Digital Transformation and Firm Innovation Quality A Text-Based Analysis of Annual Reports

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Abstract—Digital transformation has become an important path for enterprises to obtain competitive advantage and realize differentiation. This paper examines the impact of digital transformation on enterprise innovation investment and innovation quality, based on the 2009-2017 data set of A-share listed companies in China. Using a new text-based analysis of annual reports to measure digital transformation at the firm level. This study contributes to the developing literature on enterprise digital transformation by providing empirical evidence of enterprise digitization and innovation quality in China's new era. The results show that digital transformation can significantly improve the quality of enterprise innovation. Meanwhile, government subsidies have a positive regulatory effect on the relationship between digital transformation and enterprise innovation, which further reveals the policy effect of strengthening the construction of the digital economy and promoting its integration and development with the real economy.

Keywords: digital transformation; innovation; subsides

1 INTRODUCTION

In recent years, China's economy has entered the stage of high-quality development from high-speed growth, and the pattern of economic development has transformed from extensive to intensive. Enterprises are the micro foundation for achieving high-quality economic development. Technological innovation creates sustainable competitive advantages for enterprises, which is the root path to realize high-quality development. Because it is difficult to be replaced by imitation, it can bring long-term economic benefits to enterprises [1]. According to existing research, corporate innovation generally stems from external market competition, internal resource endowments, or financial resource support [12; 7; 3]. Since the 21st century, the rapid development of digital technology has provided new impetus for enterprise innovation. For example, the digitization of internal processes in enterprises provides new and disruptive market opportunities for high-quality innovation, which also significantly affects the current fiercely competitive business environment. Specifically, the development of digital technology has changed the form of interaction and value exchange between enterprises and consumers, formed a dynamic learning and collaboration trend inside and outside the organization, and improved the ability to integrate internal and external resources of enterprises [5; 4; 15; 19].

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Digital technology empowerment can strengthen the drive for technological innovation, improve output efficiency based on achieving intensive allocation of resources, and thus promote high-quality economic development. Morton (1991) argues that companies must undergo a fundamental transformation to use digital technologies effectively, giving rise to the concept of digital transformation in his seminal book. At present, the research on digital transformation mainly focuses on the changes in the organizational structure, resource capabilities, market strategies, and business models driven by digital transformation [2; 16; 20]. Some literature discusses the impact of emerging digital technologies and the application of digital processes on corporate innovation [11; 6], but little literature is on the role of digital technologies in shaping entrepreneurial opportunities, decision-making, innovation capabilities, and the quality of innovation. In addition, Chinese enterprise digital transformation has a policy-driven effect besides being a cutting-edge transformation strategy [23].

In this context, enterprises that comply with national policies to actively carry out digital transformation will have more opportunities to obtain government financial support for their internal digital projects. It injects funds directly into innovation activities, reduces the internal financing pressure of enterprises, and mitigates the risk of enterprise innovation. On the other hand, the government subsidy is an official certification for enterprises' innovation ability and the supervision of innovation process. It sends a positive signal to external investors from the side. Therefore, it is beneficial to increase the opportunities for enterprises to obtain external financing, which creates conditions for enterprises to carry out high-quality innovation in terms of funds.

Based on the above analysis, this paper raises the following research questions: How does the degree of digital transformation affect the investment of enterprise innovation? How does digital transformation affect the quality of innovation in enterprises? How do government subsidies regulate the relationship between digital transformation and enterprise innovation investment and the relationship between digital transformation and innovation quality?

This paper examines the impact of digital transformation on enterprises' innovation investment and innovation quality. The expected innovation and theoretical contributions are as follows: Firstly, in terms of research concept, this paper links enterprise digitization and enterprise innovation in China, enriching and expanding the micro-study of enterprise digital transformation in influence mechanisms and economic consequences. Secondly, at the methodological level, this paper adopts textual analysis approach to shed light on the subsequent evaluation of the digital transformation. Machine learning is used to construct indicators that comprehensively reflect the degree of digital transformation of Chinese enterprises, and the measurement of the digital level of enterprises is further improved at the micro-level. Thirdly, at the theoretical level, it systematically tests whether the digital transformation of enterprises can effectively promote the improvement of innovation quality. Our work makes contributions on confirming government subsidies plays a significant role in the causal relationship between digital transformation and the quality of enterprise innovation, providing further evidence for the research on the influencing factors of enterprise innovation quality.

2 THEORETICAL BASIS AND RESEARCH HYPOTHESIS

Digital transformation is "transformation triggered by transformative information technology" that involves several aspects of business processes [22], operational processes [8], and organizational capabilities, as well as the entry or exit of businesses into new markets or exits current markets [9]. With information technology as the underlying architecture, it digitizes the daily production and management operations of enterprises, establishes a complete closed-loop of data collection, transmission, storage, processing, and feedback, removes obstacles to internal and external data transmission, improves the transmission and processing efficiency of data, organically combines traditional production and digital platforms, and forms a new digital economic system. Therefore, digital transformation may have the following two economic consequences. The first economic consequence is that enterprises regard data as a resource, a new type of production factor that is as important as common production resources such as people, money, and goods. Through the analysis, calculation, and application of data, new information and knowledge can be extracted, which can help enterprises discover market opportunities, determine the direction of innovation, and reduce uncertainty and risk. Specifically, enterprises can use intelligent tools to collect more detailed user data and analyze it, which will make them deeply understand customer needs and grasp the direction of developing innovative products or services. Besides, it can also optimize and adjust the innovation process based on the collected customer feedback information on time, thereby reducing the cost and uncertainty of innovation activities. In this way, it can mitigate the potential risk of enterprises due to the long time taken from development to commercialization of innovative activities effectively.

According to innovation theory, innovation activities require continuous resource investment. With the deepening of digital transformation, the development of digital technology has improved the efficiency of enterprise information acquisition, processing, flow, and resource allocation, which brings better innovation results under the existing constraints of innovative resources [17]. By implementing digital transformation, enterprises will release the innovation resources and capabilities confined within each department. It integrates traditional business deeply with the new digital operation in resources, technology, products, experience, and customers. Digital technology and traditional production mode are mutually embedded. It means that production resources can be reorganized and optimized using digital technology, so the boundaries of original production elements will be broken, thereby stimulating the value vitality of data and information elements. Hence, it accumulates resources for enterprises to carry out high-quality innovation activities. Finally, the organizational changes driven by digital transformation have made the organization more open, transforming the original vertical linear structure between enterprises and external suppliers into a network structure. Therefore, it can greatly promote the exchange of knowledge between the internal and external enterprises and strengthen the trend of continuous learning and dynamic collaboration. Then, a better nurturing environment can be created for high-quality innovation in enterprises.

The second economic consequence is explained by taking digitalization as an advanced stage after informatization and internetization in the development of information technology. Digital transformation continues the functions of informatization and internetization, playing the role of information media. In another vein, although data is a factor of production, it is only another manifestation of other production elements. The main effect of digital transformation is to

alleviate the asymmetry of internal and external information. In this case, there is no difference between digitization, informatization, and internetization. Data is an important carrier of modern information networks. Enterprises can enhance internal information transparency through digital transformation, reduce the asymmetry between them and external investors in information, improve the risk evaluation level of external investors, and increase the possibility of obtaining external financing. Sufficient funds are also one of the necessary conditions for enterprises to carry out high-quality innovation. Based on this, this paper proposes the following research assumptions:

H1: Assuming other conditions remain the same, digital transformation will significantly increase enterprise innovation investment.

H2: Assuming other conditions remain the same, digital transformation will significantly increase enterprise innovation quality.

According to the theory of market failure, the externalities and spillover effects of innovation make the innovation investment of enterprises lower than the optimal level of social investment. Direct government transfer payments or indirect tax relief provides net cash inflows to enterprises, which reduces the cost of capital for innovation activities. In this case, the uncertainty and risk of innovation can be mitigated, which motivate enterprises to invest in innovative projects [14]. According to the signaling theory, in addition to being taken as direct funds injected into enterprises, government subsidies can also serve as a positive signal to increase the opportunities for enterprises to obtain external financing. The distribution of government innovation subsidies is not completely random but contains a large amount of market information [21]. Before providing scientific and technological innovation support to enterprises, the government will conduct rigorous project screening and demonstration procedures. The measurement criteria of the project mainly include the following aspects: technological innovation ability, project technical elements, development prospect and economic contribution. Therefore, the innovation funding of enterprises is equivalent to the official recognition of the government for their research capabilities and projects. It also conveys a positive message to the outside that enterprises have technological advantages. In this case, external investors can make credit policy decisions based on whether the company is the subject of innovation funding, thus avoiding adverse selection problems. Second, after enterprises have been funded, the government will effectively monitor the implementation of their projects and give them continuous guidance, thereby reducing the moral hazard of external investors. In conclusion, the dual signal of technology and regulatory certification released by the innovation subsidy based on government credit has prompted market investors to generate higher credit recognition based on their trust in the government, thereby stimulating the continuous investment of other enterprises, financial institutions, and social capital, and ultimately forming a stable and diversified innovation investment system. In the context of the current high-quality economic development, enterprises that carry out digital transformation in line with the current digital economy policies can apply for more subsidies from the government through digital projects such as intelligent platforms that they invested and built. As mentioned above, the financial needs to carry out innovation activities are effectively met in enterprises that received subsidies, which improves the motivation of enterprise innovation. It is conducive to improving enterprise innovation investment and innovation performance. Therefore, the following research hypothesis is proposed and tested:

H3: Assuming other conditions remain the same, government subsidies will have a positive regulatory effect on the relationship between digital transformation and enterprise innovation investment.

H4: Assuming other conditions remain the same, government subsidies will have a positive regulatory effect on the relationship between digital transformation and enterprise innovation quality.

3 SAMPLE SELECTION AND RESEARCH DESIGH

This paper selects the data of all A-share listed companies in China's capital market from 2009 to 2017 as the initial research sample to empirically study the impact of digital transformation on the innovation performance of enterprises. Following the convention, the basic steps of data selection in this article are as follows: Firstly, remove the companies that had been ST and *ST during the sample exclusion period. Secondly, remove the financial and insurance industry companies. Thirdly, remove the samples with missing control variables. Finally, the final sample includes a panel with 7137 firm-year observations. This paper extract financial data from China Stock Market and Accounting Research (CSMAR) and China Center for Economic Research (CCER) database. The relevant annual report texts come from the official websites of the Shenzhen Stock Exchange, the Shanghai Stock Exchange, and the Juchao Consulting Network. While the patent sample data comes from the patent databases of CSMAR listed companies and subsidiaries. Winsorization is performed on all continuous variables at 1% and 99% quantiles, respectively, to reduce the potential impact of outliers.

Prior literature has provided an effective measure of enterprise innovation investment: R&D expenditure. Due to the huge difference in the size of enterprises, it is easily affected by scale to take the total R&D expenditure as a means of measurement directly. Therefore, following existing research, this paper selects the proportion of R&D expenditure to operating income to measure the company's innovation investment (RD_S). The measurement of innovation quality (Innova_r) follows the research of Hall and Harhoff (2012) to use breakthrough (substantive) innovation as a proxy variable for the quality of innovation in enterprises, which is measured by the total number of invention patent applications. Since the patent sample data has obvious right-biased characteristics, this paper adds the total number of invention patent applications to 1 and takes the natural logarithm as the final proxy variable. The explanatory variable of this paper, the degree of digital transformation, is the natural logarithm of the word frequency of the corresponding keywords about digital transformation in the annual report of listed companies. It is measured by text analysis methods such as jieba word segmentation and word frequency statistics [23]. The specific steps are as follows: First, build a digital dictionary. To ensure the rationality and prescriptiveness of the digitized dictionary, follow the digitized thesaurus identified by Wu (2021) by collating academic literature and policy reports. Secondly, expand words in the confirmed thesaurus to a custom dictionary in Python's jieba word segmentation function. Then use machine learning algorithms to divide the annual report into segments, compare the words with the words in the digital dictionary and calculate the frequency that each word in the digital dictionary is determined to appear in each company's annual report. Finally, add up the word frequency of each digital word, and the total number of word frequencies is logarithmically processed to obtain the degree of digital transformation (Dig) of

the enterprise. By observing the distribution of data, the samples are closer to the normal distribution after logarithmic treatment. The regulatory variable government subsidy is defined as the logarithm of the total amount of government subsidies, using the total amount of government subsidies disclosed under the "non-operating income" account in the annual financial report of the listed company selected. To solve the estimation bias caused by the large difference in government subsidies between enterprises, we take the logarithm of government subsidies. Then we can obtain the government subsidy variable. The remaining variable definitions are shown in the table.

Table 1 Variable Design

Proxy Variables	**Variable Definitions**
RD_S	Total R&D expenditure/operating revenue
Innova_r	The number of annual invention patent applications + 1 to get the logarithm
Dig	The natural logarithm of the word frequency of the keyword corresponding to digital transformation in the annual report of the listed company
Subsides	The total amount of government subsidies disclosed under the "non-operating income" account in the annual financial report of the listed company.
Size	The natural logarithm of the total assets of the enterprise
Lev	Total liabilities/total assets of the enterprise at the end of the period
Fage	The natural logarithm of the difference between the current year and the year the company was founded
ROE	net profit/ownership equity
Cash	Cash and cash equivalent balance/total assets at the end of the period
MtoB	Total market capitalization/total assets of the company
First	Number of shares held by the largest shareholder/ total share capital
Dual	Dumb variable, the chairman and general manager by one person concurrently as 1, otherwise 0
Audit	Dumb variable, 1 if the accounting firm issues a standard unqualified opinion, otherwise it is 0
Export	Dumb variable, if the enterprise has an export business it is 1, otherwise 0
Contend	The Heffendaal Index of the industry calculated by the sales of companies in the industry binary code
Industry	According to the CSRC Industry Classification Standard (2012), 18 industries are involved, and 17 dummy variables are set
Year	Involving 8 years, 7 dummy variables are set

We use the general least squares model (OLS) to test the main research hypotheses. According to assumptions 1-3, the innovation investment (RD_S) and the innovation quality (Innova_r)

are the explanatory variables. The degree of digital transformation of enterprises (Dig) is the explanatory variable. The government subsidy variable (subsidies) is the regulatory variable. It controls the influence of other variables.

$$RD\_S_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$Innova\_r_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$RD\_S_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_2 Subsides_{i,t} + \alpha_3 Dig_{i,t} \times Subsides_{i,t} + \alpha_4 Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$Innova\_r_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_2 Subsides_{i,t} + \alpha_3 Dig_{i,t} \times Subsides_{i,t} + \alpha_4 Controls_{i,t} + \varepsilon_{i,t} \quad (4)$$

4 EMPIRICAL RESULTS

4.1 Descriptive statistics

Table 2 Descriptive statistical results

Variable	N	Mean	Sd	Min	Max
RD_S	7137	4.8581	4.2295	0.0300	25.5100
Innova_r	7137	1.8387	1.2169	0.0000	5.6312
Dig	7137	0.9243	1.2250	0.0000	4.4308
Subsides	7137	16.2719	1.4462	10.9332	20.2917
Size	7137	21.8070	1.1684	19.2426	26.8954
Lev	7137	0.3619	0.1965	0.0454	0.9849
Fage	7137	3.0821	0.2154	2.6391	3.6109
ROE	7137	0.0787	0.0894	-0.3967	0.3923
Cash	7137	0.2009	0.1570	0.0099	0.7231
MtoB	7137	4.1789	3.0689	0.7644	23.6046
First	7137	35.0292	14.2485	0.4738	74.9800
Dual	7137	0.3120	0.4634	0.0000	1.0000
Audit	7137	0.0116	0.1072	0.0000	1.0000
Export	7137	0.1198	0.3247	0.0000	1.0000
Contend	7137	0.0919	0.0862	0.0147	0.7044

As can be seen from the table, the average Dig of enterprise digital transformation is 0.9243, the standard deviation is 1.2250, and its maximum and minimum values are 4.4308 and 0.0000, respectively, indicating that the degree of the digital transformation varies between different companies. The average value of enterprise innovation investment is 4.8581, the

standard deviation being 4.2295, and its maximum and minimum values being 25.5100 and 0.0300, respectively, indicating that innovation investment varies greatly among enterprises. It means that the funds used for innovation by different enterprises are noticeably different, which may be related to the enterprise's capabilities or how much attention they paid to innovative activities. The average innovation quality of enterprises measured by breakthrough innovation (number of invention patents) is 1.8387, the standard deviation being 1.2169, the maximum and minimum values being 5.6312 and 0.0000, respectively, indicating that the number of invention patent applications varies greatly between different enterprises.

4.2 Basic test results

Table 3 Regression results of model (1), model (2)

Variable	***Model (1)***	***Model (2)***
	RD_S	***Innova_r***
Dig	0.7374*** (8.6635)	0.1298*** (5.8660)
Size	0.1462 (1.6358)	0.4780*** (13.7966)
Lev	-5.1036*** (-9.9428)	-0.2307 (-1.3698)
Fage	-1.5651*** (-4.1819)	0.0204 (0.1852)
ROE	-6.6821*** (-7.5889)	0.6564*** (2.7289)
Cash	2.7894*** (4.2690)	0.2904* (1.8472)
MtoB	0.2023*** (6.6235)	0.0356*** (4.6392)
First	-0.0265*** (-4.5905)	-0.0027 (-1.6309)
Dual	0.1954 (1.1333)	0.0959** (2.0096)
Audit	1.3936* (1.7762)	-0.0715 (-0.4964)
Export	0.1009 (0.7714)	0.1518*** (3.2166)
Contend	-5.9474*** (-6.4413)	-1.0242*** (-3.4130)
Constant	6.8123*** (3.2695)	-9.1932*** (-11.1213)
Industry FE/Year FE	YES	YES
Observations	7137	7137
Adj_R^2	0.3358	0.1879

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

According to the above regression results in a model (1), the regression coefficient of the degree of digital transformation, Dig, is 0.7374, which is significant at the 1% level. It indicates

that enterprise digital transformation can significantly increase innovation investment, consistent with research hypothesis 1. In model (2), the regression coefficient of Dig, the degree of digital transformation, is 0.1298, significant at the level of 1%. It proves that enterprise digital transformation can improve enterprise innovation quality significantly. H2 is true. In addition, the coefficient of the enterprise size variable, Size, is 0.1462 and is not significant in a model (1). While the coefficient is 0.4780, significantly positive at the 1% level in a model (2), indicating that the quality of enterprise innovation is more affected by scale than innovation investment. The coefficient of asset-liability ratio Lev in the model (1) is significantly -5.1036, which is significantly negative at the level of 1%, indicating that enterprises with higher liabilities have relatively low investment in enterprise innovation. Their regression coefficient with innovation quality is also negative, but it is not significant, indicating that the quality of innovation has little relationship with the asset-liability ratio. The ROE has a coefficient of -6.6821, which is significantly negative at the 1% level in a model (1). While the coefficient is 0.6564, significantly positive at the 1% level in a model (2), indicating that the enterprise innovation investment has a significant negative correlation with profitability. But the quality of enterprise innovation is significantly positively correlated with profitability. The coefficients and significance of the remaining control variables are shown in Table 3.

Table 4 Regression results of model (3), model (4)

Variable	***Model (3)***	***Model (4)***
	RD_S	***Innova_r***
Dig	0.5954*** (7.5260)	0.0854*** (4.3375)
Subsides	0.7297*** (11.2844)	0.1947*** (10.8545)
Dig*Subsides	0.2340** (2.4497)	0.0947*** (3.8933)
Size	-0.5029*** (-5.4429)	0.3029*** (8.7261)
Lev	-5.0957*** (-10.4509)	-0.2217 (-1.3687)
Fage	-1.5825*** (-4.4125)	0.0153 (0.1449)
ROE	-7.2911*** (-8.3255)	0.4784** (2.0332)
Cash	2.8417*** (4.5982)	0.3053** (2.0367)
MtoB	0.1763*** (6.0314)	0.0286*** (3.8519)
First	-0.0218*** (-4.0359)	-0.0013 (-0.8239)
Dual	0.2179 (1.3239)	0.1015** (2.2043)
Audit	1.4165* (1.8923)	-0.0699 (-0.5111)
Export	0.0506 (0.3988)	0.1380*** (3.0141)
Contend	-5.6756*** (-6.1194)	-0.9454*** (-3.2080)

Variable	*Model (3)*	*Model (4)*
	RD_S	***Innova_r***
Constant	8.6083*** (4.3877)	-8.6850*** (-11.1255)
Industry FE/Year FE	YES	YES
Observations	7137	7137
Adj_R^2	0.3727	0.2229

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

According to the regression results of the Chow test, after introducing the intersection variable of digital transformation and government subsidies, the coefficient of Dig* Subsidies is 0.2340, significant at the 5% level in the model (3). While in the enterprise innovation quality model measured by breakthrough innovation (number of invention patents), the Dig*Subsides's coefficient is 0.0947 and significant at the 1% level. It proves that government subsidies have a significant positive regulatory effect on the relationship between digital transformation and innovation investment and the relationship between digital transformation and innovation quality of enterprises. Therefore, it can prove that digital transformation is more conducive to improving the investment and quality of innovation in enterprises with government subsidies. H3 and H4 are both true.

4.3 Robust test results

4.3.1 Lagging the key explanatory variable

Based on previous studies, the key explanatory variable will be lagged by one period and be included in the regression models again as a new explanatory variable, L.Dig, to overcome the possible interference of reverse causality between the degree of digital transformation and enterprise innovation. It further eliminates indigenousness and draws more robust research conclusions.

$$RD\_S_{i,t} = \alpha_0 + \alpha_1 L.Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$Innova\_r_{i,t} = \alpha_0 + \alpha_1 L.Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (6)$$

Table 5 Robust test results of Lagged variable

Variable	*Model (5)*	*Model (6)*
	RD_S	***Innova_r***
L.Dig	0.7638*** (7.8791)	0.1516*** (6.0889)
Size	0.1269 (1.3041)	0.4830*** (12.8866)
Lev	-5.1499*** (-9.2026)	-0.1930 (-1.0328)
Fage	-1.5662*** (-3.8185)	0.0159 (0.1300)

Variable	*Model (5)*	*Model (6)*
	RD_S	***Innova_r***
ROE	-6.7369*** (-7.0958)	0.7205*** (2.7045)
Cash	3.4199*** (4.0343)	0.3631* (1.8542)
MtoB	0.2072*** (5.3986)	0.0324*** (3.4003)
First	-0.0260*** (-4.0254)	-0.0035* (-1.9440)
Dual	0.2867 (1.4557)	0.1235** (2.3251)
Audit	1.4869* (1.9574)	-0.0802 (-0.5158)
Export	0.0534 (0.3685)	0.1438*** (2.7631)
Contend	-5.9530*** (-6.0138)	-0.9573*** (-2.7388)
Constant	7.1212*** (3.1633)	-9.3273*** (-10.4269)
Industry FE/Year FE	YES	YES
Observations	5708	5708
Adj_R^2	0.3475	0.1917

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

Because there may be reciprocal causation between the degree of digitization and innovation quality, we lag the key explanatory variable, the degree of digital transformation, by one period to prevent interference with research results. And the regression results are shown in Table 5. As can be seen, after lagging behind the degree of digital transformation for one period, the coefficients of the digital transformation degree are still positive and significant. In regression models with innovation investment and breakthrough innovation (number of invention patents) as explanatory variables, the coefficients of L.Dig for the degree of digital transformation were 0.7638 and 0.1516, respectively, which were significant at the level of 1%. After lagging the degree of digital transformation, it still performed significantly with a higher significance, which proved that after reducing endogenous interference, the degree of digital transformation still has a significant effect on the enterprise innovation quality and further confirmed the establishment of H1 and H2.

4.3.2 Replacing the proxy variable

Some studies believe that the patent grant rate is a good indicator of patent quality judged from the perspective of censorship. Referring to Feng's (2021) study, the number of patent grants, Innova_g, is selected as a replacement variable for the quality of innovation of enterprises. As mentioned earlier, the innovation investment is measured by the proportion of R&D investment in operating income to eliminate the impact of scale on R&D investment. But the measure of innovation quality is still to use the logarithm of the number of invention patents applied without considering the size of the enterprise. Therefore, to eliminate the impact of scale, the number of invention patent applications per capita, Innova_a, is selected

as another replacement variable for the quality of enterprise innovation. So the robustness of the main assumptions in this paper is further tested.

$$Innova\_a_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (7)$$

$$Innova\_g_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_3 Controls_{i,t} + \varepsilon_{i,t} \quad (8)$$

Table 6 Robust test results of changed variable

Variable	***Model (7)***	***Model (8)***
	Innova_g	***Innova_a***
Dig	0.1492***	0.0010***
	(6.6027)	(4.2677)
Size	0.3383***	-0.0001
	(8.8154)	(-0.5101)
Lev	0.2486	-0.0040***
	(1.4358)	(-2.8427)
Fage	-0.0782	-0.0007
	(-0.6475)	(-0.8523)
ROE	0.9233***	-0.0010
	(3.4890)	(-0.5021)
Cash	0.3972**	0.0070***
	(2.3745)	(4.3688)
MtoB	-0.0053	0.0003***
	(-0.6103)	(4.2797)
First	0.0029	-0.0000
	(1.6302)	(-1.4573)
Dual	0.1436***	0.0007*
	(2.8046)	(1.7087)
Audit	-0.0207	0.0008
	(-0.1137)	(0.5707)
Export	0.1088**	0.0011**
	(2.1916)	(2.5451)
Contend	0.8743***	-0.0090***
	(2.5997)	(-3.6967)
Constant	-6.2795***	0.0068
	(-6.9604)	(1.0689)
Industry FE/Year FE	YES	YES
Observations	7135	7135
Adj_R^2	0.1598	0.0891

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

This table shows the regression results after replacing the proxy variable of the explanatory variable, enterprise innovation quality, with the number of patents granted Innova_g and the number of invention patents per capita, Innova_a. As can be seen from the following table, in the model that replaces the proxy variable of enterprise innovation, the coefficients of the degree of digital transformation, Dig, are 0.14921 and 0.0010, respectively, which are significantly positive at the 1% level. The regression results prove that digital transformation has a significant role in promoting the quality of enterprise innovation. The above results show that after measuring the quality of enterprise innovation from another perspective and

considering the impact of scale, the regression results about the relationship between the degree of digital transformation and enterprise innovation are still positive and significant, which further confirms the robustness of the essential research conclusions in this paper.

5 CONCLUSION

Based on the background of the digital economy empowering the entity enterprise system, this paper examines the impact digital transformation has on the innovation investment and innovation quality of enterprises, explores the regulatory role played by government subsidies in it, and draws the following conclusions: (1) The digital transformation of enterprises can significantly promote the innovation investment and innovation quality of enterprises, which effectively reflects the effect that digital transformation emerged on innovation at the micro-enterprise level and the policy effect of macro digital economy policies. (2) Government subsidies have played a positive regulatory role in how digital transformation can promote enterprise innovation investment and innovation quality. It confirms that government subsidies play a key role in the mechanism of digital transformation's impact on enterprise innovation. After lagging behind the explanatory variable(digital transformation) by one stage to solve endogenous problems, the results remain robust. The findings provide new empirical evidence for the relationship between digital transformation and enterprise innovation and also prove that government subsidies can further strengthen the positive effect of digital transformation on innovation investment and innovation quality. The relationship between digital transformation and enterprise innovation quality studied in this paper is a priority to accelerate the integration of the digital economy and the real economy and to empower high-quality development. The discussion on the microeconomic consequences of the digital transformation of enterprises further reveals the policy effect of strengthening the construction of the digital economy and promoting its integration and development with the real economy. At the same time, the discussion on the impact of digital transformation on enterprise innovation quality is conducive to summarizing the development process and successful experience of empowering the real economy through digital technology. Therefore, it can accelerate the upgrading and transformation of traditional industries, vigorously cultivate and develop new digital businesses, and furtherly provide policy inspiration for making policies related to digital transformation and high-quality economic development.

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