

Digital Transformation and R&D Innovation: The Moderating Effect of Marketization Degree

Yichen Xun*, Yujing Ye, Bowei Jia

School of Management, Northeastern University at Qinhuangdao, Qinhuangdao, China

*Corresponding author e-mail: 846424819@qq.com

Abstract. With the continuous development of socialist market economy, more and more enterprises use digital technology to realize digital transformation. Digital transformation has an important impact on enterprise R&D and innovation. Based on the data of Shanghai and Shenzhen A-share listed companies from 2016 to 2020, this paper empirically tests the impact of enterprise digital transformation on R&D innovation. It is found that digital transformation has a significant positive impact on R&D innovation, and the degree of this impact is related to regional differences and the nature of equity. Digital transformation has a more significant impact on enterprise R&D innovation in high marketization areas. This effect is generally significant in areas with low degree of marketization, but the degree of influence is lower than that in areas with high degree of marketization. The digital transformation of non-state-owned enterprises has a more significant impact on R&D innovation; The influence of state-owned enterprises on the whole is significant, but the influence degree is lower than that of non-state-owned enterprises. Therefore, it is a feasible path to enhance the level of enterprise R&D innovation and strengthen digital investment to realize the digital transformation of enterprises. The government should also support the digital transformation of enterprises according to the location and nature of enterprises.

Keywords: Digital transformation, R&D innovation, Degree of marketization, Nature of equity.

1. Introduction

Tapscott et al. first proposed digital economy (Don Tapscott et al., 1999). After the 21st century, with the popularization of Internet and other technologies, digital economy became hot in China. After the reform and opening up, China's economy has developed rapidly, and people's income and consumption level have risen significantly. After 2015, with the supply-side structural reform and the target of "overcapacity reduction" proposed, enterprises need to locate more accurate consumer demand, correct production, and resolve excess capacity. Faced with huge and diverse consumer demands, enterprises need to acquire and integrate a large amount of market information, and analyze and position market demands based on this, so the demand for digital technology arises at the right moment. The report of the 19th National Congress of the Communist Party of China proposed the construction of "digital China". The Central Committee of the Communist Party of China has attached great importance to the digital transformation of enterprises, and it is an irresistible trend for enterprises to apply digital technology to realize digital transformation.

Digital technology includes information technology, big data technology and Internet technology. Through digital transformation, enterprises can integrate existing technologies and form new products or technologies, that is, "portfolio innovation". Digital technology has redefined the relationship between enterprises and consumers, channels and the value chain of enterprises, and innovated the logical paradigm for enterprises to create value, namely "business model innovation". Digital technology enables faster and more convenient information transmission, promotes organizational reform, pays more attention to equal communication, extended training, career planning and other ways, and improves employees' sense of honor and sense of belonging, namely corporate culture innovation (Qi Yudong, CAI Chengwei, 2019). In recent years, the global "core shortage tide" has caused the security of supply chain worries. Europe and the United States have expressed concerns about the excessive concentration of the semiconductor industry in Japan, South Korea and Taiwan, and put forward a series of stimulus plans to attract the return of the chip industry. The localization of China's chip industry chain is also accelerating (China Newsweek, 2021). This shows that it is very

important for enterprises to intensify research and development and improve the level of science and technology to get rid of technological dependence and cultivate core competitive advantages.

Some papers have studied the relationship between digital transformation and enterprise innovation, but few papers consider the impact of digital transformation on enterprise innovation under different marketization processes, which provides an opportunity for the study of this paper. This paper first examines the impact of digital transformation on enterprise innovation, and then further analyzes the impact of digital transformation on enterprise innovation under different marketization processes. It verifies that digital transformation can improve resource allocation efficiency and promote enterprise R&D behavior by complementing the deficiency of regional marketization degree. It also plays a synergistic role in promoting the development of areas with high marketization degree. Starting with digital transformation and enterprise R&D and innovation, this paper establishes the model of "Enterprise digital transformation -- R&D and innovation", analyzes the promotion effect of enterprise digital transformation on R&D and innovation from the perspective of heterogeneity, and analyzes the difference of the promotion effect of enterprise digital transformation on R&D and innovation from the perspective of equity nature. In addition, suggestions are put forward for enterprises to improve the level of R&D innovation and economic benefits, which has reference significance for enterprises in different regions with different degree of marketization and different ownership nature to improve their independent innovation ability.

2. Literature Review

Since the innovation-driven development strategy was put forward in the 18th CPC National Congress, innovation has become a key factor for enterprises to improve market competitiveness, and R&D innovation is an important content of the broad concept of innovation. Driving factors on enterprise innovation, Liu Wei (2015) argues that the market structure, government support, enterprise scale, the ownership structure of four environmental factors significantly influence the innovation efficiency of high and new technology enterprise, and the less government support, enterprise denationalization proportion is higher, the higher the degree of market concentration, enterprise scale, the greater the enterprise innovation efficiency is higher. Shen Guobing etc. (2022) from the perspective of the protection of intellectual property rights and innovation model research pharmaceutical industry research and development innovation, think to strengthen the protection of intellectual property rights can significantly enhance pharmaceutical enterprise innovation level, British and American innovation model more than continental Europe innovation mode and Chinese innovation mode can promote the research and development innovation, it has reference significance to China. As for the changes brought about by enterprise innovation, Jonker et al. (2006) drew a conclusion that R&D innovation was significantly positively correlated with output performance through the study of mechanical paper industry. Chen Heng and Hou Jian (2016) also believe that R&D personnel investment in high-tech industries has a significantly positive effect on improving industrial science and technology performance than technology introduction, and is limited by the regional knowledge accumulation level.

Under the trend of enterprises applying digital technology to realize digital transformation, many scholars have observed the changes brought by digital transformation to enterprises, especially the impact on enterprises' innovation behavior. Yi Loulou etc. (2021) through text analysis to obtain the text associated with the digital transition on the number of word frequency and logarithmic treatment after as measure of the strength of digital transformation, the study found that the impact on corporate performance digital transformation, and the impact characteristics by internal and external economic policy uncertainty. Liu Zheng et al. (2020) believe that digital transformation of enterprises promotes organizational change and causes organizations to weaken the power of senior executives and increase the power of grass-roots level, and that specialized knowledge and agency cost play a key role. He Fan and Liu Hongxia (2019) believe that under the influence of digital economy policies, enterprises' digital transformation has deepened, and digital transformation has significantly

improved the economic benefits of real enterprises. Moreover, international digital transformation policies have reference significance for promoting the digital transformation of domestic real enterprises.

As for the impact of digital transformation on enterprise innovation, the existing literature mainly focuses on its mechanism. Xu Meng (2020) believes that digital transformation is the external motivation to promote enterprise innovation, and enterprise innovation is the internal demand to realize digital transformation. Lou Runping et al. (2022) believe that the total amount of enterprise digital investment has a statistically significant positive effect on enterprise innovation performance, digital software investment has a significant positive effect on innovation performance of technology-intensive manufacturing enterprises, and human capital has a partial intermediary effect. Chi Maomao et al. (2022) believe that digital transformation is a key and necessary condition for enterprise innovation performance, and digital transformation has a complete mediating role between IT capability and product innovation performance. Xiao Jinghua etc. (2018) to build from the perspective of enterprise and the consumer co-evolution ordinary consumers to participate in research and development of the large data environment theory framework, think consumers is an important participant of enterprise innovation, and the participation can be divided into two kinds of research and development innovation model, namely the user oriented form of data driven and the model of designer guide formation of the data to support. In the above study on the influence of enterprise digitization on enterprises, enterprise digitization will promote enterprise innovation from different aspects. However, Wu Fei et al. (2021) proved that fiscal science and technology expenditure has a promoting effect on enterprise digital transformation, and this effect is affected by enterprise attributes and regional differences. At present, there are few articles from the perspective of regional marketization degree to study the positive impact of enterprises' digital transformation under the difference of marketization degree in different regions. This paper aims to study whether enterprises' digital transformation has a complementary or synergistic effect on regional marketization.

3. Theoretical Analysis and Hypothesis Formulation

Digitization helps improve the level of internal corporate governance of enterprises (He Quanquan, 2021). Businesses use big data technology, artificial intelligence, such as block chain innovation, help enterprises to set up management cockpit, easy access to the enterprise core data, combined with industry data efficient sequential, insight into business, early warning and abnormal data in time, reduce the risk of enterprise development, reduce the uncertainty of enterprise management, mass transfer efficiency, help enterprise to establish the core competitiveness, Lay a solid foundation for enterprise development. Digitization helps improve the investment efficiency of enterprises (Zhai Shuping et al., 2022). "Digitization" is conducive to timely acquisition of customer demand by enterprises, which can reflect the external environment much faster than traditional enterprises, enabling them to survive in the fierce competition and fickle market environment and maintain continuous competitiveness. Therefore, digital enterprises are easier to obtain market demand, actively carry out research and development of new products, and grasp market opportunities. Digital transformation requires enterprises to invest in digital equipment. As for the use of equipment, talents with more digital knowledge reserves are required to operate and design the use scheme. Digital human capital can provide more innovation resources for enterprises with its own knowledge, increase the number of patents of enterprises and promote R&D and innovation. By using digital technology, enterprises can more quickly collect market information, integrate resources, and analyze market pain points. Based on this, enterprises can use R&D and innovation to inject technology into products and services, so as to better meet consumer needs, expand the market and improve economic benefits. Therefore, this paper argues that enterprise digital transformation can promote enterprise R&D and innovation.

H1: Enterprise digital transformation has a positive impact on enterprise R&D and innovation.

Digital technology needs to acquire a large amount of market information and analyze it. Areas with high marketization degree often have developed economy, dense population and large number of enterprises, and there is a large amount of complex information in the market. In such areas, enterprises need to correctly deal with market information in order to adapt to the market. Simple market research is difficult to locate the large-scale market. Therefore, it is easier for enterprises to accurately locate market demand by using digital technology to process market information. With the popularization of digital technology among enterprises, market analysis is also popular, and the advantage of market information processing in enterprise competition is no longer obvious. In order to gain competitive advantages, enterprises will invest in research and development according to market analysis, apply new technologies, develop new products and increase the added value of products to better meet consumer demand, or even create new consumer demand by using new technologies and new products. However, in areas with low marketization degree, where population density and enterprise density are not as high as those with high marketization degree, the competitive pressure of the local market is relatively small. Enterprises can accurately position the market by using digital technology to process local market information, and enterprises are less motivated to further increase research and development to expand the market. Therefore, this effect is not obvious in areas with low degree of marketization. Therefore, this paper argues that in regions with high degree of marketization, enterprise digital transformation has a high degree of impact on enterprise R&D innovation, and vice versa.

H2: In regions with different degrees of marketization, digital transformation of enterprises has different degrees of influence on R&D and innovation of enterprises, and this influence is more obvious in regions with high degrees of marketization.

4. Research Design

4.1 Data Sources

This paper selects the data of A-share listed companies in Shanghai and Shenzhen from 2016 to 2020 as the analysis object. The original data comes from CSMAR database, and the marketization degree index comes from Yan Meng et al. (2021). The marketization degree is divided by the median of factor marketization index ranking of each province. In order to improve the regression quality, this paper processed the data as follows: First, eliminate the listed companies with ST, *ST and terminated listing status; Secondly, enterprises with missing key data should be eliminated and only the majority of samples without missing data should be retained. Third, in order to reduce the interference degree of outliers, all continuous variables at the micro level are tailed 1% and 99%. Finally, 17,296 samples were obtained in this paper.

4.2 Variable Setting

(1) Explained variables

Enterprise Research and Development Innovation (ERDI). The relevant characteristics of enterprise R&D innovation are highlighted in enterprise R&D investment. Referring to the research of Shen Guobing et al. (2022), this paper chooses R&D density (RDS), an indicator closely related to R&D investment, to measure the level of enterprise R&D innovation. R&D density is the ratio of an enterprise's R&D investment to its total operating income (Guellec et al.,2001). In order to make the data more intuitive, this paper represents R&D density as the result of 100 times itself. With the help of CSMAR, we obtained the R&D investment and operating income of A-share listed companies in Shanghai and Shenzhen from 2016 to 2020, and the ratio of the two was used to obtain the data of enterprise R&D density.

(2) Core explanatory variables

Enterprise Digital Transformation (DT). When studying the degree of enterprise digital transformation, this paper refers to the research of Wu Fei et al. (2018) and the occurrence times of subdivision indicators of keywords related to digital transformation in the annual reports of Shanghai

and Shenzhen A-share listed companies from 2016 to 2020, and then sums them up as an indicator to evaluate enterprise digital transformation. Keywords: Artificial Intelligence technology (AIT), block chain technology (BCT), cloud computing technology (CCT), big data technology (BDT), digital technology application (DTA)

(3) Adjustment variables

In order to verify the influence of marketization degree on the relationship between enterprise digital transformation and R&D innovation, the moderating variable of marketization degree (MD) was set up in this paper. The degree of marketization (MD) is described by "0-1" variable. The enterprise in the region with high marketization degree is 1, and the enterprise in the region with low marketization degree is 0.

(4) Control variables

In order to improve the accuracy of research results and reduce the endogenous effect of enterprise R&D innovation on digital transformation, this paper sets a series of control variables that may affect enterprise R&D innovation. Referring to the studies of Shen Guobing et AL. (2022), Tong Jinzhi et AL. (2018) and Liu Wei (2015), the control variables selected in this paper include return on equity (ROE), asset-liability ratio (AL), capital intensity (CI) and government subsidies (GS).

Table 1. Variable definitions

Variable	Measure	Sy mb ol	Definition
Research and development innovation	Research and development density	ER DI	R&D investment/Total operating revenue ×100
Digital transformation	Frequency of keywords in digital transformation	DT	The number of times that subdivided indicators of the application of artificial intelligence technology, blockchain technology, cloud computing technology, big data technology and digital technology appear in an enterprise's annual report
Regulated variable	Marketization degree	MD	Enterprises in areas with high degree of marketization =1 Enterprises in areas with low degree of marketization =0
Control variables	Return on equity	RO E	Net profit/average net assets
	Asset-liability ratio	AL	Total liabilities/total assets
	Capital intensity	CI	Net fixed assets/Number of employees
	Government subsidies	GS	The amount of government subsidy detail project in current period is treated as logarithmic

4.3 Model Setting

In order to verify the positive impact of enterprise digital transformation on R&D innovation, and to study the degree of influence of regions with different degrees of marketization on the positive impact of enterprise digital transformation on R&D innovation, the following "enterprise digital transformation -- R&D innovation" model is set and tested.

$$RDS_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \alpha_2 MD_{i,t} + \alpha_3 DT_{i,t} \times MD_{i,t} + \alpha_4 ROE_{i,t} + \alpha_5 AL_{i,t} + \alpha_6 CI_{i,t} + \alpha_7 GS_{i,t} + \varepsilon_{i,t}$$

Among them, R&D density (RDS) is used to measure the explained variable enterprise R&D innovation (ERDI); Enterprise digital transformation (DT) is the core explanatory variable. MD is the digital transformation of the moderating variable; ROE, AL, CI and GS were control variables. ε is the random error term. In addition, the model uses firm individual and annual fixed effects to control firm time-invariant factors and annual effects.

In order to reduce variable measurement errors, the robustness test is carried out by substituting the explained variable and the core explanatory variable. The substitution variables of the explained

variables are ENTERPRISE R&D intensity (RDST) and number of R&D personnel (RDP), and the substitution variables of the core explanatory variables are the occurrence of five digital transformation keywords of the enterprise respectively. The occurrence is regarded as 1, and the absence is regarded as 0. Due to limited space, only partial robustness test results are listed in this paper.

5. Empirical Results and Analysis

5.1 Descriptive Statistics and Correlation Analysis

Table 2 shows the descriptive statistical results of the whole country. From the perspective of R&D density, the mean value of RDS is 1.640, the standard deviation is 4.271, the minimum value and maximum value are 0 and 22.90 respectively, indicating that the R&D investment of enterprises is not high in general, and the R&D investment density of different enterprises varies greatly. The mean value of DT is 10.55, the standard deviation is 22.29, and the minimum value and maximum value are 0 and 133 respectively, indicating that the degree of digital transformation of enterprises is not high in general. There are still some enterprises that have not used digital technology, and the degree of digital transformation of different enterprises also varies to some extent. The mean value of MD is 0.787, indicating that the number of enterprises in areas with high marketization degree is larger than that in areas with low marketization degree. The mean value of ROE is 0.0632, standard deviation is 0.132, minimum value and maximum value are -0.646 and 0.364 respectively, indicating that the profitability of different enterprises varies greatly, and some enterprises show a loss state. The mean value of AL was 0.421, the standard deviation was 0.209, and the minimum and maximum values were 0.927. Asset-liability ratio reflects the long-term debt paying ability of enterprises. If the differences between industries are not taken into account, enterprises with small asset-liability ratio have low long-term debt paying pressure and can invest more funds to promote the digital transformation of enterprises. The mean value of CI is 3.377, the standard deviation is 5.673, and the minimum value and maximum value are 0.425 and 42.22 respectively. This variable reflects the difference between industries. There is an obvious difference in capital intensity between different industries and enterprises. The likelihood of transforming companies digitally to achieve higher profits is also higher. The mean value of GS is 16.07, the standard deviation is 3.217, and the minimum value and maximum value are 0 and 20.49 respectively. Before taking the logarithm of this variable, there is a great difference in the government subsidies obtained by enterprises, and the scale of government subsidies obtained by enterprises is relatively large in general.

Table 3 and Table 4 respectively show the descriptive statistical results of enterprises in regions with high and low marketization degree. By contrast, the number of enterprises in areas with high marketization degree is much more than that in areas with low marketization degree. In terms of research and development density and degree of digital transformation, high degree of marketization of the mean value, maximum value is greater than the low marketization degree of region, and the standard deviation, on the other hand, shows that in high degree of marketization, enterprise development density and marketization degree is higher than generally low marketization degree, low marketization degree in enterprise development density and the digitized transformation degree is generally low. In terms of control variables ROE, AL, CI and GS, the mean value, standard deviation, maximum value and minimum value of enterprises in regions with high and low marketization degree are not significantly different.

Table 2. Descriptive Statistics (nationwide)

variable	(1) N	(2) mean	(3) sd	(4) min	(5) max
RDS	17296	1.640	4.271	0	22.90
DT	17296	10.55	22.29	0	133
MD	17292	0.787	0.409	0	1
ROE	15797	0.0632	0.132	0.646	0.364
AL	17295	0.421	0.209	0.0596	0.927
CI	17292	3.377	5.673	0.425	42.22
GS	17296	16.07	3.217	0	20.49

Table 3. Descriptive Statistics (high degree of marketization)

variable	(1) N	(2) mean	(3) sd	(4) min	(5) max
RDS	13609	1.884	4.524	0	22.90
DT	13609	11.77	23.65	0	133
ROE	12308	0.0661	0.132	0.646	0.361
AL	13608	0.414	0.208	0.0604	0.927
CI	13605	3.338	5.736	0.425	42.22
GS	13609	16.07	3.190	0	20.49

Table 4. Descriptive Statistics (low degree of marketization)

variable	(1) N	(2) mean	(3) sd	(4) min	(5) max
RDS	3683	0.695	2.737	0	17.85
DT	3683	5.684	13.17	0	87
ROE	3488	0.0532	0.130	0.640	0.364
AL	3683	0.447	0.210	0.0596	0.922
CI	3683	3.474	5.098	0.451	36.80
GS	3683	16.07	3.313	0	20.20

Table 4, Table 5 and Table 6 respectively show the correlation analysis results of enterprises in the whole country, areas with high marketization degree and areas with low marketization degree. Pearson correlation analysis is in the lower left corner and Spearman correlation analysis is in the upper right corner. From the perspective of correlation analysis, digital transformation DT and R&D investment density RDS are significantly positively correlated, which preliminarily verifies hypothesis 1. The correlation coefficients between explanatory variables and control variables were all less than 0.5, which preliminarily proved that there was no serious collinearity between variables. In addition, the correlation coefficient between DT and RDS of digital transformation of enterprises in areas with high marketization degree is greater than that in areas with low marketization degree, which initially verifies hypothesis 2.

Table 5. Correlation Analysis (Nationwide)

	RDS	DT	MD	ROE	AL	CI	GS
RDS	1	0.417 ***	0.139 ***	0.036 ***	0.151 ***	0.025 ***	0.099 ***
DT	0.450 ***	1	0.136 ***	0.017 **	0.004	0.025 ***	0.180 ***
MD	0.113 ***	0.111 ***	1	0.090 ***	0.059 ***	0.046 ***	0.013 *
ROE	0.047 ***	0.019 **	0.041 ***	1	0.063 ***	0.257 ***	0.124 ***
AL	0.186 ***	0.042 ***	0.056 ***	0.148 ***	1	0.018 **	0.226 ***
CI	0.022 ***	0.023 ***	0.012	0.059 ***	0.230 ***	1	0.112 ***
GS	0.084 ***	0.073 ***	0.001	0.041 ***	0.031 ***	0.218 ***	1

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively, the same below

Table 6. Correlation analysis (high degree of marketization)

	RDS	DT	ROE	AL	CI	GS
RDS	1	0.432 ***	0.054 ***	0.155 ***	0.035 ***	0.116 ***
DT	0.445 ***	1	0.003	0.002	0.017 *	0.189 ***
ROE	0.053 ***	0.028 ***	1	0.037 ***	0.237 ***	0.131 ***
AL	0.193 ***	0.031 ***	0.132 ***	1	0.021 **	0.216 ***
CI	0.029 ***	0.026 ***	0.048 ***	0.257 ***	1	0.097 ***
GS	0.092 ***	0.072 ***	0.039 ***	0.006	0.246 ***	1

Table 7. Correlation analysis (low degree of marketization)

	RDS	DT	ROE	AL	CI	GS
RDS	1	0.287 ***	0.033 **	0.110 ***	0.038 **	0.044 **
DT	0.429 ***	1	0.039 **	0.015	0.029 *	0.166 ***
ROE	0.050 ***	0.012	1	0.131 ***	0.321 ***	0.110 ***
AL	0.130 ***	0.061 ***	0.193 ***	1	0.024	0.256 ***
CI	0.014	0.021	0.106 ***	0.129 ***	1	0.166 ***
GS	0.052 ***	0.090 ***	0.047 ***	0.116 ***	0.120 ***	1

5.2 Baseline Regression

This part conducts benchmark regression to investigate whether the digital transformation of enterprises has a positive impact on the digital transformation and the difference in the impact degree of different regions. Table 8 report the regression results, of which the column (1) (2) the report did not control the year respectively, individual and individual control of the year, under the fixed effects digital transformation of enterprises and the relationship between the innovation, it can be seen that can promote innovation enterprise digital transformation, both show significant positive correlation, hypothesis 1 is proved. Column (3) reported after joining regulating variable digital transformation of enterprises and the relationship between the innovation, on the basis of the column (3), column (4) the inspection of joined by a DT * MD, from the column (3) (4) the regression results can be seen, be explained variables RDS and adjust MD and handed in by DT * MD exist significant correlation, This indicates that the positive impact of digital transformation on enterprise R&D innovation is influenced by the marketization degree of moderating variables, which further verifies hypothesis 2.

Table 8. Baseline regression

Variable	(1) RDS	(2) RDS	(3) RDS	(4) RDS
DT	0.0159 *** (0.000961)	0.00516 *** (0.00101)	0.00511 *** (0.00101)	0.00198 (0.00324)
MD	-	-	0.899 *** (0.242)	0.773 *** (0.248)
DT*MD	-	-	-	0.00779 ** (0.00339)
ROE	1.260 *** (0.0889)	1.058 *** (0.0874)	1.057 *** (0.0873)	1.054 *** (0.0873)
AL	1.062 *** (0.122)	0.457 *** (0.129)	0.468 *** (0.129)	0.466 *** (0.129)
CI	0.0288 *** (0.00455)	0.0377 *** (0.00478)	0.0373 *** (0.00478)	0.0373 *** (0.00478)
GS	0.0197 *** (0.00407)	0.00863 ** (0.00418)	0.00846 ** (0.00418)	0.00836 ** (0.00418)
Constant	1.670 *** (0.105)	1.444 *** (0.0895)	0.752 *** (0.207)	0.853 *** (0.211)
Year	NO	YES	YES	YES
Individual	NO	YES	YES	YES
Number of samples	15796	15796	15795	15795

5.3 Robustness Test

In order to further verify the influence of marketization degree on the relationship between digital transformation and enterprise R&D innovation, this paper grouped the total data according to the marketization degree of enterprises' regions, and conducted a robustness test on the influence of digital transformation on enterprise R&D innovation. As shown in Table 9, columns (3) and (4) respectively report the regression results of uncontrolled and controlled Individual fixed effect of enterprises located in areas with high marketization degree. Columns (5) and (6) respectively report the regression results of uncontrolled and controlled Individual fixed effect of enterprises located in areas with low marketization degree. It can be seen that there is a significant positive relationship between digital transformation and enterprise R&D innovation in areas with high marketization degree, and a significant positive relationship between digital transformation and enterprise R&D innovation in areas with low marketization degree without controlling individual fixed effect. Without control individual fixed effects under the condition of high degree of marketization in DT coefficient is greater than the low degree of marketization in DT coefficient, indicating that high degree of marketization is digital transition area and the influence degree of the enterprise innovation relations is greater than the low marketization degree of regional digital transformation and the influence degree of the enterprise innovation relations, more to verify the hypothesis 2.

This paper argues that a higher degree of marketization can effectively promote the free flow of capital, labor and other factors between regions (Gao Haifeng, 2022). Regions with a high degree of marketization have obvious geographical advantages such as resource, market and transportation due to the concentration of enterprises, and the government subsidies obtained by enterprises can be used more for R&D and innovation. And in low degree of marketization of the region, the enterprise needs to use government subsidies in such aspects as resources, market, traffic condition of to make up for these disadvantages, on research and development innovation to some less stable, Therefore, in regions with low degree of marketization, the impact of government subsidies on promoting R&D and innovation in enterprises' digital transformation is far less than that in regions with high degree of marketization.

Table 9. Robustness test 1

Variable	(3) RDS	(4) RDS	(5) RDS	(6) RDS
DT	0.0153 *** (0.00106)	0.00471 *** (0.00111)	0.00979 *** (0.00224)	0.000430 (0.00237)
ROE	1.500 *** (0.106)	1.263 *** (0.104)	0.417 *** (0.122)	0.328 *** (0.120)
AL	1.171 *** (0.148)	0.530 *** (0.157)	0.497 *** (0.158)	0.212 (0.164)
CI	0.0254 *** (0.00582)	0.0355 *** (0.00624)	0.0286 *** (0.00563)	0.0328 *** (0.00579)
GS	0.0257 *** (0.00500)	0.0120 ** (0.00512)	0.00217 (0.00503)	0.000756 (0.00525)
Constant	1.885 *** (0.126)	1.670 *** (0.108)	0.774 *** (0.141)	0.643 *** (0.118)
Year	NO	YES	NO	YES
Individual	NO	YES	NO	YES
Number of samples	12307	12307	3488	3488

In order to improve the robustness of the test results, the explained variables and core explanatory variables were replaced and the robustness test was carried out. Due to space limitation, this paper only lists the regression results after the replacement of two variables, that is, the number of subdivision indicators of blockchain technology (BCT) and big data technology (BDT) appearing in the annual report of the enterprise instead of the core explanatory variable digital transformation (DT). The rest of the substituted variables have also been verified and the results are similar to those

listed. Table 10, column (1) (2) respectively report to all of the samples to replace the core variable regression results, column (3) (4) report a high degree of marketization of area of samples to replace the core variable regression results, column (5) (6) samples reported low degree of marketization of the region, to replace the core variable regression results. From the point of view of regression results, it is basically consistent with the results of the benchmark regression results report. It can be clearly seen that in the overall sample, digital transformation and enterprise R&D innovation are significant at 1% level; In grouping samples, the samples of marketization of high and low marketization areas without control individual under the condition of fixed effects, digital transformation and enterprise innovation significant at the 1% level, under the condition of fixed effects in the control of individuals, marketization of high area digital transformation of enterprises and enterprise innovation significant at the 5% level, low marketization areas there are no significant correlation, Hypothesis 2 is further verified.

Table 10. Robustness test 2

Variable	(1) RDS	(2) RDS	(3) RDS	(4) RDS	(5) RDS	(6) RDS
BCT	0.365 *** (0.0825)	- -	0.499 *** (0.0926)	- -	0.376 *** (0.138)	
BDT	- -	0.135 *** (0.0428)	- -	0.104 ** (0.0476)	- -	0.0840 (0.0696)
MD	0.799 *** (0.243)	0.794 *** (0.243)	- -	- -	- -	- -
DT*MD	0.00505 *** (0.00107)	0.00659 *** (0.00108)	- -	- -	- -	- -
ROE	1.050 *** (0.0873)	1.053 *** (0.0873)	1.251 *** (0.104)	1.249 *** (0.104)	0.317 *** (0.120)	0.326 *** (0.120)
AL	0.466 *** (0.129)	0.463 *** (0.129)	0.518 *** (0.157)	0.512 *** (0.157)	0.218 (0.164)	0.211 (0.164)
CI	0.0373 *** (0.00478)	0.0372 *** (0.00478)	0.0350 *** (0.00624)	0.0351 *** (0.00624)	0.0332 *** (0.00579)	0.0328 *** (0.00579)
GS	0.00824 ** (0.00418)	0.00838 ** (0.00418)	0.0118 ** (0.00512)	0.0121 ** (0.00513)	0.000931 (0.00524)	0.000504 (0.00525)
Constant	0.835 *** (0.207)	0.844 *** (0.207)	1.706 *** (0.108)	1.718 *** (0.108)	0.642 *** (0.117)	0.630 *** (0.117)
Year	YES	YES	YES	YES	YES	YES
Individual	YES	YES	YES	YES	YES	YES
Number of samples	15795	15795	12307	12307	3488	3488
R ²	0.030	0.029	0.033	0.030	0.019	0.017

5.4 Heterogeneity Test

In the process of digital transformation, enterprises of different natures may have different degrees of reflection of R&D innovation. Therefore, in accordance with the classical research method, this paper will divide enterprises into state-owned enterprises and non-state-owned enterprises according to the nature of ownership, and conduct tests respectively to verify the difference between enterprises with different attributes in the positive impact of enterprise digital transformation on R&D innovation. In Table 4, columns (1), (2) and (3) respectively report the degree of influence on R&D innovation of all non-state-owned enterprises in the sample, non-state-owned enterprises in areas with high marketization degree and non-state-owned enterprises in areas with low marketization degree. Columns (4), (5) and (6) respectively report the degree of influence on R&D innovation of all State-Owned enterprises in the sample, state-owned enterprises in areas with high marketization degree, and state-owned enterprises in areas with low marketization degree. It can be seen that the impact of non-state-owned enterprises' digital transformation on R&D innovation is much higher than that of state-owned enterprises. As can be seen from the internal comparison results of the two types of enterprises with equity nature, the regression results of non-state-owned enterprises are more

consistent with the conclusions of hypothesis 1 and Hypothesis 2, but the regression results of state-owned enterprises are not.

Table 11. Heterogeneity test

Variable	(1) RDS	(2) RDS	(3) RDS	(4) RDS	(5) RDS	(6) RDS
DT	0.00361 *** (0.00123)	0.00339 *** (0.00130)	0.00336 (0.00351)	0.00372 ** (0.00173)	0.00235 (0.00203)	0.00517 * (0.00285)
ROE	1.305 *** (0.111)	1.551 *** (0.126)	0.293 (0.188)	0.301 ** (0.135)	0.339 * (0.181)	0.136 (0.133)
AL	0.711 *** (0.166)	0.715 *** (0.191)	0.530 ** (0.257)	0.346 * (0.208)	0.749 *** (0.276)	0.536 *** (0.206)
CI	0.0507 *** (0.00678)	0.0437 *** (0.00861)	0.0488 *** (0.00921)	0.0375 *** (0.00590)	0.0565 *** (0.00823)	0.00698 (0.00600)
GS	0.0135 ** (0.00647)	0.0187 ** (0.00752)	0.00321 (0.00977)	0.00203 (0.00462)	0.00249 (0.00603)	0.000189 (0.00477)
Constant	1.789 *** (0.124)	1.955 *** (0.142)	0.951 *** (0.196)	0.792 *** (0.134)	1.078 *** (0.178)	0.0948 (0.133)
Year	YES	YES	YES	YES	YES	YES
Individual	YES	YES	YES	YES	YES	YES
Number of samples	10537	8678	1859	5259	3629	1629
R ²	0.035	0.040	0.028	0.016	0.027	0.012

This paper argues that the political relevance for the state-owned enterprises to provide the institutional protection, compared to the private enterprises, state-owned enterprises are more likely to use commercial credit access to bank financing, by improving the management to improve enterprise management status, and use the political relevance policy information and market information in advance, in order to establish market dominance (national, Huang Dongya, 2018), Therefore, for state-owned enterprises, digital transformation has less impact on their R&D investment. State-owned enterprises is the state rather than the private ownership, has "the state-owned capital advantage", can rapidly to form a stronger competitive advantage position in state-owned enterprises in the industrial chain, state-owned enterprises advantage mainly originates from monopoly and preferential policies (Nie Huihua, 2015), the difficulty of make big profits is low, on research and development innovation in order to improve the competitive power is insufficient, Therefore, the digital transformation of state-owned enterprises has less impact on R&D innovation than non-state-owned enterprises. And dominant position of the state-owned enterprises in the industrial chain is more noticeable in every region, and in high degree of marketization, the factors affecting the innovation of state-owned enterprises, more digital transformation impact on innovation is not outstanding, therefore low marketization degree areas appear even the impact of digital transformation of innovation is higher than the high degree of marketization of the phenomenon of region, But this was only in a small number of samples, and most of the samples still followed the general pattern.

6. Conclusions and Recommendations

Based on the study of Shanghai and Shenzhen two city of a-share listed companies from 2016 to 2020 data, pioneering combine enterprise digital transformation and innovation, enterprise digital transformation - R&D innovation model is set up and carry on the empirical analysis and economic interpretation, but also the heterogeneity of robustness test and inspection, to improve the rigour of the study. In this paper, the following conclusions are drawn: First, when enterprises use digital technology, they also carry out digital transformation. Regardless of regional differences, enterprises' digital transformation has a positive impact on enterprises' R&D innovation, and this conclusion is still valid after the robustness test and heterogeneity test. Second, considering the regional differences, different regional economic development level to the enterprise the influence degree of the digital

transformation of enterprise innovation, in a high degree of marketization of digital transformation of enterprises to the enterprise innovation degree is higher, the influence of the low degree of marketization of digital transformation of enterprises to lower the influence degree of the enterprise research and development innovation. This conclusion was verified again in robustness test and heterogeneity test. Third, the degree of influence of ownership nature on enterprise digital transformation on enterprise R&D innovation is different. Non-state-owned enterprise digital transformation has a higher degree of influence on R&D innovation, while state-owned enterprise digital transformation has a lower degree of influence on R&D innovation.

This paper proposes the following policy implications: First, digital transformation is the general trend and can improve the level of R&D innovation. Under the national innovation driven development strategy, enterprises should increase investment in digital, using artificial intelligence technology, block chain technology, cloud computing, big data technology, such as digital technology, digital talent, digital management, digital production, complete digital transformation, realize the luxuriant turned, improve the level of enterprise innovation, and improve enterprise economic benefits. Second, the degree of marketization of higher areas, top clustering enterprises, the market competition pressure, digital transformation can improve the level of enterprise innovation, improve product technology content, into the higher level of the market, and expand market share, improve market competitiveness, but also can prevent the backward production capacity and elimination. In regions with a relatively low degree of marketization, enterprises have a wide space for development. Although enterprises in this region can improve their R&D and innovation level through more ways, it is clear that improving their R&D and innovation level through digital transformation is usually a feasible way. In short, whether in the marketization degree is high or low, the digital transformation for an enterprise to raise the level of innovation is a feasible path, for state-owned enterprises, to deepen the reform of state-owned enterprises, on the premise of guarantee the state-owned capital holding as much as possible into social capital, improve the state-owned enterprise vitality, better by implementing the digital transformation to raise the level of innovation; For non-state-owned enterprises, enterprises should take the initiative to carry out digital transformation. Meanwhile, the government should also encourage, support and guide non-state-owned enterprises to realize digital transformation according to the specific conditions of different regions, improve market vitality, promote the better development of socialist market economy, and build a strong country in scientific and technological innovation.

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