Digital transformation, uncertainty in the business environment, and total factor productivity of enterprises

Yifan Yang*

Department of Economics and Management, Nanjing University of Science and Technology, Nanjing, China

*Corresponding author: njustyyf@163.com

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Abstract: Based on the signal theory, agency theory and information asymmetry theory, this paper takes A-share listed companies in Shanghai and Shenzhen as samples from 2013 to 2023 to study the impact of digital transformation on the total factor productivity of enterprises and the moderating effect of uncertainty in the business environment on the relationship between the two. This paper concludes that digital transformation can improve the total factor productivity of enterprises. The uncertainty of the business environment has a positive moderating effect on the correlation between digital transformation and enterprise total factor productivity.

1. Introduction

Countries around the world are actively promoting the development of the digital economy, especially after the financial crisis, the progress of digital technology and digital economy has accelerated significantly. In order to strive for a favorable position in the global industrial chain, China is also actively following up the development of the digital economy and showing a strong growth momentum. According to the Research Report on the Development of China's Digital Economy released by the China Academy of Information and Communications Technology in August 2024, the scale of China's digital economy will reach 53.9 trillion yuan in 2023, accounting for 42.8% of GDP. In addition, most Chinese companies are accelerating their transformation and applying technology to a wider range of processes and business scenarios. According to the 2023 Accenture China Digital Transformation Index, more than half (53%) of Chinese companies surveyed plan to continue to invest in digitalization. Digital investment enables enterprises to upgrade their industries through smart production, product and service innovation, and digital marketing, so as to gain competitive advantages and promote high-quality development.

Despite the enthusiasm for digital transformation, the results are not as good as they could be. According to the 2022 China Enterprise Digital Transformation Index, under the influence of various factors, the digital investment decisions of Chinese enterprises have diverged, the digital transformation index has declined for the first time, the international competitiveness of enterprises has also been affected, and the digital gap between leading enterprises and small and medium-sized enterprises has further widened. According to McKinsey's global survey, only 16% of companies believe that their digital transformation has achieved sustained results. There are two main reasons: First, digital transformation is facing difficulties due to limitations in strategic awareness, digital skills, and capital reserves. According to the China Industrial Digitalization Report 2020, enterprises face five major problems in the process of digital transformation: insufficient transformation capabilities leading to "not being able to transfer", insufficient funds leading to "unable to transfer", lack of talent leading to "not daring to transfer", unclear strategy leading to "poor transfer", and unsuitable organizational model leading to "unwillingness to transfer". On the other hand, many enterprises lack motivation for digital transformation, and often stay in the "arms race" stage of pursuing comprehensive digitalization without actually advancing it. In addition, the complexity of the environment also increases uncertainty in business operations. PwC's 2022 Digital Factory Transformation Survey points out that complex challenges make "digitalization" an inevitable choice

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for enterprises to cope with change.

Overall, there is a sense of urgency between the need to improve the quality of development and the room for improvement in digital transformation. What digital transformation means for enterprises, how it affects production efficiency, and what kind of effect it will have in a highly changing environment are all questions that need to be deeply considered by the practical and academic communities. This article will explore this further[1-3].

2. Literature Review

2.1 Research on digital transformation

2.1.1 Influencing factors for digital transformation

Digital transformation has become the core strategy of modern enterprises to enhance their competitiveness and achieve high-quality development, and some scholars have explored the influencing factors of digital transformation.

In terms of internal factors, enterprise resources, manager characteristics, and corporate behaviors will all have an impact on the digital transformation of enterprises. Yu et al. (2024) show that redundant resources play a crucial role in the digital transformation of enterprises, specifically precipitating redundant resources, such as long-term assets and funds accumulated by enterprises, and non-precipitating redundant resources, such as flexible cash flow and temporary resources, have an inverted U-shaped relationship with digital transformation. Executive factors can also have a significant impact on digital transformation. Niu et al. (2024) found that the vertical pay gap and the external pay gap have a promoting effect on digital transformation, while the horizontal pay gap has a restraining effect. Yu et al. (2024) found that CEO's education level, emotional stability, agreeableness and extraversion promoted digital transformation, while conscientiousness inhibited it, and CEO's experience and openness had inverted U-shaped and U-shaped nonlinear effects on digital transformation, respectively, and these influences showed certain heterogeneity in different external environments and enterprises.

In terms of external factors, Peng Cheng and Chen Yuansheng (2024) found that the field research of institutional investors reduced financing constraints and increased innovation investment through information and governance effects, thereby promoting the digitalization process of enterprises.Gu Fangrui and Li Qing (2024) explored the impact of interest rate marketization reform on the digital transformation of enterprises, and found that the abolition of the upper limit of deposit interest rate and the lower limit of loan interest rate reduced financing constraints and improved the R&D innovation ability and productivity of enterprises, especially in small enterprises, non-state-owned enterprises and non-technology-intensive industries, and the role of interest rate marketization reform in promoting digital transformation is more obvious. He Yong and Ling Ji (2024) found that the level of local fintech can significantly promote the digital transformation of enterprises by improving information quality and risk-taking

2.1.2 The economic consequences of digital transformation

Digital transformation is a research hotspot that has a profound impact on the economic growth pattern with the help of emerging technologies such as big data, artificial intelligence, blockchain, and cloud computing. The academic community has conducted a wealth of research on the possible economic consequences of digital transformation, which can be generally divided into the impact on the macroeconomy and the impact on micro enterprises.

In terms of macroeconomic consequences, Liu Jia and Qin Fang (2024) explored the issue of income distribution from the perspective of digital transformation, and found that the digital transformation of enterprises can help increase the share of labor income.Zhang and Yu (2024) found that digital transformation has a significant effect on narrowing the innovation gap between regions.

This paper focuses on the microeconomic consequences of digital transformation by focusing on the economic consequences of digital transformation at the firm level. At the micro level, data has become an important factor of production, and the integration of digital technology and traditional

business of enterprises can improve the capabilities of enterprises in many aspects, and play a non-negligible role in the production process, corporate governance, and business results of enterprises.

In terms of production processes, Mikalef and Pateli (2017) argue that digital production methods can increase the flexibility of business operations and help companies gain a competitive advantage. Yang (2022) took Taiwan's electronics industry as the research object and found that the invention of artificial intelligence technology has greatly changed the labor force composition of enterprises, reduced the proportion of labor force with low education, and had a significant positive impact on the productivity of enterprises.

In terms of corporate governance, Qi Yudong and Xiao Xu (2020) found that the organizational structure of digital enterprises will continue to shift from a pyramid of centralization to a flat development of decentralization, and the authority of management tends to be decentralized, and employees and consumers are given more authority in production and transactions, thus making the internal governance of enterprises more flexible.Qi Huaijin et al. (2020) believe that digital systems can provide more internal information, reduce the irrationality of managers to a certain extent, improve their decision-making ability and quality, and reduce various risks encountered in business operations.

In terms of business results, Nie Xingkai et al. (2022) believe that the digital transformation of enterprises can improve the comparability of accounting information by strengthening the quality of internal control, inhibiting corporate earnings management, and improving the asymmetry of enterprise information.Jin Xiankun et al. (2023) studied the impact of the application of digital technology in business practice on enterprise accounting information, and found that enterprise digitalization can improve the information collection and processing ability of enterprises, provide a high-quality data basis for accounting information, optimize the internal control of enterprises, and comprehensively improve the quality of accounting information of enterprises[4-6].

2.2 Research on total factor productivity

2.2.1 Factors influencing total factor productivity

The factors affecting the total factor productivity of enterprises can be divided into two parts: internal factors and external factors.

External factors include industrial policies, tax rates, and regional development levels. Wu Jinghua et al. (2021) found that the liberalization of loan interest rates promotes the improvement of total factor productivity by optimizing the efficiency of capital allocation among enterprises and improving the technological innovation ability of enterprises.Shen et al. (2021) have a similar view, arguing that the market-oriented reform of loan interest rates can improve the total factor productivity of enterprises and promote the high-quality development of enterprises.

The factors influencing the enterprise include corporate strategy, enterprise technology, executive capabilities, etc. Huang Bo et al. (2022) believe that the strategic alliance cooperation of enterprises can promote the flow of factors, optimize the allocation of resources, and significantly improve the total factor productivity of enterprises.Luo Jia et al. (2023) found that digital technology innovation has a significant positive impact on the improvement of total factor productivity of manufacturing enterprises, and the higher the degree of industry digitalization, the greater the impact.

2.2.2 Measurement of total factor productivity

The research and measurement of total factor productivity (TFP) has gone through a long process of development. Originally, the concept originated from the study of economic growth, which Solow measured through the "surplus value" method. Following Solow's work, Krugman's The Growth Miracle of East Asia brought total factor productivity to widespread prominence and continued to be discussed and measured. Total factor productivity (TFP) was first used in the evaluation of national macroeconomy, which is a key indicator to measure the level of national economic development, and provides an important basis for policy formulation and development forecasting. With the increasing improvement and disclosure of enterprise data, the research focus has gradually shifted to the micro level of enterprises and the development of the industry.

At the enterprise level, the calculation of total factor productivity is usually based on the production function and evaluated through the input-output ratio, which affects the production efficiency, operating efficiency and performance management of the enterprise. All else being equal, a higher level of technology and efficiency usually leads to more output. With the advancement of digitalization and the wide application of digital technology, enterprises have accumulated a large number of data resources in production and operation. The application of data as a factor of production enhances the synergistic effect of data with other factors and promotes productivity growth.

Therefore, this paper argues that in the era of digital economy, the total factor productivity of enterprises comprehensively reflects the overall efficiency of transforming various input factors into output, such as technological progress, management level improvement, human capital increase, and data resource accumulation. TFP has gradually become an important comprehensive indicator to measure the transformation of production methods and high-quality development of enterprises.

3. Research Hypothesis

The interplay of digital technology and data is reshaping the competitive model of enterprises and driving change in business organizations. With the widespread application of digital technology in all walks of life, data has gradually become a key factor of production. Technological progress and the transformation of production factors have promoted the digital transformation of enterprises, giving them new sources of vitality and efficiency. Through digital transformation, we can improve the way of production organization, optimize resource allocation, improve production technology, and improve the production process, so as to control the production process more effectively, improve internal control capabilities and asset operation efficiency, and at the same time expand commercial credit financing, improve the quality of accounting information, and ultimately help improve total factor productivity.

Based on this, the following hypotheses are proposed:

H1: Digital transformation can improve the total factor productivity of enterprises.

The digital economy era is closely linked to a highly changing environment, and the complex business environment faced by enterprises will also have a non-negligible impact on the relationship between digital transformation and enterprise total factor productivity. From the perspective of the outside of the enterprise, when the environment is complex and the operational uncertainty is high, the enterprise will bear greater survival pressure and risks, and at the same time, the constraints of material, human and other resources will be more obvious, and the motivation and ability of the enterprise to increase investment in digital transformation may also be insufficient. However, major changes in economic forms, industry ecology, and market structure will prompt the government to adopt support policies such as financial subsidies and tax incentives to motivate enterprises to improve total factor productivity, thereby accelerating the process of digital transformation of the economy and society. In this context, enterprises can not only obtain stronger external support, but also play an active role in promoting innovation, improving efficiency, reducing costs, and achieving a greater degree of productivity improvement. From the perspective of enterprises, the uncertainty of the business environment will make it difficult for enterprises to predict the dynamic changes of the future market, and there may even be resource misallocation behaviors such as production and operation imbalance and investment decision-making errors under traditional channels, which will increase the operating pressure. At this time, enterprises have to play the role of digital transformation in order to maintain their own survival or maintain their market position. With the help of digital transformation, enterprises will further improve their internal and external information mining capabilities, aggregate and analyze complex data and information to improve internal control and operational efficiency, thereby improving their ability to identify and respond to risks, and helping enterprises adjust their strategies in a timely manner in a complex environment, so as to alleviate the negative impact of uncertainty on enterprises. Risks and opportunities coexist, and changes in the business environment have prompted enterprises to increase their digital transformation, which may promote enterprises to acquire new knowledge, seize new opportunities, and further improve total

factor productivity.

Based on this, the following hypotheses are proposed:

H2:The uncertainty of the business environment positively moderates the positive correlation between digital transformation and enterprise total factor productivity[7-10].

4. Empirical Design

4.1 Total Factor Productivity (TFP)

The deep integration of digitalization and the real economy mainly occurred after 2013, and considering the availability of data, this paper selects the data of A-share listed companies in Shanghai and Shenzhen from 2013 to 2023 as the initial research sample, and processes the data as follows: (1) the samples of enterprises that were ST, *ST, and PT during the sample period are excluded; (2) Exclusion of financial enterprises; (3) Eliminate samples with sales revenue less than 0; (4) Eliminate samples with missing data for other major variables; (5) In order to reduce the influence of outliers, 1% and 99% tailing are performed for all continuous variables. All regressions were cluster-adjusted for standard errors at the company level.

The data in this paper are mainly derived from the following sources: the basic information and financial indicators of enterprises are from the CSMAR database; Digital transformation and financial sharing data are collected and sorted from the company's annual reports published on the company's official website and Juchao Information Network by using a combination of Python and manual collation; The internal control data comes from the DIBO internal control database.

The total factor productivity calculated by the LP method is used as a proxy variable.The LP method model is as follows:

$$LnY_{i,t} = \beta_0 + \beta_1 LnK_{i,t} + \beta_2 LnL_{i,t} + \beta_3 LnM_{i,t} + \bar{\omega}_{i,t} + \varphi_{i,t}$$

Among them, LnY_(i,t) is the total output of enterprise i in year t (operating income plus 1 logarithm), and there are three input factors in the production process, namely: capital input LnK _ (i, t) (fixed assets plus 1 logarithm), labor input LnL_ (i, t) (cash paid to employees and for employees plus 1 logarithm) and intermediate input LnM_(i, t) (cost minus depreciation, labor remuneration plus 1 logarithmic). ω¯_(i,t) is a partial residual term that can be observed by the enterprise and affects the factor selection or enterprise decision, and φ_(i,t) is the random residual term that has no effect on the factor selection or enterprise decision. The logarithm of ω¯_(i,t) residual term is obtained by fitting the model by the extended command levpet, which is the total factor productivity (TFP) value obtained by the LP method.

4.2 Digital Transformation

This paper mainly measures digital transformation by analyzing the text of the company's annual report and extracting relevant information about the use of enterprise digital technology. The specific steps are as follows: first, refer to previous literature, important policy documents, and Internet dictionaries, and summarize and sort out specific keywords related to digital transformation as digital transformation dictionaries. Then, using the Jieba word segmentation algorithm in Python software, the roots of words in the dictionary were imported into the Jieba thesaurus, and the corresponding text segments in the annual reports of listed companies published from the company's official website or Juchao Information Network were analyzed, and the word frequency of each type of digital technology in each company-year was calculated, and the natural logarithm was taken as the proxy variable Digital for digital transformation.

4.3 Uncertainty in the operating environment (EU)

The uncertainty of the operating environment in a given year is measured by the coefficient of variation of sales revenue for the past five years from that year. The specific model is as follows:

$$\mathrm{SALE} = \alpha + \beta \mathrm{year} + \varepsilon$$

Where year is an annual variable, if it is the year of the current year, i.e., the first year, year=5, and the previous year, i.e., the second year, year= 4, and so on, from the fifth year to year= 1, the residuals of the five models are the abnormal income of the enterprise in the past five years, and the environmental uncertainty without industry adjustment can be obtained by dividing the standard deviation of the abnormal income in the past five years by the average sales revenue of the past five years; For the above-mentioned unadjusted environmental uncertainty by industry, the median of each industry is taken to obtain the industry environmental uncertainty, and finally the environmental uncertainty of each enterprise in the current year is divided by the uncertainty of the industry environment to obtain the environmental uncertainty EU of each enterprise in the current year[11-14].

4.4 Model building

Based on the research hypothesis, the following basic model is established to test the proposed hypothesis:

$$TFP_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 Control_{i,t} + \varepsilon_{i,t}$$

$$TFP_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 EU_{i,t} + \alpha_3 Digital_{i,t} * EU_{i,t} + \alpha_4 Control_{i,t} + \varepsilon_{i,t}$$

5. Empirical Results and Analysis

5.1 Descriptive statistics

Table 1. reflects the descriptive statistics of the main variables, with a total of 30,250 samples. The maximum value of the explanatory variable enterprise total factor productivity (TFP_ LP) was 11.271, the minimum value was 6.254, the standard deviation was 1.052, and the mean value of 8.443 was greater than the median value of 8.339, indicating that the total factor productivity of enterprises in actual production and operation was quite different.

The mean value of the explanatory variable digital transformation (Digital) is 1.627, the standard deviation is 1.411, the maximum value is 5.037, and the minimum value is 0, which shows that the digital transformation level of most enterprises is lower than the average, and the digital transformation of enterprises varies greatly, which indicates to a certain extent that there is still a lot of room for improvement in the digital transformation of Chinese enterprises.

Among the other variables, the mean, standard deviation, minimum, median, and maximum values of the sample enterprises are all within a reasonable range and logical, indicating that the sample selection is effective.

Table 1. Descriptive statistics

Variable	Num	Mean	SD	Min	Median	Max
TFP_ LP	30249	8.443	1.052	6.254	8.339	11.271
Digital	30249	1.627	1.411	0	1.386	5.037
EU	30249	1.349	1.157	0.146	1.004	6.848
Size	30249	22.394	1.296	20.080	22.199	26.422
Lev	30249	0.431	0.201	0.063	0.423	0.900
ROA	30249	0.035	0.065	-0.227	0.035	0.214
Growth	30249	0.141	0.367	-0.559	0.087	2.114
Board	30249	2.112	0.196	1.609	2.197	2.639
Dual	30249	0.282	0.450	0	0	1
Top1	30249	0.331	0.146	0.082	0.306	0.731
FirmAge	30249	3.003	0.295	2.079	3.045	3.584
SOE	30249	0.366	0.482	0	0	1
Mfee	30249	0.083	0.065	0.008	0.066	0.389
TobinQ	30249	2.053	1.319	0.828	1.634	8.511

5.2 Regression results analysis

Regression is performed according to model to determine the relationship between digital transformation and enterprise total factor productivity, and the empirical results are shown in Table 2. In column (1), the explanatory variable digital transformation (Digital) and each control variable were used to regress the explanatory variable enterprise total factor productivity (TFP_LP), but did not control for industry and year, column (2) added the year fixed effect to exclude the impact of time shock, and column (3) added the year and industry fixed effect to further exclude the impact of industry differences. All regressions are clustered at the firm level. From the regression results, it can be seen that the relationship between digital transformation and enterprise total factor productivity is significantly positive at the level of 1% before and after the time of joining and the fixed effect of the industry, indicating that there is a significant positive correlation between digital transformation and enterprise total factor productivity.

Table 2. Digital Transformation and Total Factor Productivity

	(1) TFP_LP	(2) TFP_LP	(3) TFP_LP
Digital	0.093***	0.101***	0.063***
	(18.25)	(19.30)	(11.84)
Size	0.519***	0.525***	0.540***
	(75.07)	(74.44)	(81.19)
Lev	0.598***	0.557***	0.474***
	(13.64)	(12.63)	(11.67)
ROA	1.167***	1.051***	1.033***
	(11.53)	(10.32)	(10.86)
Growth	0.068***	0.053***	0.072***
	(6.56)	(5.06)	(7.07)
Board	-0.082**	-0.110***	-0.071**
	(-2.23)	(-2.98)	(-2.13)
Dual	-0.036***	-0.030**	-0.030**
	(-2.80)	(-2.35)	(-2.50)
Top1	0.021	0.010	0.055
	(0.41)	(0.20)	(1.18)
FirmAge	-0.015	0.059**	0.041
	(-0.64)	(2.15)	(1.57)
SOE	0.027	0.010	0.025
	(1.49)	(0.57)	(1.46)
Mfee	-5.265***	-5.458***	-5.365***
	(-38.75)	(-39.12)	(-39.67)
TobinQ	0.045***	0.048***	0.044***
	(10.38)	(10.39)	(9.69)
_cons	-3.084***	-3.201***	-3.720***
	(-17.75)	(-18.04)	(-20.70)
Year	No	Yes	Yes
Industry	No	No	Yes
N	30249	30249	30249
R_2	0.7707	0.7735	0.8058

Note: *, **, *** indicate significant at the level of 10%, 5%, and 1%, respectively

5.3 Moderating mechanisms for uncertainty in the business environment

This section examines the moderating effect of uncertainty in the business environment on the relationship between digital transformation and firm total factor productivity. In the empirical test, the explanatory variable Digital Transformation (Digital) and the moderating variable business environment uncertainty (EU) are centralized, and then the cross-multiplication terms of the two are generated for regression. The regression results after the addition of moderating effects are shown in

Table 3. Digital*EU represents the multiplier term between digital transformation and the uncertainty of the business environment. After controlling for other variables and adding fixed effects, the linear fit degree (R^2) of the model was 0.8062, indicating that the moderating effect regression model had strong explanatory power [15-17].

Table 3. Digital transformation, uncertainty in the business environment, and total factor productivity of enterprises

	(1) TFP_LP	(2) TFP_LP
Digital	0.063***	0.062***
	(11.70)	(11.66)
EU	-0.016***	-0.016***
	(-3.46)	(-3.36)
Digital*EU		0.008**
		(2.45)
Size	0.540***	0.541***
	(81.39)	(81.45)
Lev	0.476***	0.478***
	(11.71)	(11.78)
ROA	0.979***	0.987***
	(10.46)	(10.56)
Growth	0.093***	0.092***
	(8.74)	(8.64)
Board	-0.074**	-0.075**
	(-2.20)	(-2.23)
Dual	-0.030**	-0.031***
	(-2.55)	(-2.58)
Top1	0.055	0.054
	(1.18)	(1.17)
FirmAge	0.043*	0.043*
	(1.65)	(1.65)
SOE	0.024	0.024
	(1.39)	(1.41)
Mfee	-5.322***	-5.312***
	(-38.81)	(-38.88)
TobinQ	0.044***	0.045***
	(9.83)	(9.88)
_cons	-3.703***	-3.626***
	(-20.68)	(-20.10)
Year	Yes	Yes
Industry	Yes	Yes
N	30249	30249
R_2	0.8060	0.8060

Note: *, **, *** indicate significant at the level of 10%, 5%, and 1%, respectively

6. Conclusion

By selecting the relevant data of A-share listed companies in Shanghai and Shenzhen from 2013 to 2023, and through empirical tests such as basic regression, robustness test, and further analysis, the following research conclusions are obtained:

Digital transformation can promote the improvement of enterprise total factor productivity. The wide application of digital technology has promoted the progress of technological use and the transformation of production factors in enterprises, which in turn has promoted the digital transformation of enterprises and given them new sources of vitality and efficiency. Starting from the agency theory, digital transformation can effectively alleviate the problem of information asymmetry

between managers and shareholders, large shareholders and small and medium-sized shareholders, and can also reduce agency costs and improve the total factor productivity of enterprises through precise management and optimization of the decision-making process. Starting from the signal theory, digital transformation can make the internal operations, production processes and resource allocation of enterprises more transparent, help to better coordinate production factors, optimize the efficiency of resource allocation, and improve total factor productivity.

The uncertainty of the business environment positively regulates the relationship between digital transformation and enterprise total factor productivity. The high degree of uncertainty in the business environment may disrupt the supply chain, lead to the failure of production planning and inventory management, and traditional production management tools and information systems may be chaotic to varying degrees, which will have a negative impact on the production efficiency and economic scale of enterprises and even at the macro level. At this time, digital transformation can help enterprises obtain more additional policy dividends implemented by the government to encourage development, and can also provide new solutions for enterprises when traditional operation and management tools fail.

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