How Digital Transformation of Enterprises Can Improve Labor Productivity: Evidence from Chinese-Listed Companies

Xuan Zhang(✉)

School of Marxism, Guangdong University of Technology, Guangzhou, Guangdong, China
zhangxuan-400@foxmail.com

Abstract. This paper examines the impact of digital transformation on labor productivity as firms drive digital transformation through the adoption of digital information technologies such as artificial intelligence, cloud computing, and big data, as well as the intermediate mechanisms and heterogeneity of this relationship. The results show that digital transformation improves firms' labor productivity, and confirming that increased capital intensity and innovation investment are intermediate mechanisms for achieving this relationship, but that regional differences in development significantly weaken the positive impact of digital transformation on labor productivity. The results also show that the internal skill structure of employees and the external human capital environment have a significant impact on labor productivity when firms are actively engaged in digital transformation. We provide effective strategies for digital transformation and performance improvement of firms from a labor productivity perspective.

Keywords: Digital Information Technology · Digital Transformation · Productivity · Laborers · Capital Intensity · Innovation

1 Introduction

There has been a constant focus on the relationship between technological development and work efficiency. Information technologies such as artificial intelligence, cloud computing, blockchain, and big data are rapidly emerging as core drivers of innovation development and efficiency change in the digital economy, and companies are looking to build digital governance systems through the introduction of digital information technologies to achieve improved performance and productivity. Available studies point out that the widespread use of digital information technologies such as AI, blockchain, cloud, and data analytics has improved companies' ability to innovate [1, 2], optimize organizational structures [3, 4], reduce operating costs [5, 6], improved input-output efficiency [7, 8] and enhanced matching and flow of information [9]. These governance benefits provide the foundation for improving business efficiency. Akter [1], Ferschli [7], and Liu [8] further point out that the digital transformation of digital information technology-led firms is effective in improving productivity. However, scholars such as

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Acemoglu [10], Autor [11], and Zhang [12], who focus on the relationship between digital technology and labor competition, argue that the efficiency of workers in the digital era will be affected by technology and will have a negative effect on firm labor productivity. In addition, evidence from Cai [14] and Kawashima [15] also suggests that the digitization of firms may increase labor mobility and thus harm labor productivity.

In conclusion, the core of the above debate lies in the effect of digital transformation of firms on labor efficiency and workers, which is what this paper hopes to address. Song [16] and Borovskaya [17] et al. initially discuss the positive effect of the digitalization process on labor productivity, however, few existing studies examine the effect of digital transformation on firms from the perspective of labor productivity fluctuations, which is what firms achieve efficiency growth that cannot be ignored. The purpose of this paper is to analyze the effect of digital transformation on labor productivity and its intermediate mechanisms using data at the level of listed firms. The rest of this paper is organized as follows. Section 2 derives the hypothesis that digital transformation of firms affects labor productivity by summarizing the existing literature; Sect. 3 explains the model and data; Sect. 4 reports the results that digital transformation enhances the labor productivity of firms. Specific mechanism tests and robustness analysis are also provided; Sect. 5 concludes the results.

The contributions of this paper. First, we analyze the relationship between digital transformation and enterprise efficiency from the perspective of labor productivity, which provides new theoretical support for the study of digital transformation and enterprise labor efficiency. Second, we identify the intermediate mechanism of digital transformation to improve labor productivity by enhancing capital intensity and innovation input and provide clear strategic suggestions for enterprises to realize digital transformation. Third, we conduct a heterogeneity analysis based on the differences in enterprises' internal governance and external regional conditions, and draw targeted conclusions for enterprises facing different development environments.

2 Literature Review and Hypothesis

The application of digital technologies significantly improves the overall efficiency of the firm. First, the introduction of digital information technology helps to improve the efficiency of matching information and production factors within the enterprise [16, 18], thus eliminating information asymmetry [9] and effectively achieving the optimal allocation of resources. Second, digital transformation contributes to the efficiency of enterprise innovation [1, 7, 8], and the process by which enterprises upgrade technology, optimize processes and update products19, and thus achieving changes in labor production efficiency. Third, the information marginal effect of enterprise digital transformation. The application of technologies such as big data and cloud computing in enterprise information analysis provides richer information and data support for enterprise decision making and investment, and these reduce the risk and time of decision making [2], and thus make more complex and rational strategy models. In conclusion,

digital transformation enhances the efficiency of resource allocation, promotes technological innovation and optimizes management processes, thus contributing to labor productivity.

- H1: Digital transformation of enterprises enhances labor productivity.

An increase in capital intensity will have a positive impact on the productivity of the firm [20–22]. In the digital economy era, companies will transform into capital-intensive and technology-intensive enterprises by upgrading their technological capital [13]. In fact, Zhou's study further confirms that capital intensity significantly positively affects firm productivity [20], with capital-intensive firms exhibiting more efficiency and technological advantages. At the same time, the effect of capital and technology to achieve efficiency growth by supplanting labor cannot be neglected. Acemoglu [10, 24], Michaels [23], and Zhang [12] argue that digital information technology makes the risk of employment substitution more severe for low- and medium-skilled workers. Digital transformation implies that firms invest more technological capital in the firm's production process, and capital becomes more abundant relative to labor, thus replacing repetitive, low-skill levels and inefficient simple labor processes [11, 23, 24]. The skill structure of the company's employees increases among the high-skilled workers and decreases in the low- and medium-skilled workers, i.e., technological capital the increase in production efficiency is achieved by replacing human capital [21, 22]. In short, changes in capital intensity and employee skill bias will cause an increase in overall labor productivity [21].

- H2: Digital transformation enhances labor productivity by improving the capital intensity of firms.

Digital transformation strengthens companies' ability to innovate [18]. On the one hand, the efficient sharing of innovation factors. The application of digital information technology accelerates the process of informatization and digitization of enterprises, which makes the sharing and integration of internal and external information resources efficient [3, 14], thus accelerating the flow and integration of innovation factors such as knowledge and technology among enterprises and enhancing their technological innovation capabilities. On the other hand, the innovation model is optimized. Digital transformation enhances firms' motivation to innovate [3], reduces the risk of innovation investment [25], and enhances the foresight of firms' innovation activities [9], which leads to a significant increase in the marginal benefits of innovation activities.

- H3: Digital transformation improves labor productivity by increasing firms' innovation inputs.

3 Models and Data

3.1 Models

To provide further credible evidence on the process by which digital transformation of firms affects labor productivity. This study built the following empirical model using individual and time fixed effects, which draws on the labor productivity analysis model

constructed by Song [16] and Chen [21].

$$\begin{aligned} &\text{Lproductivity}_{i,t} = \beta_0 + \beta_1 \text{Transformation}_{i,t} \\ &+\beta_2 Controls_{i,t} + P_i + I_i + \varepsilon_{i,t} \end{aligned} \tag{1}$$

In Eq. (1), Lproductivty is the explanatory variable to measure the labor productivity of firm i in year t, borrowed from scholars such as Bender [26] and Kale [27] who construct the labor productivity of firms using the output per unit of labor of the firm (in terms of business income per capita). Transformation is the explanatory variable to measures the degree of digital transformation of firm i in year t, obtained by word frequency statistics based on keywords about the firm's digital technology in the firm's annual report [16, 19]. Controls are a set of variables that may affect the efficiency and labor productivity of the firm. There are two main dimensions, the first of which includes: gearing (LEV); fixed asset intensity (PPE); market-to-book ratio (BM); cash ratio (CASH); and return on assets (ROA). The second dimension controls for the overall economic development of the city in which the firm is located by including the GDP growth rate (CGDP) of the city in which the firm is located to reduce estimation bias. Also, the model controls for province fixed effects Pi and industry fixed effects Ii to reduce estimation bias caused by unobservable reasons such as regional development differences and industry differences.

The above model can effectively test the impact of digital transformation on the labor productivity of enterprises, and if digital transformation helps to improve the labor productivity of enterprises, it will appear that β1 is significantly positive. However, this cannot provide clear evidence of the intermediate mechanism for the effect between digital transformation and firm labor productivity to occur, and this study further constructs the following empirical model to clarify the intermediate mechanism [14, 16].

$$\begin{aligned} &\text{Lproductivity}_{i,t} = \beta_0 + \beta_1 \text{Transformation}_{i,t} \\ &+ \beta_2 Controls_{i,t} + P_i + I_i + \varepsilon_{i,t} \end{aligned} \tag{2}$$

$$\begin{aligned} &Mechanism_{i,t} = \beta_0 + \beta_1 \text{Transformation}_{i,t} \\ &+ \beta_2 Controls_{i,t} + P_i + I_i + \varepsilon_{i,t} \end{aligned} \tag{3}$$

$$\begin{aligned} &\text{Lproductivity}_{i,t} = \beta_0 + \beta_1 \text{Transformation}_{i,t} \\ &+ \beta_2 Mechanism_{i,t} + \beta_3 Controls_{i,t} + P_i + I_i + \varepsilon_{i,t} \end{aligned} \tag{4}$$

Among them, Mechanism is the intermediate mechanism to be tested in this paper, which is mainly discussed in terms of capital intensity (CI) and technological innovation investment (R&D), and the proxy variables are the capital-labor ratio of firms and the total amount of R&D expenditure of firms, respectively.

3.2 Data

The data for this study are mainly obtained from the databases of CSMAR, WIND, and the key word statistics of enterprise digital information technology in the annual report of listed companies, as well as the China Urban Statistical Yearbook. We have carried

out some treatments on the data. (1) Excluding the sample of companies in the financial industry, excluding the sample of companies with risk warning boards or abnormal status; meanwhile, some of the samples of companies with missing or unreasonable data are not included in the study, and this way will make the research conclusions more rigorous and realistic. (2) In order to solve the influence of heteroskedasticity and serial correlation problems on the conclusions, robust standard errors are used for the regression coefficients in this study. (3) The natural logarithm treatment was used for all variables. Finally, we obtained data for a sample of 9701 listed companies from continuing operations in China during 2010–2018.

4 Results and Discussion

4.1 Digital Transformation and Labor Productivity

The results in Table 1 report the effect of digital transformation on the labor productivity of firms. Hypothesis 1 claims that digital transformation and labor productivity of firms have a positive correlation. As can be seen from Table 1, there is a positive correlation between digital transformation and labor productivity of enterprises (M1, $\beta = 0.0902$, $P < 0.01$); and after further adding firm-level and city-level control variables, the main effects of digital transformation on labor productivity of enterprises are statistically significant (M2, $\beta = 0.0621$, $P < 0.01$; M3, $\beta = 0.0587$, $P < 0.01$), the digital transformation is effective in improving the labor productivity of firms. In terms of economic significance, the regression coefficient of Transformation in M3 is 0.0587, which means that for every 1% increase in the degree of digital transformation of a firm, the labor productivity of that firm will increase by 0.0587%. Therefore, hypothesis 1 is supported.

We use explanatory variable substitution and instrumental variable techniques to test robustness. The new labor productivity variable (Rlproductivity) is constructed by replacing the original calculation method with the per capita corporate income after excluding the abnormal business income of the firm as a proxy, drawing on the treatment of Cai et al. [14]. The results in Table1 show the regression results using Rlproductivity. The regression coefficient of 0.0650 for replacing the core explanatory variable (Rlproductivity) still passes the test at the 1% significance level (M4, $\beta = 0.0650$, $p < 0.01$) and is not significantly different from the coefficient of 0.0587 in the baseline regression results (M3, $\beta = 0.0587$, $P < 0.01$). We use the number of cell phones per capita (Telephones) as an instrumental variable to overcome some of the endogeneity issues. As an important tool for employees to participate in digital transformation and the digital economy, cell phones can have a significant impact on the digital transformation of enterprises. At the same time, the number of mobile phones does not directly cause changes in the labor productivity of enterprises, which meets the requirements of relevance and exogeneity of the instrumental variable. Table 1 shows the results of using instrumental variables, and digital transformation continues to promote the labor productivity of enterprises after using instrumental variables (M5, $\beta = 0.2884$, $p < 0.05$). Therefore, the results of digital transformation to improve the labor productivity of enterprises are robust and reliable.

Table 1. The impact of enterprise digital transformation on labor productivity

	Lproductivity/Rlproductivity				
	M1	***M2***	***M3***	***M4***	***M5***
Transformation	0.0902***	0.0621***	0.0587***	0.0650***	0.2884**
	(0.0085)	(0.0085)	(0.0086)	(0.0083)	(0.1183)
Fixed Effect	YES	YES	YES	YES	YES
Controls	NO	YES	YES	YES	YES
R-square	0.0318	0.1038	0.1048	0.1100	0.0128
N.(obs)	9701	9701	9655	9643	9611

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.2 Intermediate Mechanism: Capital Intensity (CI) and Innovation Input (R&D)

Digital transformation has been effective in improving firms' labor productivity, but the intermediate mechanisms that influence this effect have not been well tested or explained. It is worth noting that firms are moving toward capital-intensive and technology-intensive in the digital era. On the one hand, digital transformation enhances the efficiency of enterprise resource allocation, and enterprises use more technological means and machines, etc., to replace laborers [10, 11, 13, 20, 24], thus achieving capital deepening; on the other hand, the digitization of production factors expands the boundaries of allocable factors possessed by transforming enterprises, and also increases the factor allocation efficiency of the technical and organizational basis, thus accelerating the technological innovation process of firms [1, 2, 8]. Therefore, this study constructs two mediating variables, capital intensity (CI) and innovation input (R&D), for analysis.

Hypothesis 2 posits that capital intensity mediates the relationship between digital transformation and firm labor productivity. As shown in Table 2, there is a significant positive relationship between digital transformation (Transformation) and capital intensity (CI) (M6, $\beta = 0.0741$, $p < 0.01$). Adding capital intensity (CI) to Eq. (4), the regression coefficient of digital transformation is significantly reduced compared to the baseline regression (M3, $\beta = 0.0587$, $P < 0.01$; M7, $\beta = 0.0357$, $P < 0.01$), while the regression coefficient of capital intensity (CI) is significantly positive (M7, $\beta = 0.3068$, $P < 0.01$), which indicates that the capital intensity of the firm has a positive mediating effect. At the level of firm management, adjusting the allocation efficiency and the proportion of technological capital factors among the firm's production factors helps the firm to achieve a rapid improvement in labor productivity in the digital transformation, which in turn strengthens its market competitiveness and advantage. Thus, firm capital intensity mediates the effect of digital transformation on labor productivity, which supports hypothesis 2.

Hypothesis 3 assumes that innovation inputs mediate the relationship between digital transformation and firm labor productivity. Table 2 shows that there is a significant positive relationship between digital transformation (Transformation) and innovation investment (R&D) (M8, $\beta = 0.2089$, $P < 0.01$). Further tests demonstrated a positive

Table 2. Mediation effect: capital intensity (CI) and innovation inputs (R&D)

	CI	***Lproductivity***	***R&D***	***Lproductivity***
	M6	***M7***	***M8***	***M9***
Transformation	0.0741***	0.0357***	0.2089***	0.0355***
	(0.0094)	(0.0084)	(0.0151)	(0.009)
CI		0.3068***		
		(0.0347)		
R&D				0.1046***
				(0.0151)
Fixed Effect	YES	YES	YES	YES
Controls	YES	YES	YES	YES
R-square	0.3275	0.2137	0.2151	0.1509
N.(obs)	9658	9655	8371	8371

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

mediation effect of corporate R&D investment (M9, $\beta = 0.1046$, $P < 0.01$), where the regression coefficient of digital transformation (Transformation) was significantly reduced (M3, $\beta = 0.0587$, $P < 0.01$; M9, $\beta = 0.0355$, $P < 0.01$). Firms in the digital economy should actively invest in R&D and promote technological innovation to embrace the digital transformation of management models, business strategies, organizational structures, and resource allocation to achieve outcomes that improve firm efficiency. Thus, innovation investment is an intermediate mechanism through which digital transformation affects labor productivity, which provides strong evidence for hypothesis 3.

In summary, digital transformation can optimize the structural relationship between labor and capital by increasing the capital intensity of firms, and increasing their investment in innovation and R&D, which in turn positively affects the labor productivity of firms. To argue the robustness of the empirical results of Hypothesis 2 and Hypothesis 3, the paper will also provide further evidence by constructing grouped regressions of firms' capital intensity and innovation investment in the heterogeneity test.

4.3 Heterogeneity Analysis

1) Further evidence for capital intensity and innovation inputs: The above section argues that firms' increased capital intensity and increased innovation inputs are intermediate mechanisms through which digital transformation affects labor productivity. A grouping regression to test the impact mechanism was used to carry out separate grouping regressions using firms' capital intensity and innovation input levels to provide further evidence for the findings. Table 3 gives the results: the regression coefficient of the high group (M10b, $\beta = 0.0436$, $P < 0.01$) is larger than that of the low group (M10a, $\beta = 0.0417$, $P < 0.01$), indicating that the effect of digital

transformation on the labor productivity of firms is more pronounced when the capital intensity of firms is higher (higher capital-labor ratio), a result that is consistent with the findings in M7. The regression coefficient of the high group (M11b, $\beta = 0.0536$, $p < 0.01$) is much larger than that of the low group (M11 a, $\beta = 0.0359$, $p < 0.01$), and the mediating effect of innovation investment is significant in the process of digital transformation, which is the same as in M9. In this paper, the mediating effects of capital-labor ratio and innovation inputs are tested separately using group regressions, and the results remain robust.

2) Differences in the internal skill structure and external human capital environment: Digital transformation enhances the internal governance of firms. Therefore, this

Table 3. Heterogeneity analysis: capital intensity and innovation input

	Lproductivity			
	Capital Intensity		***Innovation Input***	
	Low	***High***	***Low***	***High***
	M10a	M10b	M11a	M11b
Transformation	0.0417***	0.0436***	0.0359***	0.0536***
	(0.0101)	(0.0075)	(0.0132)	(0.0105)
Fixed Effect	YES	YES	YES	YES
Controls	YES	YES	YES	YES
R-square	0.0836	0.0934	0.0578	0.0899
N.(obs)	4492	5150	3713	5942

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4. Heterogeneity analysis: Differences in skill structure and external human capital

	Lproductivity			
	Internal Skill Structure		***External Human Capital***	
	Low	High	Low	High
	M12a	M12b	M13a	M13b
Transformation	0.0542***	0.0566***	0.0516***	0.0555***
	(0.0120)	(0.0104)	(0.0121)	(0.0118)
Fixed Effect	YES	YES	YES	YES
Controls	YES	YES	YES	YES
R-square	0.1016	0.1121	0.0901	0.0973
N.(obs)	4226	5419	4142	5192

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

paper focuses on the role of differences in the internal skill structure of employees in digital transformation to enhance the labor productivity of firms. Table 4 reports the regression results. The role of digital transformation in improving labor productivity is more significant in firms with better skill structure (M12a, $\beta = 0.0542$, $P < 0.01$; M12b, $\beta = 0.0566$, $P < 0.01$). Higher levels of external human capital also contribute to labor productivity (M13a, $\beta = 0.0516$, $P < 0.01$; M13b, $\beta = 0.0555$, $P < 0.01$). While companies should focus on digital transformation, they should also enhance the proportion of high-skilled employees to increase the utility of digital transformation, however, this result also indicates that the employment opportunities and power of low- and medium-skilled workers will face more severe challenges in the process of corporate digital transformation.

3) Differences in regional development: Regional differences are usually taken into account, and there are certain developmental differences in the economy, policies, and culture among the eastern, central, and western regions of China. Therefore, we used the division of China Bureau of Statistics into eastern, central, and western regions to test for heterogeneity. Table 5 reports the regression results. Digital transformation is more helpful in improving firms' labor productivity in the eastern region (M14a, $\beta = 0.0624$, $p < 0.01$). The effect is smaller in the central region than in the eastern region (M14b, $\beta = 0.0498$, $P < 0.05$). In the western region, the results are not significant (M14c, $\beta = 0.0295$, $P > 0.1$), and the regression coefficients are much smaller than those in the eastern and central regions. In conclusion, the above results suggest that there is a significant locational effect of digital transformation on the improvement of enterprise productivity, while the imbalance of regional development weakens the opportunities brought by digital transformation and may further widen the "digital divide".

Table 5. Heterogeneity: Regional differences in the eastern, Central, and Western

	Lproductivity		
	Eastern	***Central***	***Western***
	M14a	***M14b***	***M14c***
Transformation	0.0624***	0.0498**	0.0295
	(0.0103)	(0.0201)	(0.0190)
Fixed Effect	YES	YES	YES
Controls	YES	YES	YES
R-square	0.1059	0.1530	0.0887
N.(obs)	7121	964	1033

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5 Conclusions

In the digital economy, digital information technologies such as artificial intelligence, cloud computing, internet of things, blockchain, and big data have become important ways for companies to achieve digital transformation and drive innovative development and efficiency changes. However, the debate between digital transformation and labor efficiency seems to hinder the pace of enterprises. In this paper, using data from Chinese listed companies, we provide new evidence to investigate the impact of digital transformation on enterprise labor productivity.

Digital transformation can help improve labor productivity in firms. However, this process has significant regional differences and has led to a widening of the "digital divide". The positive effect of digital transformation on labor productivity is greater in the eastern region than in the central and western regions, with a significant decreasing trend.

The authors note that the capital intensity of firms plays a significant mediating role. Digital transformation optimizes the capital-labor ratio of firms and accelerates the transition to capital-intensive and technology-intensive firms, which causes labor productivity improvement. Meanwhile, innovation investment plays a mediating role in the relationship between digital transformation and firm labor productivity. Digital transformation makes firms increase their innovation investment, which improves their technological level and innovation capability, thus contributing to the improvement of their labor productivity.

This study also found that when firms actively engage in digital transformation, the internal employee skill structure of employees and the external human capital environment have a significant impact on labor productivity. Having more highly skilled employees is more conducive to efficient business growth, which may increase the employment difficulties of low- and medium-skilled employees. A better external human capital environment creates a clustering effect of highly skilled employees, which can provide more resources for digital transformation and efficiency improvement of enterprises.

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