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Does digital transformation benefit innovation in manufacturing firms? Empirical evidence based on data mining and textual analysis methods

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Abstract. With the increasing spread of the digital economy and the application of digital technologies, more and more manufacturing enterprises have begun to improve the efficiency of digital transformation with the help of big data and other digital technologies to promote the high-quality development of enterprises. Through the open big data platform, manufacturing enterprises can collect data and information reflecting the needs of users in a timely manner to achieve real-time optimization of the production process and timely detection of problems to a certain extent, thereby improving the ability to research and innovation. Through the establishment of econometric models and empirical tests, we also find that the education level of managers affects the process of digital transformation and influences the impact of digital transformation on innovation.

Keywords: Digital transformation, econometric modelling, crawler analysis, empirical study

1. Introduction

From a historical perspective, every major scientific and technological revolution is accompanied by a multitude of changes in economic and social life. Especially since the revolution in information technology, the digital economy has been developing rapidly, and more and more companies have begun to gradually carry out a "digital transformation". Digital transformation with the help of digital technology is a symbol of the transformation of enterprises from the traditional production system to intelligent production systems. However, relevant statistics show that only 10% of global manufacturing companies have been successful in digital transformation, and about two-thirds of companies have not yet embarked on the path of digitalization. The McKinsey report also reveals the fact that less than 20 percent of business leaders have sufficient digital skills, meaning that many current leaders are unprepared.

Focusing on existing relevant research. Deming Yang and Yongwen Liu [1] proposed that big data platforms help companies gain resources by facilitating the sharing and collection of information with other organizations, leading to more successful innovation initiatives [2]. In addition, the use of digital technologies has solved the problem of information silos in the development process of traditional

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manufacturing companies, and companies can realize the transfer and dissemination of knowledge across distances and obtain expertise through various channels, thereby spreading innovative thinking and increasing the level of innovation in companies. According to Khin [3], companies must not only adopt digital technologies, but also have the dynamic ability to fully utilize them and manage the innovation process as it happens. This is because digital technology makes it easier for companies to integrate and mobilize resources, accelerating the innovation process. However, some studies have also shown that the economic performance of digitization does not always have to be positive. Han Pioneer et al [4] found that innovation performance first rises and then falls with the growth of information technology. Fifi Yu et al [5] discovered an inverse U-shaped relationship between the degree of digitalization and innovation performance based on company survey data. While the impact of digital technologies such as big data on companies' innovation performance is still unknown, further research is needed to fully understand how companies use these technologies to carry out their digital transformation.

2. Mechanism analysis and variables selection

2.1. Mechanism analysis

Before the widespread application of the Internet, thetraditional innovation model often leads to asymmetric information, which maybe leads to the lack of awareness of customers' information and low efficiency of innovation. But now that barriers within research and development and clients are being broken down, thanks to the digital open innovation platform and data mining and big data analysis, user experience and preference data can be quickly gathered and clients are more actively engaged in the design and development of products [6]. That allows entrepreneurs to more effectively satisfy market demand. Also, with the help of digital supply chain network platforms, manufacturing enterprises are able to organically integrate product ordering, parts supply, product manufacturing and product delivery, thus saving time costs and improving production efficiency.

A new model of networked co-production has also been developed as a result of the deep integration of digital technology and manufacturing companies. This model improves the flow and sharing of information and expertise between many different business systems and accelerates the transition from independent to collaborative innovation [7]. Entrepreneurs with a higher level of education have more cognitive skills that enable them to gather information, analyse risks and deal with a complicated external environment. Consequently, a higher level of education at the management level can promote innovation in companies.

2.2. variables selection

Core explanatory variable: Enterprise digital transformation index (Digi). In the process of enterprise digital transformation, first of all, enterprises rely on "digital technology-driven" to strengthen the digitisation degree of the source technology system and production system, and this transformation is based on the deployment and development of major core technologies. Among them, Artificial Intelligence (Artificial Intelligence), Block chain (Block chain), Cloud Computing (Cloud Computing), Big Data and other "ABCD" technologies constitute the core layer of enterprise digital transformation. technology architecture [8]; in addition, digital transformation pays more attention to the integration and innovation of digital technology and complex enterprise ecological scenarios, therefore, the article constructs the digital transformation index from the aspects of "the use of the underlying technology" and "the practical application of technology"[9].

Technically, this paper implements the variable design by using a Python crawler function to collect and organise the annual reports of all companies listed on the A-share. The Java library PDFbox is then used to extract all the text content, which serves as a data pool for the subsequent screening of the feature words. When determining the feature words for the digital transformation of companies, the academic and industrial areas are covered in this paper. The entries with negative words such as "not", "not", "not" etc. before the keywords were removed. With the help of text analysis, segmentation indices related to

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digital transformation are counted from the dimensions of digital technology itself (big data, artificial intelligence, block chain, cloud computing technology) and digital technology application scenarios, and a dictionary of feature words is constructed. The frequency of feature words appearing in the annual reports of listed companies is counted to form the digital transformation index, and the natural logarithm is added to characterize the degree of digital transformation of listed companies in the manufacturing industry. The specific technical operation process is shown in Figure 1.

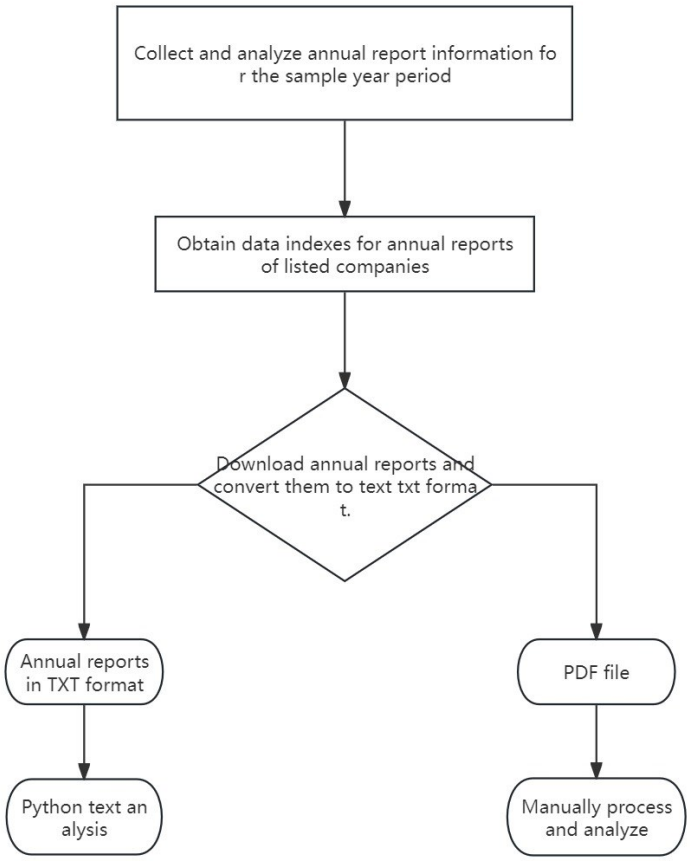

Figure 1. Digital transformation word frequency statistics operation flowchart

Explained variable: firms' ability to innovate (Apply). While invention patents are product and process innovations, their innovation value is substantially higher than utility model and design patents, indicating that they better reflect business innovation [10]. Utility model and design patents are, in some ways, strategic developments. Thus, to assess an organization's capability for innovation, this article tallies the number of invention patent applications. The explanatory variables are then created by adding one to the specified natural logarithm.

The control variables: firm size (Size), firm age (Age), asset profitability (Roa), current asset ratio (Car) reflecting the firm's operating capacity, and gearing ratio (Lev) for solvency.

3. Model construction and empirical tests

3.1. Model construction

The following two-way fixed-effects model was developed to investigate the impacts of digital transformation on manufacturing businesses' capacity for innovation:

$$\ln Apply_{it} = \alpha + \beta \ln Digi_{it} + \gamma Controls_{it} + \Sigma Year + \Sigma Firm + \varepsilon_{it} \quad (1)$$

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- $apply_{it}$ is the innovation capability of firm i in year t
- $digi_{it}$is the digital transformation index of firm i in year t
- $Controls_{it}$ are a series of control variables
- α, β and γ are the coefficients of the constant term, core explanatory variables and control variables, respectively.
- Year and Firm denote the fixed time effect and fixed individual effect respectively for the
- ε_{it} is the randomized disturbance term

The interaction term(Gdigi=lndigi×lnGedu) between the degree of digital transformation and managerial competence was added to test whether the strategic management capacity plays a moderating role in the impact of digital transformation on corporate innovation:

$$\ln apply_{it} = \alpha + \beta \ln digi_{it} + \varphi lnGedu_{it} + \delta Gdigi_{it} + \gamma Controls_{it} + \Sigma Year + \Sigma Firm + \varepsilon_{it} \quad (2)$$

Where the percentage of the executive team with a master's degree or more is used to describe Gedu, and the other variables are as mentioned above. If the coefficient of the interaction term δ is significant, it indicates a significant moderating effect. If the coefficient of the interaction term δ matches the sign of the influence coefficient β of the degree of digital transformation in equation (2), it is a positive moderating effect, and if the opposite is true, it is a negative moderating effect.

3.2. Empirical tests and analysis

Table 2 shows the results of descriptive statistics and correlation analysis of the main variables. The results show that the mean value of digital transformation index and enterprise innovation capability is small and the standard deviation is large, which indicates that there are significant differences in both digital transformation and innovation capability of China's A-share listed companies, but further analysis of the relationship between the two is needed. As can be seen from Table 2, the average VIF of all explanatory variables is 1.30, and the maximum value is 1.82, which is lower than the critical value of 10, suggesting that there is no serious problem of multi-collinearity.

Table 1. Descriptive stats

variables	mean	p50	sd	min	max	N	VIF
ln apply	0.400	0	0.830	0	6.220	3260	1.30(mean)
ln digi	0.890	0	1.130	0	5.250	3260	1.14
Size	21.88	21.76	0.990	19.66	25.93	3260	1.68
Age	14.33	14	5.800	1	43	3260	1.22
Car	0.590	0.590	0.160	0.0900	0.980	3260	1.38
Roa	0.0400	0.0400	0.0800	-1.060	1.130	3260	1.31
Lev	0.360	0.350	0.190	0.0100	2.020	3260	1.17

At Table 3, model (1) includes only the core explanatory variables, which indicate that digital transformation may greatly foster company innovation. Model (2) include control variables in turn, and the results show that the effects of digital transformation on firms' innovation capabilities are significantly positive when controlling for various control variables such as firm size and asset characteristics, indicating that digital transformation can improve firms' innovation capabilities.

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Table 2. Baseline regression results

	(1)	(2)
variables	ln_apply	ln_apply
ln_digi	0.0616***	0.0586***
	(2.719)	(2.607)
Size		0.146***
		(3.309)
Age		0.0288
		(1.569)
Roa		0.416
		(1.462)
Car		0.0956
		(0.517)
Iar		1.402*
		(1.903)
Lev		-0.147
		(-0.868)
Year fixed effects	YES	YES
Individual fixed effects	YES	YES
Observations	3,260	3,260
R-squared	0.027	0.035
Number of id	326	326

Robust t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1

Table 4 shows that the cross product term between executive education level of managers and the digital transformation index has a positive coefficient at the significance level of 5%. This result is consistent with the sign of the coefficient for the digital transformation index in model (1). Model (2) indicates that the impact of digital transformation on innovation is positively moderated by the education level of the leadership team.

Table 3. Moderating mechanism test: Executive education

	(1)	(2)
variables	ln_apply	ln_apply
ln_digi	0.0586***	0.0504**
	(2.607)	(2.342)
lnGedu		-0.0106
		(-0.182)
Gdigi		0.0769**
		(2.028)
Control variables	YES	YES
Year fixed effects	YES	YES
Individual fixed effects	YES	YES
Observations	3,260	3,214
R-squared	0.035	0.038
Number of id	326	326

Robust t-statistics in parentheses, ***p<0.01, **p<0.05, *p<0.1

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4. Conclusions and implications

In the context of the digital economy era, manufacturing companies have started to use more digital technologies such as big data or digital platforms in the production process and have carried out a digital transformation to improve their innovation capacity and competitiveness. Therefore, it is of great importance to study the impact of digital transformation on the innovation and development of manufacturing companies. First, the development of digital transformation not only means the application of enterprise software and Internet technologies by enterprises, but also relies on digital upgrading to promote the improvement of production, cost management, marketing and strategic innovation of the enterprise. Chinese manufacturing enterprises are still in the early stage of digital development and need to further transform and modernise to move forward. Secondly, the competence of top management determines the direction of enterprise development to a certain extent. Our research findings show that this competence (Executive management capacity) has a favourable influence on promoting organisational innovation and digital transformation. Therefore, companies should focus on the professional competence and expertise of top executives, cultivate their thinking ability and ability to recognise digital risks, and formulate an effective strategic direction for the company's future digital development.

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