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Effect of digital transformation on labor income share in manufacturing enterprises: insights from technological innovation and industry–university–research collaborations

Ying Miao, Yue Shi and Hao Jing
School of Economics and Management, Shenyang Aerospace University, Shenyang, China

Abstract

Purpose – This study investigates the relationships among digital transformation, technological innovation, industry–university–research collaborations and labor income share in manufacturing firms.

Design/methodology/approach – The relationships are tested using an empirical method, constructing regression models, by collecting 1,240 manufacturing firms and 9,029 items listed on the A-share market in China from 2013 to 2020.

Findings – The results indicate that digital transformation has a positive effect on manufacturing companies' labor income share. Technological innovation can mediate the effect of digital transformation on labor income share. Industry–university–research cooperation can positively moderate the promotion effect of digital transformation on labor income share but cannot moderate the mediating effect of technological innovation. Heterogeneity analysis also found that firms without service-based transformation and nonstate-owned firms are better able to increase their labor income share through digital transformation.

Originality/value – This study provides a new path to increase the labor income share of enterprises to achieve common prosperity, which is important for manufacturing enterprises to better transform and upgrade to achieve high-quality development.

Keywords Manufacturing enterprises, Digital transformation, Technological innovation, Labor income share, Industry-university-research

Paper type Research paper

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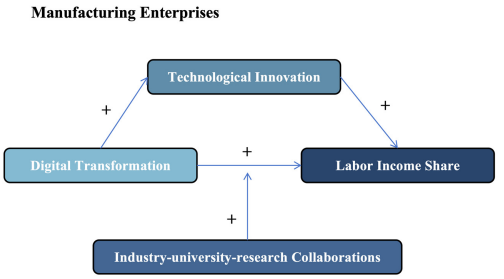
Graphical abstract



Firms with service-based transformation
Firms without service-based transformation ☑

State-owned firms
Non-state-owned firms ☑

Title: Effect of digital transformation on labor income share in manufacturing enterprises: insights from technological innovation and industry-university-research collaborations

Data: 1240 manufacturing firms, 9029 items panel data from 2013-2020

Methods: Regression Analysis

Findings:
Digital transformation has a positive effect on manufacturing enterprises' labor income share.

Technological innovation can mediate the effect of digital transformation on labor income share.

Industry-university-research cooperation can positively moderate the promotion effect of digital transformation on labor income share but can not moderate the mediating effect of technological innovation.

Firms without service-based transformation and non-state-owned firms are better able to increase their labor income share through digital transformation.

1. Introduction

The stability of the share of labor income is the basis of the macroeconomic model (Karabarbounis and Neiman, 2014). Improving the pattern of income distribution can promote the formation of a new development pattern that is conducive to sustainable economic development and social stability (Xiao *et al.*, 2022; Kuijs, 2006). However, since 1980, the share of labor income has been declining in most countries and industries (Karabarbounis and Neiman, 2014), and the share of labor income in China's manufacturing industry has also shown a clear downward trend since the 1990s (Shen and Zheng, 2022). China is a large manufacturing country, and promoting the high-quality development of the manufacturing industry is the foundation of its economic development (Liu and Lin, 2023). A decline in the level of labor income share will trigger a lack of consumer demand, hindering economic development (Song and Du, 2021), and will widen the income distribution gap, resulting in social unrest (Fan and Zhang, 2012; Daudey and García-Peñalosa, 2007). Therefore, increasing the labor income share of the manufacturing industry has become an urgent problem, and the first step is to determine the factors affecting these changes (Wu and Shao, 2019).

With the continuous transformation and development of manufacturing enterprises, digital transformation has become an important way to promote enterprise development. On the one hand, digital transformation can not only accelerate the speed of information acquisition to promote enterprise innovation but also reduce costs and improve business conditions (Jin *et al.*, 2023). On the other hand, digital transformation can improve productivity and increase corporate profits (Hasan *et al.*, 2018; Sezer *et al.*, 2021). Enterprises carry out digital transformation to improve enterprise performance. Can it enhance the share of labor income and promote stable development in the social economy simultaneously? Whether the effect of enterprise digital transformation on labor income share is applicable in manufacturing enterprises remains to be studied.

There are few academic studies on the impact of digital transformation on labor income shares. Existing literature on the impact of digital transformation on labor income share has been studied from the perspective of human capital structure (Xiao *et al.*, 2022; Li and Shi, 2023; Gong and Yu, 2023; Zhao *et al.*, 2023), financing constraints (Xü *et al.*, 2023; Huang *et al.*, 2023; Li *et al.*, 2023a), capital and technology (Wang *et al.*, 2023; Sun, 2023a), and employee wages

(Pei *et al.*, 2023). However, most of these have not been studied for manufacturing enterprises, and it is not yet known whether manufacturing enterprises have a similar effect (Xü and Wen, 2023). Some scholars have studied the impact of digital transformation on labor income share from the perspective of wage and employment effects for manufacturing enterprises, which enriches research on manufacturing enterprises. However, there is still little literature exploring the path and mechanism of the impact of digital transformation on labor income share in manufacturing enterprises from their internal and external perspectives.

From the internal viewpoint of enterprises, technological innovation can improve competitiveness (Bao and Ma, 2018) by creating differentiated value for enterprises, and digital transformation can promote enterprise technological innovation through the allocation of innovation factors (Sun, 2023c) to achieve high-quality development. From the external viewpoint of enterprises, the deep integration of industry-university-research can promote enterprise market performance (Liu *et al.*, 2020), and enhance the position of enterprises in the global value chain (Jin and Chen, 2021). However, it is not yet known whether technological innovation and industry-university-research cooperation can positively affect the labor income share of manufacturing enterprises. Therefore, this study incorporates the internal factors of technological innovation and the external factors of industry-university-research cooperation into the research framework of the impact of digital transformation on the labor income share of manufacturing enterprises. From the GSMAR database, WIND database, and CNINFO Juchao information website, we collected and collated 9,029 data points from 1,240 listed companies in the manufacturing industry, using STATA and PYTHON software to collate the data, and we used regression analysis methods (including benchmark regression analysis, robustness test, endogeneity test, and heterogeneity analysis) to study the effect of digital transformation, technological innovation, and industry-university-research cooperation on the labor income share of manufacturing enterprises.

The remainder of this paper is structured as follows: The next section consists of a literature review; section three discusses the research hypothesis; section four presents the data and research methodology; section five shows the results and analysis. Section six is heterogeneity analysis, and in the final part, discussions, conclusions, and implications are provided.

2. Literature review

We focus on the effect of digital transformation on labor income share and the mediating and moderating role played by technological innovation and industry-university-research alliances in this research. Therefore, given the large variety of literature on digital transformation, we focus on the following three areas: digital transformation and innovation performance, digital transformation and industry-academia-research collaboration, and labor income share.

2.1 The effect of digital transformation on innovation performance

With regard to the impact of digital transformation on corporate innovation, the existing literature suggests that digital transformation can significantly improve the level of corporate innovation, mainly through the three aspects of reducing cost, changing the strategic model, and enhancing technological capabilities. It is believed that digital transformation can reduce the cost to promote labor income share (Zhao and Huang, 2023; Du and Cao, 2023). Some scholars believed that digital transformation could improve corporate innovation performance by facilitating the internationalization of research and development (Wen *et al.*, 2023), technology spillover (Song and Song, 2023), and ESG performance enhancement (Chen *et al.*, 2023). Some scholars also specialized in the role of digital transformation in green innovation. Sun (2023b) found that digital economy could

contribute to green innovation through digital transformation, open cooperation, and model innovation. They also believed that the digital transformation could promote green innovation by increasing absorptive capability and strengthening internal controls (Liu *et al.*, 2023b) as well as optimizing human capital structure (Li *et al.*, 2023b). Xü *et al.* (2024) argued that increasing research and development investment and government green subsidies are the mediation mechanisms for the effect of digital transformation on green innovation. Scholars have also used organizational innovation (Korayim *et al.*, 2024) and business model innovation (Zhang and Kuang, 2024) as mediating variables to explore the role of digital transformation in improving firms' competitiveness. The utilization of resources can have an impact on the innovation performance of a company, which in turn can contribute to the development of the company in various fields. Thus, innovation as a mediator has also been found to reduce financing costs (Meng *et al.*, 2024), increase productivity (Cai *et al.*, 2023; Yuan *et al.*, 2024) and reduce negative ecological impacts (Yu *et al.*, 2023; Fosu *et al.*, 2024).

The above studies mainly affirm the positive impact of digital transformation on firm innovation. However, there is little literature that incorporated employee-level factors into the study, and little literature that explores whether factors external to the firm have a combined effect with digital transformation. In this study, two factors, labor income share, which reflects the income level of employees, and the degree of industry-university-research collaboration, which reflects the external cooperation of firms, are included under the same framework as digital transformation and firm innovation.

2.2 Digital transformation and industry-university-research collaboration

Digitalization accelerated knowledge spillover and diffusion, and promoted collaborative innovation between industry, academia and research (Yuan, 2023). Zheng and Jiang (2022) argued that cooperation between enterprises and research institutes could promote digital economy convergence and simultaneously promote the recognition of research institutes and the willingness of enterprises to transform digitally. Some scholars believed that the unions of industry, university and research could increase the level of digital transformation through talent, innovation (Su and Wang, 2023), and regulation (Li *et al.*, 2021). The degree of industry-academia-research collaboration can have a significant impact on the ability of firms to receive a wealth of knowledge resources. Wang and Yu (2018) found that ambidextrous innovation strategy of firms with industry-university-research alliance has a stronger effect on venture performance. Alpkan and Gemici (2023) believed that the high performance work system of enterprises with a high degree of industry-university-research alliance had a stronger effect on technological capability.

There is very little literature on the combination of digital transformation and industry-university-research alliances, and existing studies have mainly explored the causal relationship between the two. There is also little literature on the combination of the two and technological innovation to explore the impact of their combined effect on the labor income share of manufacturing enterprises. In the context of the digital transformation pressure faced by manufacturing enterprises, what is the role of internal technological innovation and an external industry-university-research alliance in enhancing the labor income share of manufacturing enterprises? This is the key to solving the problem of the common wealth of manufacturing enterprises.

2.3 Labor income share

Labor income share is a reflection of workers' income, while enterprise labor income share reflects labor income share from a micro perspective (Ai and Ji, 2023). Exploring the labor income share in enterprises can help realize the common prosperity of enterprises and employees.

Existing literature on labor income share mainly focuses on enterprise reform and changes in the market environment. Issues such as digital transformation, technological progress bias, and capital issues could lead to internal financial, technological, and personnel adjustments, while issues such as governmental institutional reforms, the opening up of the service sector, and global value chains could externally affect changes in the labor income share of firms. Gong and Yu (2023) believed that digital transformation can promote labor income share through the skill structure effect, the labor productivity effect, and the distributional optimization effect. Li and Shi (2023) found that total factor productivity has a positive correlation with labor income share. Zhu (2023) argued that digital inclusive finance could promote firms' labor income share. Some scholars had also explored the impact of GVC embeddedness on labor income share (Yuan and Qi, 2019; Sui *et al.*, 2021).

Specifically, there are no consensus in existing research on the impact of digital transformation on labor income share. Some scholars believed that enterprise digital transformation could promote an increase in labor income share. From the perspective of optimizing human capital structure, Xiao *et al.* (2022) believed that enterprise digital transformation could enable enterprises to invest in high-skilled labor and squeeze out part of low-skilled labor in the form of optimizing human capital structure, which in turn affects the share of labor income. Li and Shi (2023) believed that digital transformation could bring new technology to enterprises but also improve the degree of specialization of labor factors and production efficiency. From the perspective of financing constraints, Xü *et al.* (2023) argued that digitalization could improve the transparency of corporate information, increase investment in high-quality labor, and thus raise labor income share. Huang *et al.* (2023) believed that digital transformation could crack the dilemma caused by information asymmetry, improve the quality of internal controls, and enhance the share of labor income. Li *et al.* (2023a) argued that digital transformation would provide policy support, alleviate financing constraints, and increase the number of labor force hires to promote labor income share. However, some scholars believe that enterprise digital transformation could have negative effects on the labor income share. Wang *et al.* (2023) argued that the participation of data elements in the distribution and establishment of digital platforms would result in capital investment and platform monopolies, which would in turn reduce the labor income share. Sun (2023a) argued that digital transformation could raise the labor income share through the upgrading of labor factors, but it could also cause the substitution effect of capital on labor and the productivity enhancement effect to lower the labor income share. There is no consensus in the existing literature on whether digital transformation promotes or suppresses the labor income share. In addition, the above studies have been conducted in terms of internal human and external financial resources, but there is a lack of analysis in the area of joint internal innovation and external resources.

Considering the above research gaps, this study incorporates the degree of technological innovation and industry-university-research cooperation into the study of digital transformation and labor income share. Quantitative research and textual analysis are used to explore in depth the role of digital transformation and labor income share, as well as the influencing factors, to open up a new path for improving the labor income share of manufacturing enterprises.

3. Research hypothesis

Digital transformation refers to a process that aims to improve an entity through a combination of information, computing, and communication and connectivity technologies (Vial, 2021). Digital transformation can be specifically broken down into digital underpinning technology and the practical application of digital technology (Wu *et al.*, 2021). Our research focuses on the digital transformation happening in manufacturing enterprises, thus, digital

transformation here in our research means the changes in processes through digital technologies in manufacturing firms such as artificial intelligence technology, big data technology, and cloud computing technology. Digital transformation can not only promote enterprise performance (Miao *et al.*, 2023) to bring about an increase in enterprise value (Li, 2023), but also promote the share of labor income of employees, and promote the common prosperity of enterprises and employees in manufacturing firms.

The digital transformation can contribute to labor income share in manufacturing firms through four main areas: human capital, resource flows, information sharing, and outward foreign direct investment (OFDI). In terms of human capital structure, digital transformation of manufacturing enterprises can increase the proportion of highly educated and skilled employees, change the composition of the staff structure, increase the average wage of employees (Arvanitis and Loukis, 2015; Zhou and Wan, 2023), and achieve an increase in the share of labor income by means of the factor complementary mechanism (Gong and Yu, 2023). In terms of resource flows, according to the resource-based view, digital transformation can promote the efficiency of the flow of enterprise knowledge resources among employees, such as social platforms and enterprise knowledge-sharing websites, which promote the sharing of resources among employees, improve the enthusiasm of employees for their work (Dang and Li, 2023), and promote the improvement of productivity, which is conducive to the income of employees. From the perspective of information sharing, according to the information asymmetry theory, the application of digital transformation can reduce the information asymmetry problem between employees, increase the transparency and fairness of the work, and the employees can actively participate in the work and improve the efficiency of the work, which is conducive to improving the share of enterprise labor income. Regarding investment, digital transformation can provide conditions for OFDI in the form of improved resource management capabilities (Liu and Dong, 2023) and increased productivity (Hu *et al.*, 2023; Wang and Zhang, 2023). The increment of OFDI can increase the share of labor income of firms (Yuan and Yang, 2018) through reverse technological spillovers by improving factors such as firms' innovation capabilities and investment in research and development (Li and Wang, 2023).

Based on this, hypothesis H1 is proposed.

H1. Digital transformation can positively affect labor income share in manufacturing enterprises.

At the employee level, the improvement of employees' skills is a relatively direct way to increase the share of labor income. On the one hand, the digital transformation of manufacturing enterprises enables employees to acquire more professional knowledge through digital platforms, which makes it easier to generate technological innovation and improve labor productivity (Zhao *et al.*, 2021), which in turn directly contributes to the improvement of the share of labor income. On the other hand, the digitalization of human resource management can increase the perceived human resource intensity of employees, increase the transparency of employee management, and increase employees' willingness to carry out innovative work (Liu *et al.*, 2023c).

At the enterprise level, advances in technology will improve corporate profitability, increase employee income, and increase the share of labor income (Wu and Wang, 2022; Luo and Tie, 2021). Digital transformation can also improve the information processing capacity of enterprises (Fang *et al.*, 2023), and good information communication can optimize the technological innovation process, improve innovation performance (Fu and Bi, 2009), and drive the labor income share. In addition, the digital transformation of enterprises is more likely to receive the attention of investors (Nambisan *et al.*, 2019), and good financial support can be conducive to manufacturing enterprises to increase the proportion of investment in

technological innovation, while enterprise R&D investment will lead to enterprise demand for highly skilled labor and enhance the share of labor income (Jiang *et al.*, 2022).

Based on this, hypothesis H2 is proposed.

H2. Digital transformation can improve labor income share by increasing the level of technological innovation in manufacturing enterprises.

Industry-university-research cooperation is a channel for enterprises, universities, and research institutions to obtain complementary resources and share technology and knowledge (Ma *et al.*, 2018). Different industry, university, and research environments affect the allocation of resource endowments in cities (Zhang *et al.*, 2022), which in turn affects the resources available to manufacturing firms for digital transformation. Enterprises with a higher degree of digital transformation can gain a larger market share, increase the total amount of rent shared by employee participation (He and Wang, 2023), increase the average wage level of employees, and drive an increase in the share of labor income. At the same time, manufacturing enterprises that strengthen industry-university-research cooperation have a higher integration of organizational strategies, can enhance the key core technology innovation capacity (Shi *et al.*, 2019), promote reliance on highly skilled labor (Zhou and Wan, 2023), and increase the share of labor income.

Manufacturing enterprises need certain innovation resources as well as the ability to carry out technological innovation. A higher industry-academia-research partnership can provide manufacturing enterprises with more knowledge resources needed for innovation (Su and Wang, 2023), which is conducive to the efficient use of digital transformation tools and promotes the level of technological innovation (Li *et al.*, 2021). At the same time, university-industry-research collaborations can make manufacturing enterprises more effective in promoting the transformation of their technological innovation capability into innovation results through academic achievements, and promote the close integration of digital transformation with the actual production situation of the manufacturing industry, which in turn enhances the output of technological innovation results.

An industry-university-research alliance can promote manufacturing enterprises to know more about the research frontier, strengthen the training of enterprise staff (Wang and Hu, 2014), and be conducive to the transformation of technological innovation into production efficiency, enhance the profitability of enterprises, increase the interest income of employees, and increase the share of labor income. In addition, manufacturing enterprises with a higher degree of industry-university-research alliance can also know more about the protection of technological innovation results and other information (Xiao and Li, 2023), increase the willingness of employees to share innovative ideas, increase the value of employees, and promote the share of labor income.

Based on this, hypotheses H3a, H3b and H3c are proposed.

H3a. Industry-university-research collaborations positively moderate the facilitating effect of digital transformation on labor income share in manufacturing enterprises.

H3b. Industry-university-research collaborations positively moderate the facilitating effect of digital transformation on technological innovation in manufacturing enterprises.

H3c. Industry-university-research collaborations positively moderate the facilitating effect of technological innovation on labor income share in manufacturing enterprises.

Figure 1 shows the variable relationship of the Hypotheses.

4. Data and research methodology

4.1 Data sources and sample selection

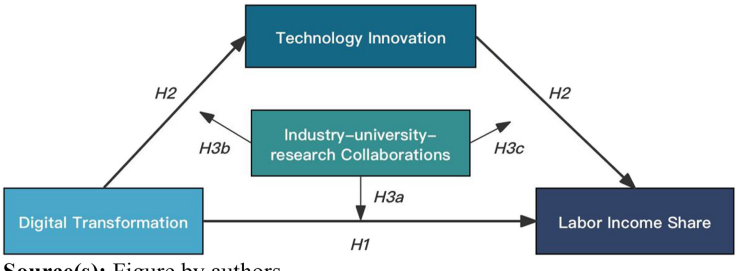
The data related to digital transformation in this study come from the annual reports of enterprises obtained from the CNINFO website, and Python was used to crawl the annual reports and perform word frequency statistics. The information in the annual reports from CNINFO is primary data. Data on labor income share, technological innovation level, and control variables were obtained from CSMAR and WIND. These two major databases provide secondary data on enterprises and are mature databases used in the academia field. Variables related to industry-university-research collaborations were selected from the China Research Data (CNRDS), which provides primary data.

The sample data we selected is the panel data of A-share-listed companies from 2013 to 2020 (8 years). Then, we used industry codes to filter the data that belongs to the manufacturing industry. Afterward, the data was matched and organized according to stock code and year as unique values. To maximize the accuracy of the results, the samples were then processed as follows: (1) ST and *ST samples are removed (special treatment). (2) To ensure data continuity, firms established after 2012 are excluded. (3) Firms with missing data are removed after data matching. Finally, 1,240 companies with 9,029 sample values were obtained. Considering the effect of outliers, the data were shrun-tailed at the 1% up and down levels using STATA software.

4.2 Variable definition

Dependent variable. Labor Income Share (LIS). The labor income share represents the proportion of the total profit allocated to workers. The cash paid by an enterprise to its employees in the current period includes wages, various allowances, and benefits such as five insurances and one pension, which can directly reflect the labor income of the employees. Therefore, referring to the practices of Xiao *et al.* (2022) and Shi *et al.* (2019), the ratio of the enterprise's current cash payments to employees to total operating revenues is used as an indicator of the share of labor income (labor share).

Independent variable. Digital Transformation (Digital). We used textual analysis here to construct digital transformation indicators. Specifically, Python software was used to crawl the enterprise annual report information on the CNINFO website. Then the Python Parser function is used to convert the annual report documents into text format. Finally, we used Python code to count the digital-related word frequency statistics as a measure of the degree of digital transformation. Referring to the practice of Wu *et al.* (2021), 76 digital-related word frequencies in five dimensions, namely, artificial intelligence technology, big data technology, cloud computing technology, blockchain technology, and the use of digital technology, were counted.



Source(s): Figure by authors

Figure 1.
Variable relationship of the hypotheses

Mediating variable. Technological Innovation (Inno). R&D expenditures can reflect the level of technological innovation of enterprises. Therefore, referring to the practices of Feng and Wen (2008), Xü *et al.* (2018), and Lu and Dang (2014), the ratio of R&D expenditures to operating revenues is used as a measure of the level of technological innovation.

Moderating variable. Industry-university-research collaborations (Union). The number of patents jointly applied for by enterprises can reflect cooperation between industry, university and research. Referring to the measurement methods of Liu *et al.* (2020, 2023a), this study adopts the proportion of the number of jointly filed patents to the total number of patent applications as an indicator of the degree of union between industry, university, and research.

Control variables. Referring to the existing studies, Owners' Equity Ratio (OER): total shareholders' equity as a proportion of total assets; Asset Liability Ratio (ALR): total liabilities as a proportion of total assets; Operating Cost Ratio (OCR): operating costs as a proportion of operating revenues; Working Capital Ratio (WCR): the difference between total current assets and total current liabilities as a proportion of total assets; Top1 Shareholder Shareholding Ratio (Top1): the number of shares held by the largest shareholder as a proportion of total shares. Company size (SIZE): the natural logarithm of total assets at the end of the year indicated; Total Asset Turnover (ATO): the ratio of operating income to average total assets indicated; Inventory Ratio (INV): the ratio of net inventory to total assets indicated; Accounts Receivable Ratio (REC): the ratio of net accounts receivable to total assets indicated; Intangible Assets expressed as the ratio of net receivables to total assets; and the Intangible Assets Ratio (IAR): net intangible assets expressed as the proportion of total assets. The results of the descriptive statistics for the variables are presented in Table 1.

4.3 Model construction

Referring to the research of Chen *et al.* (2023), with digital transformation of manufacturing enterprises as the independent variable and labor income share as the dependent variable, the following model is constructed to test the direct effect of digital transformation on labor income share, as in model (1). Where i denotes an individual manufacturing enterprise, t denotes the year, $Digital_{it}$ denotes the degree of digital transformation of manufacturing enterprises, LIS_{it} denotes the share of labor income in enterprises, and μ_{it}, γ_{it} and ε_{it} denote the individual fixed effect, time fixed effect, and random perturbation factors, respectively.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
LIS	9,029	0.126	0.068	0.018	0.355
Digital	9,029	3.492	7.565	0	48
Inno	9,029	4.257	3.381	0.048	19.602
Union	9,029	0.073	0.241	0	1
OER	9,029	0.596	0.187	0.145	0.943
ALR	9,029	0.405	0.187	0.057	0.855
OCR	9,029	0.723	0.166	0.189	0.992
WCR	9,029	0.224	0.223	−0.332	0.724
Top1	9,029	0.326	0.139	0.085	0.712
SIZE	9,029	22.275	1.161	20.141	25.696
ATO	9,029	0.657	0.369	0.127	2.284
INV	9,029	0.136	0.083	0.018	0.45
REC	9,029	0.131	0.094	0.001	0.433
IAR	9,029	0.046	0.034	0.002	0.199

Source(s): Authors

Table 1. Description of variables

The significance and positive or negative value of coefficient a1 are judged to determine whether the digital transformation of manufacturing enterprises will have an impact on the labor income share.

$$LIS_{it} = a_0 + a_1 Digital_{it} + a_2 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (1)$$

Referring to the study of Wen and Ye (2014a), the following mediating effect models were constructed to test the mediating role of technological innovation in the impact of digital transformation and labor income share in manufacturing enterprises, as models (2) and (3). Model (2) represents the test of the effect of digital transformation on technological innovation, and Model (3) represents the test of the effect of the independent variable digital transformation and the mediating variable technological innovation on labor income share in manufacturing firms. $Inno_{it}$ denotes the level of technological innovation in manufacturing firms.

$$Inno_{it} = b_0 + b_1 Digital_{it} + b_2 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (2)$$

$$LIS_{it} = c_0 + c_1 Digital_{it} + c_2 INNO_{it} + c_3 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (3)$$

Referring to the study of Wen and Ye (2014b), the following moderated mediating effects model is constructed to test whether the degree of industry-university-research alliance in manufacturing firms can moderate the role of digital transformation as well as technological innovation in labor income share. In this study, the direct and indirect effects in the model with mediated effects were tested by adding the moderating variable, the level of industry-university-research cooperation, respectively.

Model (4) is used to test the moderating effect of the degree of industry-university-research cooperation on the direct effect model, which is model (1). If the coefficient d_3 of the $DigitalitxUnion_{it}$ term is significant, it reflects that the moderating effect on the direct effect is significant. Models (5) and (6) are used to test the moderating effect of the degree of industry-university-research cooperation on the indirect effect models, which are models (2) and (3). The coefficient e_3 of the $Digital_{it} \times Union_{it}$ term in model (5) and the coefficient f_4 of the $Inno_{it} \times Union_{it}$ term in model (6) can reflect whether the moderating effect on the indirect effect is significant, and they can also indicate in which period the moderated variable is significant in the mediating effect.

$$LIS_{it} = d_0 + d_1 Digital_{it} + d_2 Union_{it} + d_3 Digital_{it} x Union_{it} + d_4 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (4)$$

$$Inno_{it} = e_0 + e_1 Digital_{it} + e_2 Union_{it} + e_3 Digital_{it} x Union_{it} + e_4 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (5)$$

$$LIS_{it} = f_0 + f_1 Digital_{it} + f_2 Union_{it} + f_3 Inno_{it} + f_4 Inno_{it} \times Union_{it} + f_5 Digital_{it} \times Union_{it} + f_6 Controls_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (6)$$

5. Results and analysis

5.1 Benchmark regression

Compared to simple regression, benchmark regression is able to compare models. Benchmark regression helps us make better predictions for the real problems of enterprises. We first performed regression analysis on the selected samples while using robustness and

endogeneity tests to verify the robustness of the regression results and, at the same time, excluded the endogeneity problem arising from the possibility that the dependent variable might inversely affect the independent variable. Finally, we would consider the heterogeneity of the samples and conduct further group regression. According to model (1), the regression of digital transformation and labor income share indicators is conducted using individual fixed effects as well as time fixed effects to exclude the influence of variables that are only affected by individuals and do not change with other factors and variables that only change with time factors and do not change with other factors. The accuracy of the regression results is guaranteed. The regression results are shown in Table 2, with columns (1), (2), and (3) indicating the regression results of gradually adding control variables and fixed effects, which show that the coefficients of the indicators of digital transformation are significantly positive at the levels of 1%, 1%, and 5%, respectively, indicating that digital transformation can positively contribute to the increase in the share of labor income, verifying Hypothesis 1.

5.2 Robustness tests

5.2.1 Substitution of dependent variable. Referring to Wang and Huang (2017), LIS_A is used as a replacement variable for labor income share, which is calculated as (cash paid by the enterprise for employees in the current period plus employee compensation payable at the end of the period by the enterprise minus employee compensation payable at the beginning of the period by the enterprise)/total operating revenue. The test results are shown in column (1) of Table 3, and the coefficient of digital transformation of manufacturing enterprises is 0.0004, which is significantly positive at the 5% level, further verifying the authenticity of the results.

5.2.2 Substitution of independent variable. The replacement variable is Digital_A. Referring to Zhao *et al.* (2021), 99 digitization-related word frequencies of the four dimensions of digital technology application, Internet business model, intelligent manufacturing, and modern information system are counted. The test results are shown in column (2) of Table 3, with a coefficient of 0.0001, which is significant at the 10% level. This indicates that the regression test results of Hypothesis 1 are robust.

5.3 Endogeneity tests

To test the possible reverse causality between firms' digital transformation and labor income share, this study uses instrumental variables (IV) for the 2SLS two-stage estimation method for the endogeneity test. The instrumental variables are selected to be tested by lagging the

	(1) LIS	(2) LIS	(3) LIS
Digital	0.0006***	0.0007***	0.0004**
	(7.5622)	(10.1248)	(2.4402)
_cons	0.1230***	0.4609***	0.6783***
	(71.0310)	(4.9876)	(8.2200)
Year fixed	NO	NO	YES
Individual fixed	NO	NO	YES
Control variables	NO	YES	YES
N	9,029	9,029	9,029
R^2	–	–	0.2581
Adj. R^2	–	–	0.2566

Note(s): *, **, and ***indicate statistical significance at the 10, 5, and 1% levels, respectively. Similar levels are employed in all tables
Source(s): Authors

Table 2.
Results of the effect of digital transformation on labour income share

	(1) LIS_A	(2) LIS
Digital	0.0004**	
	(2.5281)	
Digital_A		0.0001*
		(1.9002)
_cons	0.6300***	0.6755***
	(7.4769)	(8.1687)
Year fixed	YES	YES
Individual fixed	YES	YES
Control variables	YES	YES
N	9,029	9,029
R^2	0.2326	0.2562
Adj. R^2		0.2547

Source(s): Authors

Table 3. Robustness testing results

explanatory variables by one period and testing the explanatory variables at the same time in the same province and in the same industry with the mean value of other firms. Since the use of instrumental variables presupposes that the explanatory variables are endogenous, it is also necessary that the instrumental variables are not weak instrumental variables. Therefore, the instrumental variables were tested separately as follows:

5.3.1 Independent variable lagged one period (L1_LIS). Referring to Yue and Meng (2021), the indicator value of the lagged period of the explanatory variable digital transformation is used as an instrumental variable. The lagged explanatory variables can avoid the endogeneity of instrumental variables while correlating with the explanatory variables. The Durbin and Wu-Hausman test is conducted, and the results are significant, indicating that the explanatory variables are endogenous and meet the prerequisites for the application of instrumental variables. The F-statistic of the weak instrumental variable test for the lagged second-period indicator of the explanatory variables is 14538.8, which is greater than 10, and the rejection of the original hypothesis of the weak instrumental variable indicates that the lagged first-period indicator of the enterprise's digital transformation is a strong instrumental variable. The results of IV estimation are shown in columns (1) and (2) in Table 4, and the coefficients of both phases are significant, indicating that the main conclusions are valid.

	(1)	(2)	(3)	(4)
	IV = L1_LIS		IV=Same_TPI_LIS	
	First stage	Second stage	First stage	Second stage
Variables	Digital	LIS	Digital	LIS
IV	0.8483***		0.6185***	
	(0.007)		(0.017)	
Digital		0.0017***		0.0047***
		(0.000)		(0.000)
Constant	1.8806	0.6709***	−10.1733	0.6373***
	(13.565)	(0.169)	(21.700)	(0.187)
Control variables	YES	YES	YES	YES
Observations	7,657	7,657	7,716	7,716
R-squared	0.671	0.318	0.185	0.167

Source(s): Authors

Table 4. Endogeneity testing results

5.3.2 Independent variable mean value of other firms in the same province and industry at the same time (Same_TPI_LIS). Referring to Xü *et al.* (2022), the mean values of digital transformation of other firms in the same province and industry simultaneously were used as instrumental variables to test the endogeneity problem of reverse causality. The Durbin and Wu–Hausman test results were significant. The F-statistic of the weak instrumental variable test is 1332.48, which is greater than 10, indicating that the instrumental variable is not a weak instrumental variable. The instrumental variable IV estimation results are shown in columns (3) and (4) of Table 4, with significant coefficients at both stages, further mitigating the endogeneity problem of the regression results of Hypothesis 1.

5.4 Mediation effect test

According to the test results of models (2) and (3), that is, the test results of the mediating role of technological innovation in manufacturing enterprises are shown in Table 5, the coefficient of digital transformation in Column (1) is 0.0114, which is significantly positive at the 10% level, and the coefficients of digital transformation and technological innovation in Column (2) are significantly positive at the 5 and 1% levels (coefficients are 0.0003 and 0.0069, respectively), which indicates that technological innovation mediates the facilitating effect of digital transformation on the share of labor income in manufacturing enterprises. Thus, Hypothesis 2 is verified.

5.5 Moderating effects test

According to the test of the moderating effect of the degree of industry-university-research association in Models (4), (5), and (6), the results are shown in Table 6. The coefficient of the cross-multiplier terms in column (1) is significantly positive (coefficient = 0.0005, which is significant at the 10% level), indicating that the degree of industry-academia-research association has a significant moderating effect on the main effect in manufacturing firms. Thus, hypothesis H3a is validated. The coefficients of the cross-multiplier terms $Digital_{it} \times Union_{it}$ and $Inno_{it} \times Union_{it}$ in columns (2) and (3) are not significant, indicating that the degree of industry-academia-research association does not have a significant moderating effect on the mediating effect of technological innovation in manufacturing firms. Thus, hypotheses H3b and H3c are not validated.

The reasons might be that the current industry-university-research cooperation of manufacturing enterprises is not tight enough and remains only at the theoretical level,

	(1) Inno.	(2) LIS
Digital	0.0114*	0.0003**
	(1.7607)	(2.1862)
Inno		0.0069***
		(15.4353)
_cons	4.8155	0.6451***
	(1.2044)	(8.6005)
Year fixed	YES	YES
Individual fixed	YES	YES
Control variables	YES	YES
N	9,029	9,029
R^2	0.1125	0.3590
Adj. R^2	0.1107	0.3577

Source(s): Authors

Table 5.
Mediation effect testing results

	(1) LIS	(2) Inno.	(3) LIS
Digital	0.0003**	0.0120*	0.0003*
	(1.9994)	(1.6775)	(1.6969)
Inno.			0.0068***
			(15.1252)
Union	−0.0015	−0.0732	−0.0035
	(−0.6977)	(−0.7402)	(−0.9803)
Digital × Union	0.0005*	−0.0039	0.0005*
	(1.7609)	(−0.3372)	(1.7568)
Inno × Union			0.0007
			(0.7978)
_cons	0.6766***	4.7748	0.6430***
	(8.2155)	(1.1929)	(8.5876)
Year fixed	YES	YES	YES
Individual fixed	YES	YES	YES
Control variables	YES	YES	YES
N	9,029	9,029	9,029
R^2	0.2588	0.1126	0.3600
Adj. R^2	0.2572	0.1107	0.3585

Source(s): Authors

Table 6. Moderating effects testing results

lacking practical in-depth exchanges, such as in-depth enterprise visits and research by universities, and therefore does not have an impact on the effect of digital transformation on technological innovation (Li *et al.*, 2021). Additionally, as it takes a long period of time from the idea of technological innovation to its actual realization in the production process. The knowledge resources brought about by industry-university-research cooperation cannot be digested and utilized by manufacturing enterprises in the short term and cannot be instantly reflected in the increase in labor income share.

6. Heterogeneity analysis

To further investigate whether the digital transformation of manufacturing firms has different effects on labor income shares depending on the type of firm, the sample firms are divided into firms implementing servitization and firms not implementing servitization, as well as state-owned and non-state-owned firms. The test results, as shown in Table 7, show that the effect on labor income share is more pronounced when digital transformation is carried out by firms that have not implemented servitization. The digital transformation of non-state-owned firms is better able to increase their labor income share than that of state-owned firms.

The reason for this may be that for manufacturing enterprises that have implemented a servitization transformation, the enterprises have already received dividends from the increase in service business; therefore, the increase in the labor income share when implementing digital transformation will not be very significant. For enterprises that have not implemented servitized business, the enterprises are still in a position to produce products profitably with a relatively homogeneous industrial structure; when undergoing digital transformation, the impact on the enterprise is more pronounced, and the rise in the share of employee income is more pronounced. State-owned enterprises, due to their special corporate nature, will be affected to a certain extent the government's policies and investment benefits. The development of enterprises is more stable and not easily affected by the development of digital transformation. For non-state-owned enterprises, the system is more flexible and

	(1) Enterprises implementing servitization LIS	(2) Enterprises not implementing servitization LIS	(3) State-owned enterprises LIS	(4) Non-state-owned enterprises LIS
Digital	0.0003	0.0003**	0.0002	0.0005**
	(1.2095)	(2.2049)	(0.4869)	(2.5103)
_cons	0.0733	0.7258***	13.0152	0.6174***
	(0.4892)	(7.0314)	(0.6360)	(6.8562)
Year fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Control variables	YES	YES	YES	YES
N	2,934	6,095	2,914	6,115
R^2	0.2364	0.2838	0.3153	0.2346
Adj. R^2	0.2317	0.2817	0.3110	0.2323

Source(s): Authors

Table 7. Heterogeneity analysis testing results

needs to rely on their own product characteristics to improve enterprise competitiveness and survive fierce market competition. Therefore, the implementation of digital transformation is a good tool for enterprises to achieve high-quality development and increase the share of labor income by increasing the degree of differentiation of their products and services and improving their productivity and labor structure.

7. Conclusions and implications

7.1 Discussion

The innovations in this study include the following: Digital transformation, technological innovation, industry-university-research alliances, and employee labor income share of manufacturing enterprises are included under the same research framework. While most previous studies have explored the impact of digital transformation on enterprise performance, enterprise value, and other factors, this study takes into account the importance of innovation and industry-university-research alliances involving both internal and external factors to explore their combined effect on the share of labor income. Furthermore, this study also analyzes whether there are differences in the impact of digital transformation on the share of labor income depending on the nature of enterprise ownership as well as the transformation strategy and provides targeted recommendations for enterprises.

This study finds that the digital transformation of manufacturing enterprises has a positive contribution to the share of labor income, which is important for the long-term development of the enterprise, and reveals the impact of the digital transformation from the perspective of employees' income. Employees are a fundamental part of realizing enterprise value, so realizing the win-win situation between employee value and enterprise value is the key to the long-term development of manufacturing enterprises. After clarifying this issue, it will help to improve the work motivation of enterprises and employees and jointly and actively respond to enterprise digital transformation.

This study finds the mediating and moderating roles of technological innovation and industry-university-research cooperation. Technological innovation is the path through which manufacturing enterprises can help companies adapt to the needs and changes in the

marketplace. This result indicates that employees of manufacturing enterprises can simultaneously achieve an increase in innovation ability and income level through the digital transformation of manufacturing enterprises. Employees can also enhance their own value in this transformation of the enterprise by being more willing to actively participate in the work, which is important for the development of the enterprise. In addition, this study finds a positive moderating effect of the industry-university-research association. This result suggests that cooperation with universities and research institutes outside the enterprise is a channel for manufacturing enterprises to absorb external knowledge for enterprise practice. Taking advantage of this can contribute to promoting the effect of digital transformation on labor income share in manufacturing enterprises.

In addition, this study finds that digital transformation by non-state-owned and manufacturing firms that have not implemented service-oriented transformation is more likely to contribute to labor income share. This is a reminder that non-state-owned firms should take full advantage of institutional flexibility to enhance digital transformation, while state-owned firms can achieve better development by having the advantage of the government's support. At the same time, digital and service-oriented transformation are important forms of enterprise reform, and manufacturing enterprises that have not yet carried out service-oriented transformation should pay attention to the embedding of digital elements, so as to avoid entering the predicament of facing obsolescence due to failing to keep up with the trend of the development of the manufacturing market.

7.2 Conclusions

Digital transformation of enterprises has become a general trend, and manufacturing enterprises can use data technology to improve labor productivity, improve the structure of the workforce, increase the share of labor income, and achieve high-quality development. Based on the samples of listed manufacturing companies in China from 2013 to 2020, this study explores the impact of the digital transformation of manufacturing enterprises and the share of labor income, as well as the internal mechanism.

The conclusions of this study are as follows. First, the digital transformation of manufacturing enterprises can promote the improvement of labor income share. Second, the technological innovation of manufacturing enterprises can mediate the effect of digital transformation on labor income share. Third, industry-university-research cooperation can positively moderate the promotion effect of digital transformation on labor income share but cannot moderate the mediating effect of technological innovation. Finally, compared to manufacturing enterprises that have carried out service-oriented transformation and state-owned manufacturing enterprises, firms without service-based transformation and non-state-owned firms are better able to increase their labor income share through digital transformation.

The research has two limitations. First, Digital transformation is specifically divided into many aspects, such as the use of digital platforms and systems, the use of digital smart devices, the application of cloud computing and blockchain. This study does not differentiate between specific categories of digital transformation to explore whether they may have different impact roles on labor income shares. Second, this study explores the moderating effect of industry-university-research association on the share of labor income in the process of digital transformation in manufacturing enterprises, but the form of industry-university-research association has not been studied in depth. Future research can continue to explore whether different digital transformation types will have different effects on labor income share and whether different forms of industry-university-research alliances, such as technology development alliances and talent cultivation alliances, have different impacts on the labor income share in manufacturing enterprises.

7.3 Managerial implications

First, China's manufacturing enterprises should increase the breadth and depth of digital transformation. In addition to increasing the integration of digital elements into the scene, digital system platforms, cloud computing, big data analysis and other application tools, it also focuses on increasing intelligent manufacturing equipment, and improving the development and use of digital technology. Through digitalization, production efficiency is improved, the labor force structure is improved, and the income level of employees is improved to achieve common profits.

Secondly, manufacturing enterprises should focuses on technological innovation in the digital transformation process. On the one hand, enterprises are able to cultivate the technological innovation potential of existing employees with the help of digital tools, and comprehensively improve the labor force level of employees to transform it into labor productivity, increase the share of labor income, and improve employee satisfaction. On the other hand, manufacturing enterprises should focus on optimizing the labor force structure through the tendency of a high-skilled labor force in digital transformation, pay attention to the introduction of high-level talent, and increase the share of labor income.

Finally, to increase the labor income share of manufacturing enterprises, enterprises that have not carried out service-oriented transformation should pay more attention to the introduction of digital elements and talents when carrying out digital transformation, and make full use of the digital dividend to improve the production efficiency of enterprises, optimize the structure of the labor force, and increase the share of labor income. At the same time, we should pay attention to the special characteristics of non-state-owned enterprises in manufacturing enterprises, make full use of their institutional flexibility of non-state-owned enterprises to carry out digital transformation strategies, through the introduction of digital hardware and software to assist production, attract and cultivate talent in the field of digitalization, promote enterprise development, and increase the share of labor income. State-owned enterprises can make full use of the government's policy dividend, continue to develop in depth in accordance with their own enterprise characteristics, and can appropriately introduce digital elements to improve production processes.

7.4 Practical implications

This study confirms the important role of digital transformation of manufacturing enterprises in promoting the share of labor income, as well as the mediating and regulating role played by technological innovation and cooperation between industry, academia and research institutes, which brings important practical insights for manufacturing enterprises. First, government departments should focus on policy support for the digital transformation of manufacturing enterprises, increase financial investment, and encourage cooperation between enterprises and universities and research institutes, in order to increase the share of labor income of enterprises and strive to achieve common prosperity.

Secondly, manufacturing enterprises should increase the introduction of digital equipment, pay attention to the investment in projects related to digital themes, and strengthen the application of digital scenes in order to enhance the share of labor income of enterprise employees, enhance enterprise cohesion, and promote enterprise development. At the same time, manufacturing enterprises should strengthen cooperation with universities and other research institutions, invite researchers to conduct in-depth research in enterprises, and promote the transformation of digitalization results through industry-university-research synergy, so that the output of academic results is closer to the actual situation of enterprises, promote the all-round development of enterprises, and realize the two-way promotion of enterprise development and academic progress.

Finally, colleges and universities as well as research institutions should strengthen the cooperative relationship with manufacturing enterprises, and conduct research on the actual problems faced by manufacturing enterprises through actual visits and face-to-face in-depth surveys. Through cooperation, they can help with the development of enterprises, provide enterprises with advanced scientific research support and theoretical basis, facilitate the transformation of digital transformation results, and create more economic value for workers.

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About the authors

Ying Miao (1978-), first author, female, Shenyang, Liaoning, China; School of Economics and Management, Shenyang Aerospace University, associate professor, doctor, with research interests in industrial economics.

Yue Shi (1992-), second author and corresponding author, female, Shenyang, Liaoning, China; School of Economics and Management, Shenyang Aerospace University, with research interests in industrial economics. Yue Shi is the corresponding author and can be contacted at: shiyue1@stu.sau.edu.cn

Hao Jing (1978-), third author, male, Shenyang, Liaoning, China; School of Economics and Management, Shenyang Aerospace University, Dean of the School of Economics and Management at Shenyang Aerospace University, professor, doctor, with research interests in digitalization, business model innovation.