The Effect of Digitization on Enterprise Innovation

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Abstract

This paper mainly studies the impact of enterprise digital transformation on technological innovation. Based on the whole industry data of A-share listed enterprises, the paper analyzes the text of enterprise annual report and extracts digital keywords to construct core explanatory variables, and takes cost expansion multiple as an intermediary variable to explain the mechanism between digitalization and enterprise technological innovation. The regression results show that: first, the digital transformation has a significant inverted U-shaped impact on the quantity and quality of technological innovation input and innovation output. Second, before the inflection point, the marginal benefit of digitalization is greater than the marginal cost, and the technological innovation of enterprises is promoted under the effect of economies of scale. After the inflection point, the marginal benefit of digitalization is less than the marginal cost, and the effect of diseconomies of scale makes the marginal input and output of technological innovation of enterprises decrease. Thirdly, a large number of samples are located before the inflection point where the marginal utility of the digitalization level is zero, which indicates that the vast majority of Enterprises in China are still in an uphill phase in the promotion of digital transformation. Fourthly, the empirical results show that the impact of enterprise digitization level on technological innovation has a positive decreasing effect over time, which can be regarded as a long-term impact on enterprise fixed assets in the depreciation process.

Keywords-*Digital transformation; Enterprise technology innovation; Cost expansion multiple*

1.INTRODUCTION

The digital economy has become a key driving force for the national economy these years[1]. As the previous research shows, enterprise digital transformation is of great importance in the context of the digital economy. Besides that, it also has an important impact on enterprise technological innovation[2]. Based on the above research background, we can know the importance of digital transformation for enterprises, which is a common feature of the market economy in the future, and enterprise innovation is highly necessary for a national strategy and market competition. Although the two are considered to be highly correlated in reality, the specific impact of digital transformation on enterprise innovation has not been comprehensively and deeply studied in the academic circle. Therefore, this paper will comprehensively and deeply explore the impact of digital transformation on enterprise innovation, dig out the specific logic and mechanism of digital transformation on enterprise innovation, and provide theoretical, policy, and practical suggestions for future policies and practices. Moreover, the current academic circle analyzes digital transformation and enterprise innovation either in a specific enterprise or industry or at the municipal and provincial level[3]. Therefore, it is limited by the research field and scope, and cannot carry out follow-up and expansion research well. In this paper, a-share listed companies in the whole industry will be taken as the research object, so there is A large space for development in follow-up research and expansion, and the research conclusions are more universally applicable.

2. RESEARCH DESIGN AND PROGRESS

2.1. Research Design

2.1.1. Research hypothesis

Before proceeding with the empirical design, I extensively read the literature and made the following hypothesis:

Hypothesis 1: Digital transformation of enterprises has a positive impact on technological innovation

Digital transformation brings the reduction of transaction cost, communication cost and information search cost of enterprises, improves the operation

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efficiency of enterprises, promotes the quality and efficiency of the whole process, and thus promotes the technological innovation of enterprises[4].

Hypothesis 2: Digital transformation of enterprises has an inverted U-shaped impact on technological innovation

When digital transformation reaches a certain scale, the marginal cost of digitalization is greater than the marginal benefit, which increases the cost of enterprise experience management, introduction and maintenance, adaptation and training, etc., reduces the profit space of enterprises, reduces innovation resources, and inhibits enterprise technological innovation.

In order to verify the hypothesis, I adopted the one-by-one regression method. First, the impact of the primary term at the level of digitization on the enterprise's technological innovation was not significant, and then the quadratic term was added to obtain significant regression results. Under this, model construction and mechanism testing were carried out.

2.1.2. Econometric model

In order to explore the impact of digitalization level on innovation, we set the model as follows:

$$ln(Index_{innovation}) = \beta_0 + \beta_1 Index_{\text{digital}} + \beta_2 (Index_{\text{digital}})^2 + X'\theta + \varepsilon$$

$\ln(\text{Index}_{\text{innovation}})$Represents the innovation level, which is measured from three aspects: R&D input, patent application and invention patent application, respectively representing innovation input, innovation output quantity and innovation output quality. Represents the digitalization level. Different indicators of enterprise digitalization level are obtained by the text analysis method, including the total word frequency of all keywords, the total word frequency of frequent keywords and the binary dummy variable constructed by the total word frequency of keywords/the total word number of the annual report. X Represents the set of control variables, including some enterprise microdata that affects enterprise technological innovation but is not completely correlated with core explanatory variables; εIs the error term, which contains some disturbance that cannot be observed.

2.1.3. Data source and pretreatment

The explained variables in this paper come from the data required for modeling and empirical analysis from The Tidal Information network, WIND database and CSMAR database. The tide of information network is the China Securities Regulatory Commission designated website information disclosure of listed companies, is China's first comprehensive deep Shanghai more than 2500 listed companies disclosure announcement of large securities professional website information and market data, this article on the website through web crawler for a-share listed company's annual report data, is used to construct the enterprise digital level; Obtain data of patent applications and invention patent applications in CSMAR database; Obtain enterprise R&D investment and control variable data from WIND database. In the process of data cleaning, ST, ST* and financial industry enterprises were eliminated, and missing values and incomplete information enterprises were eliminated. Finally, 2,500 a-share listed companies' data were obtained.

2.1.4. Variable construction

2.1.4.1. Explained variable: The logarithmic form of enterprise innovation variable index:$ln(Index_{innovation})$

In order to evaluate the impact of digitization on innovation, this paper uses the data of the third period to obtain the innovation indicators of enterprises from the perspectives of R&D investment, patent application number and invention patent application number by referring to Liu Chunlin and Tian Ling (2021)[5], explores the lag effect of digitization on innovation, and uses the index to de-expand the data. (lnRD)(lnApplycation)(lninvent)

2.1.4.2. Explanatory variable: Enterprise digitization level:$Index_{digital}$

In order to quantitatively evaluate the digitalization level of enterprises, this paper conducts text analysis on the annual reports of A-share listed companies, constructs keywords to measure the digitalization level and counts word frequency, so as to reflect the degree of digitalization transformation of enterprises. The specific steps are as follows:

A total of 159 possible keywords were given by referring to relevant works of literature.

Search the annual reports of a-share listed companies in the industry from 2014 to 2019 on Ju Chao Information website;

Using keywords segmentation, text analysis statistics of the word frequency of segmentation in each company's annual report, statistics of the total word frequency of keywords, defined as dig-level;

According to the association rules of word segmentation, the frequent item set of keywords was screened out and the keyword range was narrowed to obtain 18 frequent keywords. The total word frequency of frequent keywords was counted and defined as SCR_diglevel.

Control variables set X contains a series of factors that may affect the company's innovation level, including

a fixed number of years of the company's business (Age), the total assets of the company takes logarithm (TA), the company take logarithm (FA) net value of fixed assets, enterprise investment return and the ratio of total (ROA), the enterprise asset ratio and the ratio of total assets (DAR), Cash ratio (CR) derived from (monetary capital + marketable securities)/current liabilities, StateOwned, Size.

variables	definition
Interpreted variables: enterprise innovation (t, t + 1, t + 2 phases)	
$lnRD_t$ $lnRD_{t+1}$ $lnRD_{t+2}$	The company's R&D investment in that year added 1 logarithmic, and lagged behind one and two phases,reflecting the enterprise innovation investment
$lnApplycation_t$ $lnApplycation_{t+1}$ $lnApplycation_{t+2}$	The number of invention patents applied in the current year added 1 logarithmic, and lagged behind one and two periods, reflecting the innovation output of the enterprise
$lninvent_t$ $lninvent_{t+1}$ $lninvent_{t+2}$	When the number of invention patents granted by the company took 1 logarithmic, and laggedbehind one and two periods, reflecting the innovation quality of the enterprise output
Interpretation variable: digital level (t phases)	
diglevel	Total number of unfiltered digital keywords
scr_diglevel	For the total number of screened digital keywords, the frequent term set of keywords was extracted for a total of 18 by association analysis
diglevel2	The digital level square items for the total number of key words were not screened
scr_diglevel2	Filter the digital level square terms for the total number of keywords
diglevel12	dummy variable of digital level, diglevel greater than biquartile take 1, less than or equal to biquartile take 0
scr_diglevel22	after screening the frequent keywords, scr diglevel greater than biquartile take 1, less than biquartile takes the 0
metavariable: enterprise cost (t phases)	
Cost_expand	the total operating cost add 1 divided by the R&D investment add 1,take logarithm
Control variable (t phases)	
Age	Operating life of the company = current period -- enterprise registration year + 1
TA	The net value of the company, take logarithm
FA	The company's net fixed asset value, take logarithm
ROA	Ratio between enterprise investment return and total investment
DAR	Ratio between enterprise asset-liability ratio and total assets
CR	Cash ratio = (monetary capital + negotiable securities) / current liabilities
StateOwned	Company ownership property, if it is a state-owned enterprise, then StateOwned take 1, otherwise take 0
Size	Total enterprise assets greater than the mean, large enterprises, Size=1; Otherwise, Size=0

Figure 1. Variable Definition

2.1.5. Endogenous treatment

Although the empirical results have shown that there is a significant correlation between digital transformation and enterprise innovation, further discussion is needed to determine the causal effect of the two. It is worth noting that although this paper has controlled many variables that may affect enterprise innovation, such as enterprise size, enterprise operating years, and total net asset value of a company, there are still many other unobtainable factors affecting enterprise innovation in reality, so there may be a problem of missing variables in this study. Measure error may arise at the same time, the data obtained in this paper, enterprise level lead to false or exaggerated the digitized transformation errors, the data of the digital transformation of information disclosure is insufficient or excessive make enterprise annual report cannot accurately reflect the extent to which the company digital transformation, keywords cannot reflect comprehensively the digital transformation of enterprise, etc. , can cause endogenous problems. Secondly, in theory, enterprises' promotion of digital transformation,

such as digital management and digital deployment, can promote the optimization and upgrading of corporate governance structure, thus promoting enterprise innovation, and the improvement of enterprise innovation, in turn, will further promote enterprise digital transformation, and there may be a reverse causality relationship between the two.

In order to solve the endogeneity problem, this paper adopts instrumental variable method. In the field of economics, a good instrumental variable needs to satisfy the conditions of externality and correlation. In terms of correlation, the level of digitalization by province affects enterprise innovation. In regions with higher digitalization levels, enterprises can make better use of digital information to promote digital transformation, optimize corporate governance structure, promote efficient allocation of resources, and improve enterprise innovation. In exogenesis, the digitalization level of the region is independent of other random disturbance terms.

Based on this, this paper uses the digitization level of provinces as an instrumental variable. In terms of specific indicators, a comprehensive index of digitalization level is obtained by entropy weight method using mobile phone penetration rate, Internet penetration rate, number of Internet broadband access ports and number of mobile Internet users. Data source: China Economic Network database - provincial annual database.

This paper will use two-stage least square regression to test the rationality of instrumental variables in the subsequent research. In the first-stage model, we will use endogenous explanatory variables to perform OLS regression on instrumental variable IV and other control variables. The second-stage model was substituted into the original OLS model with the fitting results of the first step, so as to obtain the new fitting results and compare them with the fitting results of the original OLS model.

3. ANALYSIS

3.1. Mechanism analysis

Based on the regression results, this paper analyzes the causal effect of digitization level on technological innovation, and explores the realistic logic and specific mechanism of digitalization influencing innovation behavior at the micro level of enterprises. Preliminary regression analysis results show that there is an inverted U-shaped relationship between digitization level and technological innovation (including R&D investment and invention patent application). Through literature analysis and logical deduction, this paper further explains the inverted U-shaped nonlinear relationship with cost expansion multiple as a mediator variable. In the regression results above, we use cost expansion multiple as a mediator variable to test the inverted U-shaped relationship between enterprise digitization level and technological innovation. Combined with the economic significance, it can be explained as follows:

3.1.1. There is a U-shaped relationship between enterprise digitization level and cost expansion multiple.

Before the inflection point, the digitalization level of enterprises can reduce the cost expansion multiple, and the marginal benefit of digitalization is greater than the marginal cost of digitalization, thus producing economies of scale effect and promoting enterprise innovation. First, the transformation and upgrading of digital infrastructure will improve the quality and efficiency of the whole process of enterprises and reduce efficiency costs. According to the resource-based theory and the theory of IT capability, enterprise through the digital transformation, can make full use of big data such as the advantages of digital technology, play an important role as a factor of production data, through close enterprise internal and external resource sharing, information exchange between the main body, mutual collaboration, the whole process to improve the work efficiency and reduce unnecessary costs. Second, digital transformation sends positive signals to the outside world, increases the availability of enterprise resources and reduces enterprise communication costs. Based on the signal theory, enterprises pay attention to promoting digital transformation and related publicity, which is in line with the government's policy orientation and easier to obtain the government's orientation in policies, resources and other aspects. At the same time, it sends a signal to the market that the development prospect is sustainable and the enterprise is trustworthy and capable, and it is easier to win the trust of the market in the investment and financing activities, thus it is more likely to provide more support for its own innovation behavior. Digitization improves the availability of government and market resources, which can greatly reduce the communication costs of enterprises. Third, increase the quality supply of enterprises, improve user demand, reduce the cost of supply and demand matching. On the supply side, the key to the digital transformation of enterprises lies in the formulation of enterprise development plans from the perspective of the whole industrial chain, abandoning the strong control and solidification mode, building digital systems in an enabling, open and ecological collaborative way, and truly focusing on market demand to improve efficiency and product and service value from a global perspective. Increasingly advanced digital equipment and technology support the transformation of business models between upstream and downstream enterprises and between enterprises and channels, from a simple contractual relationship to mutual benefit, joint exploration of profit model, through the construction of 2 more efficient enterprise infrastructure and collaborative model to promote quality supply; On the demand side,

the new data capture the new demand of the market, creating the possibility of enterprise innovation. With the popularization of the Internet and the development of the digital economy, the increasingly complex and changeable market environment and the improvement of information transparency at the consumer end have put forward higher requirements for enterprises to efficiently respond to consumer needs and provide quality services. Digital technology includes big data analysis and research, application of digital scene interaction, real-time dynamic new data monitoring and rapid capture of new market demand for enterprises. Digitization brings efficiency to both supply and demand, thus reducing the marketing cost for enterprises to expand the market and attract users. Fourth, cultivate the cultural innovation and personal efficiency of high-quality employees, reduce the demand for manpower and reduce the cost of enterprise manpower. The construction of the core explanatory variables in this paper, to a certain extent, can reflect the importance and publicity of the enterprise to digitalization, and reflect the level of digital culture construction of the enterprise. Dare to innovate, demand-oriented as the core of digital adapted to the digital construction of enterprise culture, encourages employees to take the initiative to change, grasp opportunities, trial and error in attempting to promote service quality, and the effect product, helps to cultivate the ability to accept new things, learn new knowledge, inspire their exploring spirit, and, in turn, promote the realization of technological innovation. At the same time, the improvement of the personal ability and efficiency of high-quality employees and the digital replacement of part of the labor force can effectively reduce the human cost of enterprises.

After the inflection point, enterprises' over-investment in digitalization will lead to diseconomies of scale, which will increase their cost expansion multiple, reduce the efficiency of enterprises' production and operation, and thus weaken their innovation ability. First, the cost of technology introduction is rising. Similar to the logic of technology introduction between countries and regions, when an enterprise's digitalization level is in a backward position in the industry, it can learn from the experience and lessons of other enterprises in the same industry in the process of digitalization transformation through path imitation, and realize the improvement of digitalization level in a shorter time with higher efficiency and lower cost. With the continuous acceleration of technology iteration and update, enterprises based on higher level digital technology have improved their digitalization level, and the introduction of core digital technology will face the explicit cost increase brought by stricter technology patent protection. At the same time, the reduction of reference cases in the industry makes enterprises face greater risks and uncertainties, and increases the potential cost of technology introduction. Second, the equipment maintenance costs, as companies introduced in the process of digital equipment, technology is the nature of the fixed assets investment or corresponding to a large number of the form a complete set of investment in fixed assets, when digitized already meet the demand of enterprise production and business innovation, further investment and cannot ascend the marginal output of enterprise innovation, it means idle resources; Third, the cost of operation and management is rising. The digitization of enterprises is highly dependent on digital infrastructure equipment and digital platform, while digital equipment and platform are public goods. Due to the widespread governance problems of public goods, with the increasing degree of digitization of enterprises and the continuous growth of digital equipment, the difficulty and cost of governance will increase. The fourth is to adapt to the rising cost of learning. Enterprise for the investment, the introduction of digital hardware and software and services need to learn to adapt to, high levels of the digital input increased with employee training and difficulty of enterprise management system integration, even if the cost of adaptability than the digital equipment technology is applied to improve the production and business operation process to save the cost, improve enterprise digital degree will gain weight instead burden, Therefore, the continuous improvement of digitization level after the inflection point has a negative impact on enterprise efficiency.

3.1.2. Cost expansion multiple is negatively correlated with technological innovation.

The larger the cost expansion multiple is, the weaker the efficiency of the enterprise in each process of production and operation. The efficiency capacity of an enterprise is positively correlated with its innovation capacity, and the specific mechanism is as follows: A higher efficiency capacity of an enterprise means that it is better at rationally allocating various production factors including data and capital to improve the quality and efficiency of the whole process and provide economic support for its innovation behavior; It means to perceive changes in the external environment and market demand in a more timely manner and respond quickly to create space and lead the direction for technological innovation; It means more efficient realization of resource sharing, knowledge exchange, contact and cooperation among internal and external departments to establish the organizational foundation for realizing technological innovation, so as to promote enterprise technological innovation.

In addition, the increase of cost expansion multiple means that corporate profit margin is reduced. In quite common cases, the overall growth rate of operating costs of enterprises is faster than the overall growth rate of turnover. To some extent, the overall growth of operating

costs will squeeze the profit margin, leading to the decline of profits in the short term. Faced with a short-term profit decrease, business operators are likely to make corresponding adjustments, such as changing the existing cost structure, which will reduce the existing cost in many aspects, including innovation input (an important part of the cost structure). In other words, the reduction of profit margin will squeeze out innovation input.

3.1.3. The relationship between enterprise digitization level and technological innovation is inverted U-shaped.

There is an optimal level of enterprise digitization that is suitable for its industry attributes, scale and self-development needs, and there are problems of insufficient development and excessive investment in enterprise digitization. Before reaching the inflection point of optimal level, the improvement of digitization level promotes the growth of enterprise technological innovation, and after the inflection point, the continued investment in digitization will weaken the enterprise's technological innovation ability. There is an inverted U-shaped relationship between digitization level and cost expansion multiple, and the cost expansion multiple is negatively correlated with enterprise technological innovation. Enterprise efficiency capacity (cost expansion multiple) plays a mediating role as a mechanism variable. The relationship among the three is shown in Figure 2.

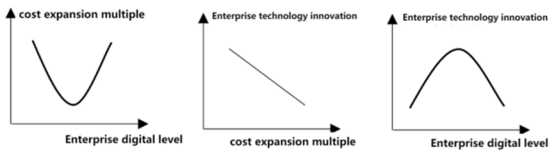

Figure 2. Enterprise digital level, cost expansion multiple and technological innovation relationship

This paper will further explore the operation mechanism of the causality effect between enterprise digitization and technological innovation by means of sub-sample regression, searching for intermediary variables and indirect transmission mechanisms.

3.2. Preliminary regression results analysis

The research selected the cross-section data of 2015 for preliminary research and empirical results to verify the feasibility and value of the study.

3.2.1. Descriptive statistics

Descriptive statistics of the main variables are shown in Figure 3. As can be seen from the table, the average digitalization degree of all enterprises except financial enterprises in 2015 is 33. 59, the maximum value is 792, and the minimum value is 1. The mean value of the square of digitalization degree in 2015 is 5247, the maximum value is 627264, and the minimum value is 1. In 2015, 2016 and 2017, the logarithmic average of r&d investment of all enterprises except financial enterprises was 17. 83, 17. 97 and 18. 17, the maximum value was 23. 68, 23. 59 and 23. 65, and the minimum value was 8. 795, 8. 454 and 7. 721, respectively. In 2015, 2016 and 2017, the logarithmic average value of patent applications by all enterprises except financial enterprises was 3. 487, 3. 612 and 3. 547, the maximum value was 9. 779, 9. 909 and 9. 823, and the minimum value was 0. 693, 0. 760 and 0. 715, respectively. In 2015, 2016 and 2017, the average value of inventions of all enterprises except financial enterprises was 2. 964, 2. 987 and 2. 991, respectively. The maximum value was 8. 874, 9. 095 and 9. 108, and the minimum value was 0. 693, 0. 0052 and 0. 693, respectively.

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
diglevel	2,500	33.59	64.18	1	792
scr_diglevel	2,500	26.67	56.22	1	771
diglevel2	2,500	5,247	28,142	1	627,264
scr_diglevel2	2,500	3,871	24,169	1	594,441
scr_diglevel12	2,500	0.502	0.500	0	1
scr_diglevel22	2,500	0.502	0.500	0	1
lnRDt	2,500	17.83	1.439	8.796	23.68
lnRDt1	2,500	17.97	1.472	8.454	23.59
lnRDt2	2,500	18.17	1.494	7.721	23.65
lnApplycation_t	2,500	3.487	1.361	0.693	9.779
lnApplycation_t1	2,500	3.612	1.375	0.760	9.909
lnApplycation_t2	2,500	3.547	1.380	0.715	9.823
lninvent_t	2,500	2.964	1.324	0.693	8.874
lninvent_t1	2,500	2.987	1.285	0.00524	9.095
lninvent_t2	2,500	2.991	1.317	0.693	9.108
Age	2,500	17.63	5.320	4	60
TA	2,500	22.16	1.325	17.64	28.50
FA	2,500	20.19	1.817	3.240	27.32
ROA	2,500	5.974	7.155	-66.89	61.15
DAR	2,500	47.71	270.6	1.969	13,531
CR	2,500	1.062	1.677	0.00260	22.15
StateOwned	2,500	0.132	0.339	0	1
Size	2,500	0.154	0.361	0	1

Figure 3. Descriptive Statistics

3.2.2. Correlation coefficient matrix and scatter diagram

The correlation coefficient matrix of independent and dependent variables is shown in Figure 4. In Figure 4, it can be seen that the correlation coefficient between the digitalization degree index extracted after correlation analysis and the untreated index is about 0. 95. At the same time, the correlation coefficients between the digitalization degree index and the logarithm of R&D investment, the logarithm of the patent application and the logarithm of invention patent are relatively small, but these coefficients are significant when P >0. 05. This indicates that although the coefficient is relatively small, the value of the coefficient is significantly not 0.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) diglevel	1.000														
(2) scr_diglevel	0.950	1.000													
(3) diglevel2	0.888	0.869	1.000												
(4) scr_sdiglevel2	0.814	0.884	0.949	1.000											
(5) scr_diglevel12	0.417	0.378	0.184	0.158	1.000										
(6) scr_diglevel22	0.404	0.382	0.179	0.158	0.868	1.000									
(7) lnRDt	0.102	0.099	0.073	0.070	0.074	0.061	1.000								
(8) lnRDt1	0.117	0.114	0.081	0.079	0.084	0.065	0.850	1.000							
(9) lnRDt2	0.110	0.108	0.078	0.077	0.074	0.054	0.771	0.856	1.000						
(10) lnApplycation_t	-0.000	-0.010	-0.027	-0.027	0.073	0.058	0.413	0.416	0.415	1.000					
(11) lnApplycation~1	-0.000	-0.010	-0.027	-0.027	0.072	0.058	0.411	0.414	0.414	1.000	1.000				
(12) lnApplycation~2	-0.002	-0.011	-0.028	-0.028	0.070	0.055	0.407	0.410	0.410	1.000	1.000	1.000			
(13) lninvent_t	0.001	-0.000	-0.015	-0.013	0.021	0.014	0.352	0.343	0.345	0.728	0.728	0.732	1.000		
(14) lninvent_t1	-0.003	-0.012	-0.000	-0.005	0.017	0.014	0.080	0.071	0.057	0.091	0.091	0.091	0.085	1.000	
(15) lninvent_t2	0.028	0.025	0.000	-0.003	0.057	0.038	0.381	0.377	0.380	0.516	0.515	0.515	0.511	0.090	1.000

Figure 4. Correlation coefficient matrix

As shown in Figure 5, it can be found that the correlation between R&D investment and digitalization degree conforms to the inverted U-shaped curve, but the correlation between patent application and invention number and digitalization degree is not obvious.

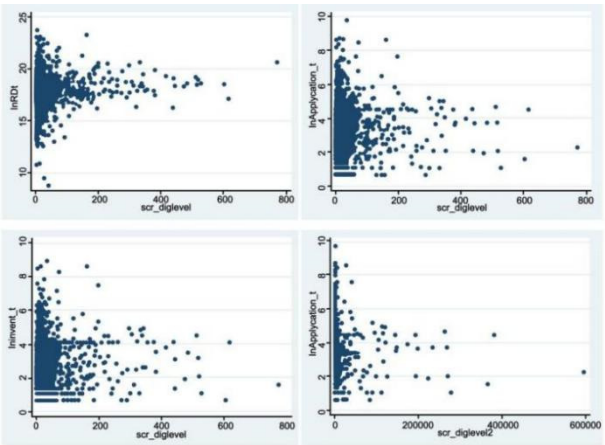

Figure 5. Scatter Diagram

3.2.3. Fundamental regression

The return of the preliminary results show that the explanation variable diglevel coefficient is positive, and extremely significant, the squared coefficient is negative, and is also very significant, we can according to this result preliminary judgment, the digital level and technology innovation is an inverted u-shaped relationship, the inverted u-shaped on innovation input and output quantity is significant, but the quality of innovation output was not significant. The influence of digitalization degree on r&d investment is positively correlated before reaching the peak point. This is because digital transformation is closely related to the technological innovation of enterprises. The improvement of the degree of digitalization will lead to the increase in the efficiency of innovation research and development of enterprises and promote technological innovation. However, after the peak point, the improvement of digitization degree is negatively correlated with the r&d investment of enterprises. This is because, in the process of digitization improvement, enterprises improve the digitalization level on a large scale, resulting in an excessive investment of enterprises, resulting in an excessive cost of enterprises, reduced R&D efficiency, and inhibiting enterprise innovation.

VARIABLES	(1) lnRDt	(2) lnApplycation_t	(3) lninvent_t
diglevel	0.004***	0.002***	0.001
	(4.06)	(2.62)	(1.60)
diglevel2	-0.000*	-0.000***	-0.000*
	(-1.91)	(-2.95)	(-1.76)
Constant	17.722***	3.438***	2.934***
	(483.07)	(98.67)	(86.47)
control	control	control	control
Observations	2,500	2,500	2,500
R-squared	0.012	0.003	0.001

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 6. Preliminary Regression Result

3.3. Mediating effect model

Previous research discussed the influence of internal micro management digital transformation on input-output efficiency [6], and deeply analyzed the nonlinear relationship between digital input and efficiency. Their research on the nonlinear relationship of variables provides the thinking support for this paper to analyze the inverted U-shaped relationship between enterprise digitization level and technological innovation. The studies on the mediating mechanism in the existing literature also provide useful inspiration for us to find the key mediating changes and further expand the mechanism analysis.

We construct the intermediary variable Cost_expand expansion ratio = (based on the research and development costs of enterprise operating cost plus a divided by r&d and a logarithmic), it's meaning total operating costs for the enterprise to eliminate r&d section, in the sectors of production and management processes can be on behalf of the enterprise efficiency, cost expansion ratio, the smaller the stronger the ability on behalf of the enterprise efficiency. The preliminary regression results show that there is an inverted U-shaped relationship between enterprise digitization

level and technological innovation, and the cost expansion factor (enterprise efficiency capacity) plays a mediating role.

In the regression of Figure 7, it can be seen that the diglevel coefficient of the explanatory variable is significantly negative, and the quadratic coefficient is significantly negative at the level of 5%, and the quadratic relationship is obvious, confirming that there is a U-shaped relationship between enterprise digitization level and cost expansion multiple.

In Figure 8, the coefficients before Cost_expand are all negative, that is, cost expansion multiple is negatively correlated with technological innovation. The smaller the cost expansion multiple is, the stronger the efficiency capability of the enterprise is, which means that the enterprise is better at making full and effective use of various production factors including information resources, realizing resource sharing and close cooperation between internal and external departments of the enterprise, thus promoting the technological innovation of the enterprise.

VARIABLES	(1) Cost_expand	(2) Cost_expand
diglevel	-0.006***	
	(-5.43)	
diglevel2	0.000**	
	(2.57)	
scr_diglevel		-0.007***
		(-5.74)
scr_diglevel2		0.000***
		(2.84)
Constant	3.648***	3.639***
	(94.34)	(97.46)
Control	control	control
Observations	2,500	2,500
R-squared	0.021	0.022

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 7. Intermediary effect: digitalization and cost expansion

VARIABLES	(1) lnApplycation_t	(2) lnApplycation_t1	(3) lnApplycation_t2	(4) lninvent_t	(5) lninvent_t1	(6) lninvent_t
Cost_expand	-0.096***	-0.098***	-0.098***	-0.073***	0.019	-0.076***
	(-5.41)	(-5.43)	(-5.44)	(-4.21)	(1.13)	(-4.39)
Constant	3.823***	3.952***	3.890***	3.219***	2.921***	3.255***
	(56.46)	(57.79)	(56.67)	(48.76)	(45.46)	(49.59)
Control	control	control	control	control	control	control
Observations	2,500	2,500	2,500	2,500	2,500	2,500
R-squared	0.012	0.012	0.012	0.007	0.001	0.008

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 8. Intermediary Effect；Cost expansion and Technology Innovation

3.4. Robustness test

Given that the influence of digital input lags in 2016 and 2017 corporate R&D, patent applications, and invention patent applications at the enterprise digital level, the results shown in Figure 9 indicate that the enterprise's digital innovation input, innovation quantity, and quality have at least three periods of sustainable and significant influence, though the degree of influence decreases as the number of years increases. The digitalization level of an enterprise can be regarded as a kind of fixed assets, which will have an impact on the technological innovation of the enterprise in the subsequent years after the investment. However, due to the depreciation of fixed assets, the updating and iteration of technical knowledge and other factors, the degree of such impact will decrease.

VARIABLES	(1) lnRDt1	(2) lnRDt2	(3) lnApplycation_t1	(4) lnApplycation_t2	(5) lninvent_t1	(6) lninvent_t2
diglevel	0.005***	0.005***	0.002***	0.002**	-0.000	0.003***
	(4.96)	(4.50)	(2.58)	(2.46)	(-0.32)	(3.08)
diglevel2	-0.000**	-0.000**	-0.000***	-0.000***	0.000	-0.000***
	(-2.53)	(-2.20)	(-2.92)	(-2.83)	(0.27)	(-2.73)
Constant	17.838***	18.041***	3.564***	3.502***	2.994***	2.927***
	(476.54)	(474.23)	(101.23)	(99.09)	(90.89)	(86.85)
control	control	control	control	control	control	control
Observations	2,500	2,500	2,500	2,500	2,500	2,500
R-squared	0.016	0.014	0.003	0.003	0.000	0.004

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 9. Robustness: Digitalization and Sustainable Impact

Considering the dispersion and marginality of 159 original digital keywords, this paper uses association analysis to select the frequent item set of enterprise digital transformation keywords, including 18 frequent keywords such as digitalization, intelligent terminal, software, information system and e-commerce, and defines variable SCR_diglevel as the total number of frequent keywords. Enterprise R&D investment, patent application and invention patent application in period T were used to regression the total number of frequent keywords respectively, and the results were still significant, as shown in Figure 10.

VARIABLES	(1) lnRDt	(2) lnApplycation_t	(3) lninvent_t	(4) lnRDt	(5) lnApplycation_t	(6) lninvent_t
scr_diglevel	0.005***	0.002**	0.001	0.004***	0.002	0.001
	(5.43)	(2.19)	(1.28)	(4.06)	(1.53)	(1.21)
scr_diglevel2	-0.000***	-0.000**	-0.000	-0.000*	-0.000**	-0.000
	(-2.67)	(-2.43)	(-1.42)	(-1.95)	(-1.99)	(-1.38)
Constant	6.218***	-3.871***	-3.144***	17.734***	3.463***	2.944***
	(9.40)	(-5.74)	(-4.78)	(500.26)	(102.79)	(89.77)
Observations	2,500	2,500	2,500	2,500	2,500	2,500
R-squared	0.223	0.096	0.092	0.011	0.002	0.001

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 10. Robustness: Frequent Keyword regression

Considering the different enterprise the length of the annual report to the total number of words in the text analysis, this paper use keywords to the total number of words and keywords to the total number of words frequently divided by the annual report to the total number of words, and will be located in the binary digits above 1, for the digital high hydration enterprise, located in the binary digits and below 0, for low digital level of enterprises, Get the virtual variables Diglevel12, scr_digLevel12. The two dummy variables are replaced by the core explanatory variables, and the results obtained are shown in Figure 11, indicating that at the significance level of 1%, enterprises with high digitalization level will have higher innovation input and high innovation output with both quantity and quality compared with those with low digitalization level.

VARIABLES	(1) lnRDt	(2) lnRDt2	(3) lnApplycation_t	(4) lnApplycation_t	(5) lninvent_t
Diglevel12	0.003***		-0.000		0.001
	(5.54)		(-0.11)		(1.42)
scr_diglevel12		0.221***		0.192***	
		(3.71)		(3.49)	
Constant	18.080***	18.055***	3.549***	3.451***	2.971***
	(539.17)	(427.44)	(113.86)	(88.41)	(99.94)
control	control	control	control	control	control
Observations	2,500	2,500	2,500	2,500	2,500
R-squared	0.012	0.005	0.000	0.005	0.001

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 11. Double-Quartile Virtual Variable Regression

4. Conclusion

As the general trend of enterprise development, digitization will be the necessary condition for enterprise survival [7]. Under the innovation-driven strategy, enterprise innovation will be the necessary competitiveness for enterprise survival. In this topic, we study the influence of digital transformation on enterprise technological innovation and the deeper mechanism behind it. Therefore, we chose to take enterprise technological innovation as the explained variable and enterprise digitization level as the core explanatory variable. In the preliminary regression, 2015 was taken as the base period and after controlling the control variables of 2015, the explained variables of three periods (2015, 2016 and 2017) were regressed to the explanatory variables of 2015.

The regression results show that: first, the digital transformation of enterprises has a significant inverted U-shaped impact on the quantity and quality of technological innovation input and innovation output, which is of great value for enterprises to carry out digital transformation. Second, based on the empirical results of regression and intermediate mechanism tests obtained directly before the inflection point, digital transformation can improve production efficiency, optimize resource allocation, reduce enterprise cost expansion, thus improving the input and output of technological innovation. The inflection point, after the digital transition, may lead to the cost of maintenance, the introduction of high increase, and reduced efficiency. With the rapid expansion of cost, the marginal revenue brought by digitalization is less than the marginal cost, which makes the input and output marginal of enterprise technological innovation decrease. Thirdly, a large number of samples are located before the inflection point where the marginal utility of digitalization level reaches zero, which indicates that the vast majority of Enterprises in China are still in an uphill phase in the promotion of digital transformation, and there is still a great space for promotion in theoretical research, policy formulation and implementation, enterprise practice and innovation. Fourthly, the empirical results show that the impact of enterprise digitization level on technological innovation has a positive decreasing effect over time, which can be regarded as a long-term impact on enterprise fixed assets in the depreciation process.

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