order to eliminate the interference of strategic behaviors of companies' digital disclosure. The third is to exclude samples that exaggeratedly disclose the digital level of enterprises, and refer to the practice of Yuan Chun et al. (2021). The fourth is to exclude companies that have been punished by the CSRC or the stock exchange during the sample period. Table 3 shows the results of the robustness test of the above four methods. The results show that the coefficient of the core explanatory variable digital is significantly positive, indicating the robustness of the empirical results in this paper.

Table 3. Robustness test results

variable	(1) TFP_LP	(2) TFP_OP	(3) TFP_OP	(4) TFP
digital	0.0531** (2.1341)	0.0635** (2.4380)	0.0942** (2.4956)	0.0671** (2.3141)
control variable	YES	YES	YES	YES
fixed effects	YES	YES	YES	YES
sample size	11955	11955	11955	119
adjustedR ²	0.633	0.524	0.485	0.5

4.4. Mechanism analysis

Based on the previous theoretical analysis, this paper uses the interaction term model to test, and the specific results are shown in Table 4.

(1) Cost saving effect. This paper draws on the method of Yuan Chun et al. (2021) and uses two methods to measure the cost saving effect of enterprises. The first is to use enterprise management expenses to measure. Specifically, this paper takes the proportion of enterprise management expenses and operating income as the standard. When the ratio is lower than the median, the dummy variable cost1 is set to 1, otherwise it is 0. The second is to use the company's sales growth rate to measure. Specifically, according to the theory of enterprise life, enterprises in the start-up stage have a single organizational structure and relatively low management costs; while when the enterprise is in a mature or declining stage, the organizational structure is

relatively bloated, and enterprise management costs are often high. Therefore, this paper uses the growth rate of sales revenue to identify the growth period of the enterprise. When the sales growth rate is higher than the median, the dummy variable cost2 is set to 1, otherwise it is 0. (2) The technological innovation effect uses the total number of patent authorizations and takes the logarithm to record it patent1 and the number of effective invention patents and takes the logarithm to record it patent2 to measure the technological innovation effect of enterprises.

According to the results of the mechanism analysis in Table 4, the coefficients of either yes digital*cost1 or no digital*cost2 are significantly positive, indicating that the lower the management cost of the enterprise, the more obvious the effect of digitalization on the total factor productivity of the enterprise, which is consistent with the theoretical analysis in this paper. In the same way, the coefficients of digital*patent1 or digital*patent2 are all significantly positive, indicating that the higher the level of technological innovation of the enterprise, the more obvious the effect of digitalization on the total factor productivity of the enterprise, which is consistent with the theoretical analysis in this paper.

Table 4. Mechanism analysis results

variable	(1) TFP_OP	(2) TFP_OP	(3) TFP_OP	(4) TFP_OP
digital * cost1	0.0384*** (2.6422)			
cost1	0.0245** (0.9802)			
digital * cost2		0.0494** (2.8534)		
cost2		0.0145** (2.4560)		
digital * patent1			0.0654*** (1.6456)	
patent1			0.2450 *** (1.8650)	
digital * patent2				0.0794*** (1.8690)
patent2				0.0452*** (2.4560)
digital	0.0525** (2.1204)	0.0504** (1.9986)	0.0505** (2.0264)	0.0546** (2.5640)
control variable	YES	YES	YES	YES
fixed effects	YES	YES	YES	YES
sample size	11955	11955	11,700	9809
adjustedR ²	0.547	0.564	0.560	0.482

5. CONCLUSIONS

In the era of digital economy, promoting the digital transformation of enterprises is the only way to achieve high-quality economic development in China. This paper measures the level of digitalization of enterprises by means of machine learning, and uses the A - share data of listed companies from 2011 to 2018 to examine the impact of digital transformation on the total factor productivity of enterprises and its mechanism. The main

conclusions are as follows: First, digital transformation has improved the total factor productivity of enterprises, and for every 1 % increase in the level of digitalization of enterprises, the total factor productivity of enterprises will increase by 0.0533 %. After instrumental variables and a series of robustness tests, the basic conclusions are still stable. Second, digital transformation mainly improves the total factor productivity of enterprises through the effect of cost saving and technological innovation.

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