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More is Better or Too Much: Enterprise Digital Inputs and Total Factor Productivity

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Abstract
Digital input is an important way for enterprise development, but there is inconsistency as to whether digital input can sustainably improve enterprise total factor productivity. This paper empirically examines the relationship between digital inputs and enterprise total factor productivity using Shanghai and Shenzhen A-share listed enterprises as research samples. The results show that the relationship between digital inputs and enterprise total factor productivity is inverted U-shape, i.e., the impact of digital inputs on enterprise total factor productivity is not more than good, but may lead to too much, and the above conclusions are still valid after a series of robustness tests and the use of a variety of methods to mitigate endogeneity. Mechanism tests further suggest that financing constraints and agency costs are important ways in which firms' digital inputs affect total factor productivity. The heterogeneity test finds that the inverted U-shaped relationship between firms' digital inputs and total factor productivity is more significant in state-owned enterprises, industries with high marketization levels, and high-tech manufacturing. The findings of this paper enrich the theoretical research on the economic consequences of enterprise digitalization inputs, and provide an important reference for promoting the implementation of enterprise digitalization and achieving high-quality development.

Keywords: digitized inputs; total factor productivity; financing constraints; agency costs

Introduction

Report of the 20th National Congress of the Communist Party of China points out that it is necessary to accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy. At present, under the support of policy guidance, more and more enterprises begin to pay attention to digital construction and actively explore ways to improve the level of digital operation of enterprises. For example, Haier's connected factory to achieve customer personalized order production, Kute Intelligence to meet the customer's personalized customization requirements, Lin Qingxuan use of digital reshaping of enterprise management organization to achieve the turnaround of crisis into opportunity, etc. The successful experience of these enterprises shows that digitalization promotes the upgrading of the enterprise management, production and operation structure, which helps the enterprise to achieve the goal of cost reduction and increase efficiency, and to increase the enterprise's total factor productivity[1]. However, some studies have found that in the process of enterprise implementation of digital transformation, blindly increasing digital investment is difficult to achieve positive results[2], because this process is inevitably accompanied by a large number of equipment investment and technology upgrades, not only increases the management costs, the number of digital talent may not be able to keep up with the new technological requirements, which may lead to a decline in enterprise productivity[3]. Accenture in the “win-win: collaboration to turn crisis into opportunity” report, pointed out that 66% of the surveyed enterprises did not improve the level of enterprise revenue through digital investment, that is, excessive digital investment will have a negative impact on the enterprise. This also suggests that there is no consensus on whether digital investment promotes or inhibits business development at the practical and theoretical levels. Therefore, further clarifying the boundaries of digital inputs affecting firms' total factor productivity can not only provide theoretical guidance for firms to rationally control the scale of digital inputs, but also be of great significance for the government to guide the policy practice of firms' digital inputs.

Based on this, this paper constructs a theoretical analysis framework of “enterprise digital input-total factor productivity” from the perspective of microenterprises, and reveals the relationship between digital input and enterprise total factor productivity in depth. Compared with the existing research literature, the potential marginal contributions of this paper are mainly reflected in the following: First, this paper finds that the relationship between digital inputs and enterprise total factor productivity is inverted U-shape, i.e., there exists a “critical value” of the impact of enterprises' digital inputs on total factor productivity, and this conclusion deepens the “double-edged sword” effect of digital inputs. This finding deepens the theoretical research on the “double-edged sword” effect of digital inputs. Secondly, this paper explores the impact of digital inputs on enterprise total factor productivity through financing constraints and agency costs, which reveals the mechanism of digital inputs affecting enterprise total factor productivity, and enriches the

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research on the mechanism of the economic consequences of enterprise digital inputs. Third, this paper identifies the contextual factors affecting the relationship between digital inputs and enterprise total factor productivity, and finds that the inverted U-shape relationship between digital inputs and enterprise total factor productivity is more significant in state-owned enterprises, industries with a higher level of marketization, and high-tech manufacturing industries, which expands the boundaries of the impact of digital inputs on enterprise total factor productivity, and provides theoretical references for the formulation of relevant policies.

Literature Review and Research Hypothesis

1. Literature Review

1.1 A Study of the Economic Consequences of Business Digitization

Research on the economic consequences of enterprise digitization mainly focuses on three aspects. First, in terms of cost reduction and efficiency. Digital technology, the degree of digitization and the ability of digital transformation are the main driving force of enterprise digital transformation, the higher the ability of digital transformation, the better the performance of the enterprise[4], and the input of digital factors can create new digital products and services, promote the enterprise business performance improvement[5], so as to have a positive impact on the enterprise's total factor productivity[6]. Secondly, it is in the aspect of enterprise innovation. Data as an emerging production factor into the production process, changing the traditional production mode of enterprises, technology update iteration speed up, help enterprises to provide products and services with high efficiency, for example, the higher level of digital technology to effectively promote the innovation of products and services[7]. Third, in the green development. Digitization enables enterprises to obtain more resources and effectively enhance the level of green innovation[8], which in turn promotes green development[9]. Another study found that digitization can only have a positive impact on enterprise development under certain conditions, and sufficient digital capacity and digital knowledge reserves can only achieve a high degree of digitization[10], i.e., the impact of digital transformation on the enterprise may not be a linear relationship[3], the phenomenon is known as the “digitization paradox”, explore The phenomenon is called “digital paradox”, and exploring the causes of “digital paradox” is also an important issue in theoretical research.

1.2 A study of the factors affecting total factor productivity

Existing literature has explored the influencing factors of enterprise total factor productivity from various aspects, this paper briefly categorizes and outlines the relevant factors from both the internal and external environment of the enterprise: First, the influence of internal factors of the

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enterprise. For example, technology level and capital investment are important factors affecting the total factor productivity of enterprises. Enterprise technology upgrading can improve total factor productivity[11], the steady growth of R&D expenditures will also improve enterprise total factor productivity[12], the development of green finance promotes enterprise green total factor productivity[13], etc.; Second, the influence of external environmental factors. For example, government subsidies and policy regulations may have different degrees of impact on enterprise total factor productivity. Government subsidies trigger rent-seeking activities of enterprises, which leads to the negative impact of government subsidies on the total factor productivity of enterprises[14]. In addition, in order to meet the realistic needs of promoting environmentally sustainable development, the relevant environmental regulation requirements are getting higher and higher, requiring enterprises to emphasize low-carbon development and increase the strength of innovation and development, which will also have an impact on total factor productivity[15]. Therefore, it is also an important issue to continuously deepen the exploration of the influencing factors of total factor productivity.

In summary, research on enterprise digitization and total factor productivity has received widespread attention, but there are still inconsistencies in the conclusions of studies on the relationship between enterprise digitization inputs and total factor productivity. Although some studies have pointed out that there may be a "digital paradox" in the process of enterprise digital transformation, the mechanism of this phenomenon needs to be further explored. Therefore, this paper further explores the non-linear relationship of digital inputs on enterprise total factor productivity and the underlying mechanisms to enrich the existing theoretical research literature.

2. Research Hypothesis

Digital inputs affect the total factor productivity of enterprises by improving efficiency, reducing costs and driving technological upgrades. Specifically: first, digital inputs improve enterprise management efficiency. Digital inputs prompt enterprises to carry out business model reforms, improve the efficiency of factor allocation, and promote the improvement of enterprise management efficiency, which in turn promotes the improvement of enterprise total factor productivity. In the process of digital inputs, the use of digital technology to reform the existing business model, or create a new business model[16], can enhance the flexibility and sensitivity to respond to the market. Moreover, digital inputs realize the real-time and transparent management of the enterprise, constrain the behavior of managers, strengthen the supervision of managers, and avoid reducing the efficiency of the enterprise due to agency problems[17]. In addition, digital technology innovation improves the enterprise's ability to capture and analyze market information, promotes the

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improvement of the efficiency of factor allocation and the improvement of the allocation method, and effectively improves the efficiency of enterprise management. For example, Feng et al[18] suggest that digitalization can promote enterprise technology innovation and improve the efficiency of factor allocation, which in turn improves the total factor productivity of enterprises. Second, digital inputs can reduce costs. Through digital technological innovation, enterprise management and operation methods are upgraded, enterprise digital development is strengthened[19], production costs are reduced, and enterprise total factor productivity is increased. The increase in digital inputs helps to break the internal information silos of enterprises, improve the efficiency of enterprise information communication, reduce enterprise transaction costs[20], and realize the improvement of resource allocation efficiency and productivity. At the same time, digitalization is also conducive to the efficient use of raw materials in the production process[21], improve the efficiency of the use of resource elements, and thus reduce management costs[22]. In addition, digital inputs to improve enterprise R & D innovation capacity, emerging digital technologies to help enterprises integrate market demand information, collect and quickly analyze product information, help enterprises produce higher quality and meet market demand for products, thereby reducing operating costs and improving enterprise total factor productivity[23]. Third, digital inputs to promote technological upgrading. Digital inputs to the enterprise to bring a new production mode, data as a new factor of production to participate in production, prompting enterprises to constantly update the technical means, and thus promote the total factor productivity of enterprises. Digital technology can broaden the enterprise information access channels, improve the integration of information resources and analytical capabilities, help to improve the quality of enterprise investment decision-making[24]. At the same time, digital technology helps enterprises accurately capture the information they need, which helps them carry out technological innovation more effectively[25]. In the production process, digital technology can also replace part of the low-skilled labor force, reduce the degree of manual involvement[26], and thus improve the productivity of enterprises. In addition, digital inputs prompt enterprises to absorb or train a group of employees with high-level skills, optimize the structure of labor resources, and thus promote the improvement of enterprise total factor productivity[24]. Finally, digital inputs also bring more advanced emerging equipment and systems, such as artificial intelligence technology to trigger a worldwide change in social productivity. Some studies have shown that AI technological innovation effectively reduces production costs, improves enterprise productivity, and significantly increases enterprise total factor productivity[27].

It has also been found that digitization is not a positive linear relationship with the enterprise total factor productivity continuously, in general, the digital input will increase the input cost and the complexity of enterprise management: one is to increase the input cost, when the enterprise over-digitization input, it will increase the enterprise information cost input, and is not conducive to the

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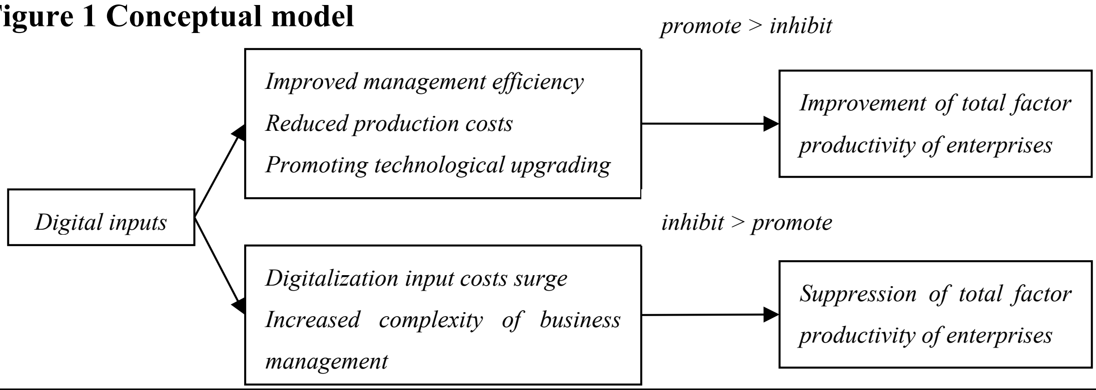
enterprise to improve its innovation performance, and even inhibit the improvement of its innovation performance[28]. Enterprise digital inputs lead to technological upgrading, to achieve the purpose of cost reduction and efficiency, but excessive digital inputs lead to an increase in the amount of capital investment, resulting in an imbalance in the allocation of the enterprise's limited resources[29], but instead inhibit the enhancement of the enterprise's total factor productivity. As Karhade et al[30] statistically found that more than half of IT projects have cost overruns, and over-investment inhibits the innovation effect, which in turn inhibits the improvement of enterprise total factor productivity. In addition, Gebauer et al[31] also proposed that excessive digital investment will weaken innovation, while failing to achieve the expected revenue growth. Secondly, it is to increase the complexity of enterprise management, enterprises should rationally plan the digital input based on the actual situation such as capital scale, operation mode, development direction, etc. Blindly carrying out the digital input will increase the burden of enterprise operation, leading to the confusion of management and production process, which is contrary to the expected effect. Among them, Pang Ruizhi et al[32] found that digital inputs can be advanced digital technology and digital systems to promote enterprises to strengthen communication and cooperation with the outside world to enhance the effect of enterprise innovation, but at the same time, under the influence of emerging technologies, it will strengthen the complexity of enterprise information management, to avoid the leakage of information into the malicious competition, resulting in a decline in enterprise total factor productivity. Digitization brings together the various processes of the enterprise on a digital platform, which is conducive to real-time monitoring and systematic analysis, and can improve the efficiency of each process; however, excessive digital inputs will lead to excessive plunging into internal analysis, affecting the enterprise's real-time adjustment of the direction of innovation and development[33], and ultimately the reverse effect.

From the above analysis, it can be seen that the appropriate amount of digital inputs promotes the total factor productivity of enterprises, and excessive digital inputs inhibit the total factor productivity of enterprises, which leads to the formulation of Hypothesis 1:

Hypothesis 1: The effect of digitization inputs on firms' total factor productivity is inverted U-shaped.

Figure 1 Conceptual model



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Research design

3. Sample selection and data processing

This paper takes the A-share listed companies in Shanghai and Shenzhen from 2008 to 2020 as the research sample, and the data are mainly from Wind database. In the process of sample collection and processing, the samples are screened with reference to the previous common practice, financial enterprises and ST, *ST these special enterprises are excluded from the samples, and the samples with missing key variables are excluded, and finally 25400 observations are obtained. In order to avoid the influence of extreme values on the estimation results, the sample is shrink-tailed by 1% up and down.

4. Variable Settings

4.1 Explained variable

Total factor productivity (lntfp). Total factor productivity is the “residual value” after removing tangible factors such as labor and capital, which reflects the system productivity of enterprises optimizing management mode and upgrading enterprise structure. The LP method is chosen to calculate total factor productivity[34], and total factor productivity is logarithmized.

4.2 Explanatory variable

Digitalization inputs (digitalRatio). Drawing on existing literature[35], the digital input of enterprises is measured using the amount of digitization-related intangible assets as a ratio of intangible assets using keywords related to digitization disclosed in the notes to the financial statements, including: digitization, big data, blockchain, Internet of Things, data systems, management systems, etc.

4.3 Intermediary variable

Drawing on existing literature, this paper uses financing constraints (SA) and agencyCost as mediating variables to measure the impact of digitized inputs on total factor productivity. In line with existing literature practices, the SA index is used to measure financing constraints, and agencyCost is measured as the sum of overhead and selling expenses divided by the proportion of

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sales revenue.

4.4 Control variable

Referring to the existing research literature[36][37], firm characteristics and governance level variables are selected as control variables. Among them, firm characteristics level control variables include: firm size (Size), firm age (Age), book-to-market ratio (MB_ratio), gearing ratio (Leverage), cash holdings (Cash_ratio), and the nature of ownership (SOE), and corporate governance level control variables include: board size, top shareholder shareholding ratio (TopHolder), and institutional investor shareholding ratio (TopHolder). Shareholder Holding (TopHolder), Institutional Investor Holding (instRatio), and Sole Director Ratio (Ind_ratio), while controlling for regional, yearly, and industry effects. The specific definitions and measurements of the variables in the model are shown in Table 1.

Table 1 List of variable definitions

	Name	Define
lntfp	Total factor productivity	Taking the natural logarithm
digitalRatio	Digital inputs	Digitization-related inputs in the notes to the financial statements
SA	Financing constraints	$SA=-0.737*Size + 0.043\times Size^2 - 0.04*Age$
agencyCost	Agency cost	(Administrative expenses + Selling expenses) divided by sales revenue
Size	Enterprise size	Natural logarithm of total assets
Age	Age of business	Difference between the current year and the year of registration
Leverage	Asset-liability ratio	Liabilities divided by assets
MB_ratio	Book-to-market ratio	Market value divided by book value
Cash_ratio	Cash holdings	Cash and cash equivalents divided by total assets at end of period
BoardSize	Board size	Natural logarithm of the number of Board members plus one
Ind_ratio	Ratio of sole director	Independent directors divided by the total number of directors
TopHolder	Shareholding ratio of the largest shareholder	Shareholding of the first largest shareholder (%)
instRatio	Institutional investor shareholding	Shareholding of institutional investors (%)
SOE	Nature of property rights	State-owned enterprises are assigned a value of 1, while others are assigned a value of 0.

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5. Measurement model

This paper uses the following model to test the inverted U-shaped relationship between digitization inputs and firms' total factor productivity:

$$\mathrm{lntfp}_{it} = \alpha + \beta_1 \mathrm{digitalRatio}_{it} + \beta_2 \mathrm{digitalRatio}_{it}^2 + \sum \gamma X_{it} + \mathrm{Year} + \mathrm{Industry} + \mathrm{Province} + \varepsilon_{it}$$

(1)

In equation (1) the explanatory variable lntfp is the total factor productivity indicator of the firm, the explanatory variables digitalRatio and $\mathrm{digitalRatio}^2$ are the primary and secondary terms of the digitized input indicator, respectively, X is the control variable, Year year control variable, Industry is the industry control variable, Province is the region control variable, and ε is the residuals .

Analysis of empirical results

6. Results of descriptive statistics

Table 2 reports the descriptive statistics of the main variables. The mean and median of total factor productivity (lntfp) are 9.101 and 8.986, respectively, which are relatively close to each other, indicating that the total factor productivity of enterprises in China roughly shows a trend of lognormal distribution. The mean value of digitalRatio is 0.091, reflecting the low level of digital input of listed enterprises in China.

Table 2 Descriptive statistics

	N	mean	sd	min	p25	p50	p75	max
lntfp	25400	9.101	1.106	5.785	8.334	8.986	9.746	13.375
digitalRatio	25400	0.089	0.212	0.000	0.000	0.011	0.055	1.000
SA	25400	-3.835	0.257	-5.778	-3.991	-3.829	-3.670	-2.644
agencyCost	25400	0.161	0.126	0.016	0.077	0.127	0.204	0.688
Size	25400	22.165	1.272	19.687	21.248	21.982	22.877	26.101

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Age	25400	18.720	5.826	1.000	15.000	18.000	22.000	66.000
Leverage	25400	0.429	0.203	0.049	0.267	0.424	0.583	0.922
MB_ratio	25400	0.619	0.244	0.120	0.430	0.618	0.807	1.148
Cash_ratio	25400	0.193	0.135	0.015	0.097	0.156	0.250	0.716
BoardSize	25400	2.253	0.176	1.792	2.079	2.303	2.303	2.773
Ind_ratio	25400	0.374	0.053	0.333	0.333	0.333	0.429	0.571
TopHolder	25400	34.992	14.876	8.810	23.285	33.055	45.090	74.820
instRatio	25400	39.083	23.299	0.068	19.349	39.741	57.380	87.947
SOE	25400	0.395	0.489	0.000	0.000	0.000	1.000	1.000

7. Benchmark regression results

Table 3 presents the results of the benchmark regression, i.e., the results of the test of whether there is a non-linear effect of digital inputs on firms' total factor productivity. The results of the benchmark regression with only industry and year fixed effects but no other control variables are presented in column 1 of Table 3, where the regression coefficient of digitalRatio2 is negative and significant at the 1% level. Column 2 of Table 3 presents the results of the regression with the inclusion of other control variables but no year, industry, and region fixed effects, and the regression coefficient for digitalRatio2 is -0.449, which is significant at the 1% level. Column 3 of Table 3 presents the results of the baseline regression with other control variables and industry and year fixed effects, with a regression coefficient for digitalRatio2 of -0.150 and significant at the 5% level. Table 3, column 4 presents the results of the benchmark regression with the addition of other control variables, and region and year fixed effects. digitalRatio2 has a regression coefficient of -0.361 and is significant at the 1% level. In column 5 of Table 3, the results of the benchmark regression with the addition of other control variables, and region and industry fixed effects, the regression coefficient of digitalRatio2 is -0.139, and it is significant at the 10% level. It can be seen that digital inputs have a significant inverted U-shaped relationship with enterprise total factor productivity, and Hypothesis 1 is verified. This suggests that appropriate digital inputs promote enterprise total factor productivity improvement, while excessive digital inputs inhibit enterprise

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total factor productivity improvement.

Table 3 Baseline regression results

	1	2	3	4	5
			lntfp		
digitalRatio	0.813***	0.570***	0.355***	0.468***	0.342***
	(0.116)	(0.068)	(0.063)	(0.068)	(0.063)
digitalRatio^2	-1.015***	-0.449***	-0.150**	-0.361***	-0.139*
	(0.125)	(0.077)	(0.072)	(0.078)	(0.071)
Size		0.675***	0.722***	0.696***	0.692***
		(0.004)	(0.004)	(0.005)	(0.004)
Age		0.002**	0.002***	0.004***	0.001
		(0.001)	(0.001)	(0.001)	(0.001)
Leverage		0.805***	0.646***	0.816***	0.688***
		(0.027)	(0.027)	(0.027)	(0.026)
MB_ratio		-0.115***	-0.244***	-0.296***	-0.084***
		(0.020)	(0.022)	(0.023)	(0.019)
Cash_ratio		0.790***	0.500***	0.742***	0.510***
		(0.032)	(0.031)	(0.032)	(0.030)
BoardSize		-0.127***	-0.055**	-0.126***	-0.005
		(0.028)	(0.026)	(0.028)	(0.026)
Ind_ratio		-0.447***	-0.328***	-0.400***	-0.244***
		(0.089)	(0.080)	(0.088)	(0.081)
TopHolder		0.002***	0.003***	0.002***	0.003***
		(0.000)	(0.000)	(0.000)	(0.000)
instRatio		0.001***	0.001***	0.001***	0.001***
		(0.000)	(0.000)	(0.000)	(0.000)
SOE		-0.062***	-0.020**	-0.025***	0.024***
		(0.009)	(0.009)	(0.010)	(0.009)
_cons	8.430***	-5.932***	-7.092***	-6.107***	-6.666***
	(0.053)	(0.108)	(0.106)	(0.112)	(0.108)
Province	No	No	No	Yes	Yes
Industry	Yes	No	Yes	No	Yes
Year	Yes	No	Yes	Yes	No
N	25400	25400	25400	25400	25400
adj_R^2	0.125	0.696	0.745	0.709	0.750

Note: Robust standard errors in parentheses, * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$, same as in the table below.

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8. Endogeneity test

8.1 Instrumental variable method

There may be endogeneity problems caused by reverse causality between digitization inputs and firms' total factor productivity, resulting in estimation bias. To mitigate the endogeneity problem, the benchmark regression is re-estimated using the two-stage least squares method, using the mean value of the digitization degree of other enterprises in the same industry (excluding the enterprise itself) (aveIndDT) as the instrumental variable, the reason being that the mean value of the digitization degree of other enterprises in the same industry except the enterprise reflects the cognitive level of digitization inputs and the degree of application of the enterprise in the industry, and the larger the mean value is the larger the digitization inputs are, which The greater the mean value, the greater the digitization investment, which meets the requirement of relevance of instrumental variables; while the digitization degree of individual enterprises will not have a direct impact on the total factor productivity of the whole industry, which meets the requirement of exogeneity of instrumental variables.

From the empirical results, Table 4, column 1 shows the first-stage regression results, aveIndDT coefficient is positive and significant at 1% level, that is, the mean digitization degree of the same industry is significantly positively correlated with the digital inputs, which meets the correlation condition of the selected instrumental variables; Table 4, column 2 shows the second-stage regression results, digitalRatio2 coefficient is significantly negative at 1% level, and it passes the instrumental variable exogeneity test, indicating that the baseline regression conclusions remain unchanged after mitigating the endogeneity problem.

8.2 Heckman two-stage model

Due to the possible endogeneity problem caused by sample selection bias, in order to solve the sample selection bias problem, this paper adopts the Heckman two-step method. In the Heckman two-stage test, the first stage sets the explanatory variable as a dummy variable, denoted by DRratio, which takes the value of 1 if the firm has implemented digital inputs, and 0 if it has not, and chooses the same control variables as in the baseline regression, and applies the Probit model for regression to compute the Inverse Mills Ratio (IMR), and the results are shown in Table 4, column 4. Column 3, the results are significant. In the second stage, IMR was included as a control variable in the regression equation, and the results are shown in column 4 of Table 4, with the quadratic term coefficient still significantly negative at the 1% level, consistent with the baseline regression, and the conclusions remain unchanged.

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8.3 Controlling for corporate fixed effects

The main test is regressed using a fixed effects model to eliminate the effects of individual heterogeneity and omitted variables. The results after controlling for firm fixed effects are shown in column 5 of Table 4, where the regression coefficient of digitalRatio2 is negative and significant at the 5% level, and digital inputs show a significant inverted U-shaped relationship with firms' total factor productivity, and the conclusion is consistent with the benchmark regression.

Table 4 Endogeneity test

	1	2	3	4	5
	digitalRatio	lntfp	DRratio	lntfp	lntfp
aveIndDT	0.336***		1.838***	3.051***	
	(0.029)		(0.657)	(0.319)	
aveIndDT^2			-7.739***	-11.011***	
			(2.900)	(1.368)	
digitalRatio		9.736***			0.157***
		(1.587)			(0.056)
digitalRatio^2		-11.253***			-0.112*
		(2.118)			(0.059)
IMR				1.242***	
				(0.210)	
Size	-0.011***	0.681***	0.067***	0.753***	0.634***
	(0.001)	(0.012)	(0.012)	(0.007)	(0.006)
Age	-0.001***	0.006***	-0.008***	-0.002**	0.001
	(0.000)	(0.001)	(0.002)	(0.001)	(0.001)
Leverage	0.071***	0.605***	0.178***	0.760***	0.198***
	(0.008)	(0.042)	(0.060)	(0.031)	(0.023)
MB_ratio	-0.045***	-0.127***	-0.125**	-0.300***	-0.080***
	(0.007)	(0.037)	(0.057)	(0.024)	(0.014)
Cash_ratio	0.099***	0.335***	0.163**	0.603***	0.191***
	(0.012)	(0.060)	(0.080)	(0.035)	(0.024)
BoardSize	-0.010	-0.147***	-0.002	-0.050*	0.110***
	(0.009)	(0.042)	(0.064)	(0.026)	(0.027)
Ind_ratio	0.028	-0.424***	0.257	-0.196**	0.187**
	(0.026)	(0.111)	(0.206)	(0.084)	(0.074)
TopHolder	0.000*	0.003***	0.002***	0.004***	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
instRatio	-0.000	0.001*	-0.000	0.001***	0.000***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
SOE	-0.007**	0.006	-0.201***	-0.128***	-0.034**

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	(0.003)	(0.013)	(0.022)	(0.021)	(0.016)
_cons	0.248***	-5.226***	-1.149***	-8.484***	-5.493***
	(0.034)	(0.410)	(0.282)	(0.285)	(0.149)
Province	No	No	No	No	No
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	No
N	25400	25400	25400	25400	25201
adj_R^2/ pseudo_R^2	0.237	0.470	0.087	0.745	0.920
Kleibergen-Paap rk LM		32.38			
		[0.000]			
Kleibergen-Paap rk Wald		16.202			
F		{7.03}			

Note: In parentheses are the critical values of the Stock-Yogo test at a level where the true significance level does not exceed 10%.

9. Robustness check

9.1 Independent variable lagged one period

The effect of digital inputs on total factor productivity is examined using the independent variable lagged one period as an explanatory variable. As can be seen from column 1 of Table 5, the coefficient of digitalRatio2 is significantly negative at the 1% level, and the relationship between digitalization inputs and firms' total factor productivity is still inverted U-shape, which further indicates that the results of this paper are reliable.

9.2 Controlling for fixed effects

In order to avoid errors caused by some unobservable factors, an interaction term between the time dummy variable and the industry dummy variable is added to the regression. The regression results are shown in column 2 of Table 5, where the regression coefficient of digitalRatio2 is significantly negative, and digital inputs show a significant inverted U-shaped relationship with firms' total factor productivity.

9.3 Exclusion of special events

Excluding the 2010 crisis event and the 2015 stock market crash event to eliminate the influence of special events on the main effect, the regression results are shown in column 3 of Table 5, where the regression coefficient of digitalRatio2 is significantly negative, and digital inputs show a

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significant inverted U-shape relationship with firms' total factor productivity.

Table 5 Robustness test

	1	2	3
		lntfp	
L.digitalRatio	0.451***		
	(0.076)		
L.digitalRatio^2	-0.367***		
	(0.087)		
digitalRatio		0.359***	0.384***
		(0.064)	(0.069)
digitalRatio^2		-0.162**	-0.151*
		(0.072)	(0.078)
Size	0.698***	0.721***	0.719***
	(0.005)	(0.004)	(0.005)
Age	0.003***	0.002***	0.002***
	(0.001)	(0.001)	(0.001)
Leverage	0.826***	0.637***	0.657***
	(0.030)	(0.027)	(0.030)
MB_ratio	-0.316***	-0.242***	-0.214***
	(0.025)	(0.022)	(0.024)
Cash_ratio	0.807***	0.493***	0.448***
	(0.037)	(0.031)	(0.035)
BoardSize	-0.152***	-0.053**	-0.086***
	(0.030)	(0.026)	(0.030)
Ind_ratio	-0.395***	-0.334***	-0.380***
	(0.096)	(0.080)	(0.092)
TopHolder	0.002***	0.003***	0.003***
	(0.000)	(0.000)	(0.000)
instRatio	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)
SOE	-0.019*	-0.019**	-0.033***
	(0.011)	(0.009)	(0.010)
_cons	-6.271***	-7.053***	-6.996***
	(0.124)	(0.143)	(0.124)
Province	Yes	No	No
Industry	No	Yes	Yes
Year	Yes	Yes	Yes
N	21206	25400	19784
adj_R^2	0.707	0.747	0.747

10. Mechanism test

When enterprises have financing constraints, it may lead to an imbalance in enterprise resource allocation and reduce enterprise total factor productivity[38]. Enterprise digitization inputs broaden the information flow channels, increase information transparency, and alleviate information asymmetry[39], which helps to reduce the financing constraints of the enterprise[40], and thus plays a positive role in enhancing the total factor productivity of the enterprise. However, in the process of digitization, it may also lead to a more prominent agency problem between corporate management and shareholders, and the agency cost will have a negative impact on corporate performance[41], which in turn inhibits the enhancement of corporate total factor productivity. The above analysis suggests that financing constraints and agency costs are important channels through which digitization inputs affect firms' total factor productivity.

10.1 The role of financing constraints

Drawing on the study of Sun Xuejiao et al[42], the SA index, which is composed of two exogenous variables, namely, firm size and firm age, is chosen as a proxy for corporate financing constraints, in order to avoid the subjectivity and measurement bias of other measures.The measurement equation of the SA index is shown in the model (2).All the SA indexes are negative, and the larger the value, the greater the constraint.

$$SA = 0.043 \times size^2 - 0.04 \times Age - 0.073 \times size \qquad (2)$$

The regression results are shown in columns 1 and 2 of Table 6. Column 1 shows the regression results of digitization on financing constraints, and the regression coefficient of digitalRatio is -0.042, which is significant at the 1% level, which indicates that increasing digitization inputs can alleviate the financing constraints of the enterprises; Column 2 shows the regression results of digitization inputs on total factor productivity after the addition of financing constraints, in which the regression coefficient of SA is - 0.211 and is significant at the 1% level, which indicates that easing financing constraints can promote enterprises to improve total factor productivity; the regression coefficient of digitalRatio2 is -0.140, which is significant at the 10% level, which shows that financing constraints play a partly intermediary role in the impact of digital inputs on total factor productivity, i.e., increasing digital inputs can alleviate financing constraints, and then promote the the increase of total factor productivity of enterprises.

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10.2 The role of agency costs

Drawing on Rashid's[43] study, this paper uses the sum of overhead and selling expenses as a percentage of sales as the first type of agency costs for the mediation effect test. The regression results are shown in columns 3 and 4 of Table 6. Column 3 shows the regression results of digital inputs on agency costs, and the regression coefficient of digitalRatio is 0.108, which is significant at the 1% level, which indicates that increasing digital inputs significantly increases the agency costs of firms. Column 4 shows the regression results of digitized inputs on total factor productivity after adding agencyCost, in which the regression coefficient of agencyCost is -1.890 and is significant at the 1% level, which indicates that the increase of agencyCost will inhibit the increase of enterprise's total factor productivity; and the regression coefficient of digitalRatio2 is -0.380, which is significant at the 1% level, which shows that the agency cost plays a partial mediating role in the impact of digital input on total factor productivity; that is, excessive increase in digital input will lead to an increase in agency cost, thus inhibiting the enterprise's total factor productivity improvement.

Table 6 Mechanism test

	1	2	3	4
	SA	lntfp	agencyCost	lntfp
digitalRatio	-0.023**	0.351***	0.107***	0.566***
	(0.011)	(0.063)	(0.013)	(0.060)
digitalRatio^2	0.031***	-0.145**	-0.121***	-0.389***
	(0.012)	(0.072)	(0.014)	(0.066)
SA		-0.175***		
		(0.035)		
agencyCost				-1.968***
				(0.039)
Size	0.023***	0.726***	-0.010***	0.703***
	(0.001)	(0.004)	(0.001)	(0.004)
Age	-0.037***	-0.004***	0.001***	0.004***
	(0.000)	(0.001)	(0.000)	(0.001)
Leverage	-0.011***	0.644***	-0.102***	0.446***
	(0.004)	(0.027)	(0.005)	(0.024)
MB_ratio	-0.036***	-0.250***	-0.078***	-0.398***
	(0.004)	(0.022)	(0.005)	(0.020)
Cash_ratio	0.073***	0.513***	0.061***	0.620***
	(0.006)	(0.031)	(0.007)	(0.029)
BoardSize	0.005	-0.055**	0.011**	-0.033
	(0.005)	(0.026)	(0.005)	(0.024)

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Ind_ratio	0.119***	-0.307***	0.081***	-0.170**
	(0.014)	(0.081)	(0.015)	(0.075)
TopHolder	0.000***	0.003***	-0.000***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
instRatio	-0.000***	0.001***	0.000*	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
SOE	-0.004**	-0.021**	-0.011***	-0.043***
	(0.002)	(0.009)	(0.002)	(0.008)
_cons	-3.672***	-7.734***	0.406***	-6.293***
	(0.026)	(0.172)	(0.020)	(0.101)
Province	No	No	No	No
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	25400	25400	25400	25400
adj_R^2	0.845	0.745	0.236	0.783

11. Heterogeneity test

11.1 Nature of property rights

There are differences between state-owned and non-state-owned enterprises in terms of resources, policies, and business objectives, so there are differences in the impact of digital inputs on the total factor productivity of enterprises. Columns 1 and 2 of Table 7 show the regression results for different property rights properties, and the regression coefficient of digitalRatio2 is negative and significant at the 1% level in state-owned enterprises, while it is not significant in non-state-owned enterprises. It can be seen that relative to non-state-owned enterprises, moderately increasing the scale of digital inputs in state-owned enterprises will increase enterprise total factor productivity to a greater extent, and excessive digital inputs will inhibit enterprise total factor productivity.

11.2 Enterprise Technology Characteristics

Compared to traditional manufacturing firms, high-tech manufacturing firms may focus more on digitization inputs to enhance their competitive advantage[44], so the impact of digitization inputs on firms' total factor productivity may also differ. Columns 3 and 4 of Table 7 report the results of the test for whether the firm is a high-tech manufacturing firm. The regression coefficient of digitalRatio2 is negative and significant at the 1% level in column 4 for high-tech manufacturing, while it is not significant in column 3 for non-high-tech manufacturing firms. It can be seen that, relative to non-high-tech manufacturing firms, for high-tech manufacturing firms, moderate digital

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inputs can increase total factor productivity, but excessive digital inputs can have a dampening effect on firms' total factor productivity improvement.

11.3 Level of marketization

There are differences in the level of marketization in different regions, and regions with a high level of marketization are rich in factor resources and have a perfect institutional environment[45], which may also have different impacts on the total factor productivity of enterprises. Columns 5 and 6 of Table 7 test the relationship between enterprises' digital inputs and total factor productivity under different marketization levels. The regression coefficient of digitalRatio2 is negative and significant at the 5% level for the sample of firms in regions with high levels of marketization in column 6, while it is not significant for the sample of firms in regions with lower levels of marketization in column 5. It can be seen that relative to enterprises in regions with lower levels of marketization, moderate digital inputs by enterprises in regions with higher levels of marketization can help to increase the total factor productivity of enterprises, but excessive increase in digital inputs can have a significant inhibitory effect on the total factor productivity of enterprises.

Table 7 Heterogeneity test

	1	2	3	4	5	6
	lntfp					
	non-SOE	SOE	Tech-low	Tech-high	MI-low	MI-high
digitalRatio	0.258***	0.534***	0.214**	0.502***	0.358***	0.510***
	(0.079)	(0.132)	(0.108)	(0.096)	(0.091)	(0.104)
digitalRatio^2	0.017	-0.408***	-0.027	-0.333***	-0.135	-0.336**
	(0.091)	(0.145)	(0.123)	(0.110)	(0.098)	(0.136)
Size	0.717***	0.737***	0.734***	0.684***	0.728***	0.720***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Age	0.000	0.006***	0.003**	0.003***	-0.002	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Leverage	0.646***	0.554***	0.556***	0.830***	0.726***	0.498***
	(0.037)	(0.051)	(0.041)	(0.044)	(0.042)	(0.041)
MB_ratio	-0.170***	-0.270***	-0.347***	-0.114***	-0.279***	-0.268***
	(0.030)	(0.042)	(0.032)	(0.036)	(0.034)	(0.032)
Cash_ratio	0.299***	0.742***	0.343***	0.731***	0.536***	0.340***
	(0.041)	(0.066)	(0.047)	(0.051)	(0.048)	(0.047)
BoardSize	-0.022	-0.169***	-0.107***	-0.165***	-0.148***	-0.037
	(0.040)	(0.044)	(0.039)	(0.049)	(0.040)	(0.041)
Ind_ratio	-0.273**	-0.388***	-0.562***	-0.248*	-0.209*	-0.602***

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	(0.119)	(0.144)	(0.121)	(0.150)	(0.127)	(0.122)
TopHolder	0.003***	0.003***	0.003***	0.002***	0.002***	0.004***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
instRatio	0.001***	-0.000	0.001***	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
SOE			0.046***	-0.080***	-0.054***	0.039***
			(0.013)	(0.018)	(0.014)	(0.014)
_cons	-7.144***	-7.131***	-7.138***	-5.840***	-7.025***	-6.788***
	(0.168)	(0.180)	(0.159)	(0.196)	(0.161)	(0.167)
Province	No	No	No	No	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	No
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	13022	7243	10340	9925	11648	8617
adj_R^2	0.713	0.760	0.752	0.715	0.740	0.749

Conclusions and recommendations of the study

With the booming development of digital economy, the driving role of data as a new production factor for enterprises has become more and more obvious, and digitization has become a necessary option for enterprise development, and the related research has become more and more abundant. This paper takes Shanghai and Shenzhen A-share enterprises as research samples to empirically examine the impact of digital inputs on enterprise total factor productivity and its mechanism, and finds that: (1) Digital inputs and enterprise total factor productivity show an inverted U-shape relationship, i.e., moderate digital inputs will promote enterprise total factor productivity, while excessive digital inputs will inhibit enterprise total factor productivity, i.e., there is a “tipping point” in the impact of digital inputs on enterprise total factor productivity. In other words, there is a “tipping point” in the impact of digital inputs on enterprise total factor productivity. In other words, there is a “double-edged sword” effect of digital inputs, and simply relying on increasing digital inputs will not increase enterprise total factor productivity in a sustainable manner. (2) Financing constraints and agency costs play a partial mediating role in the impact of digital inputs on enterprise total factor productivity, reflecting that digital inputs can affect enterprise total factor productivity through the channels of financing constraints and agency costs. (3) The impact of digital inputs on enterprise total factor productivity is characterized by heterogeneity, and the inverted U-shaped relationship of the impact of digital inputs on enterprise total factor productivity exists in state-owned enterprises, high-tech manufacturing enterprises, and enterprises in regions with higher levels of marketization.

Combined with the above conclusions, this paper puts forward the following suggestions: (1)

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Fully consider the inflection point effect of digital input, digital development is the road to high-quality development of enterprises, but enterprises need to reasonably plan the scale of digital input to achieve a sustained and stable increase in total factor productivity. For enterprises with a high level of digitization, it is necessary to rationally allocate enterprise resource inputs to ensure that the level of digital inputs is within a reasonable range, in order to avoid the occurrence of the phenomenon of "too little too late", leading to the "digital input paradox", that is, causing the total factor productivity to fall instead of rising. In order to avoid the phenomenon of "overdoing it", which leads to the "digital input paradox", i.e. the result of total factor productivity falling instead of rising. For enterprises with a low level of digitization, digital input has the role of "more is better", enterprises need to increase digital input to promote the speed of the digital development process, which in turn promotes the high-quality development of enterprises. (2) Pay attention to the heterogeneous impact of digital input on enterprise total factor productivity. Due to the heterogeneity of the non-linear impact of digital inputs on enterprise total factor productivity, enterprises with different characteristics should adopt differentiated coping strategies. For non-high-tech enterprises, non-state-owned enterprises, and enterprises in regions with a low level of marketization, there is no significant non-linear relationship between digital inputs and enterprise total factor productivity, and the current situation is still on the left side of the inflection point, i.e., the impact of digital inputs on enterprise total factor productivity is a facilitating effect. At this stage, for non-high-tech enterprises, non-state-owned enterprises, and enterprises in regions with a low level of marketization, it is necessary to accelerate the digital transformation and give full play to the positive role of digital input elements in the process of high-quality development of enterprises. (3) Promote the optimization of the external environment for the digital development of enterprises. On the one hand, since digitalization inputs can affect the total factor productivity of enterprises through financing constraints and agency costs, the policy level should create a better external financing environment for enterprises, attract more investors to pay attention to and support enterprise digitization, and provide sustainable conditions to support enterprise digitalization inputs. On the other hand, we should pay attention to the synergistic matching between different environmental factors. Although the inflection point of digitalization investment is still far away for most enterprises, we should continue to improve the "threshold value" of digitalization investment that may produce negative effects, so as to create a good external environment for the development of enterprise digitalization.

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