Journal of Environmental Science and Economics ISSN: 2832-6032
https://doi.org/10.56556/jescae.v3i2.897

RESEARCH ARTICLE

Digital transformation and enterprise dual innovation: Evidence from China's A-share listed companies

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Received: 13 April, 2024, Accepted: 23 May, 2024, Published: 30 May, 2024

Abstract

Digital transformation is an important means to promote the development of enterprises' dual innovation coordinated development. Based on the data of China's A-share listed enterprises from 2007 to 2022, this paper uses the two-way fixed effect model to conduct an empirical test, and discusses the influence of digital transformation degree on enterprises' dual innovation performance and its channel mechanism. The findings are as follows: (1) Digital transformation significantly promotes exploratory innovation and exploitative innovation, especially exploratory innovation. (2) Mechanism test shows that digital transformation promotes enterprise dual innovation by easing financing constraints and improving organizational human capital structure. (3) Heterogeneity research shows that digital transformation has a more significant effect on the improvement of dual innovation in enterprises with high operational efficiency and enterprises in the eastern region. Further, the countermeasures and suggestions are put forward as follows: First, enterprises should clarify transformation goals and promote enterprise digitalization. Second, strengthen the construction of digital infrastructure to facilitate the digital transformation process of enterprises. Third, improve the market supervision system. Fourth, promote the agglomeration of dual innovation factors at multiple levels and promote the improvement of regional dual innovation capability.

Keywords: Digital Transformation; Exploratory Innovation; Exploitative Innovation

Introduction

The digital economy can empower the real economy, and the real economy provides a market and data source for the digital economy. Promoting the deep integration of the two is an important engine for a new round of industrial structure transformation and upgrading, and an important path to achieve Chinese-style modernization. Relying on the energy advantages of the digital economy, a new economic form, digital

transformation has brought a comprehensive impact on the social and economic system, covering three levels: micro enterprises, meso industries, and macro society. The impact on micro enterprises mainly reflects the iterative upgrading of enterprise business processes, helping enterprises provide customers with high-quality consumer experience, and data-driven decision-making. Micro enterprises are the starting point of digital transformation, and then realize the iterative upgrading of meso-industries, thereby promoting macroeconomic development.

As the cells of the economic market, micro enterprises bear the responsibility of taking into account the "quality" and "quantity" of economic development, enterprises need to maintain the existing competitive position and enhance the core competitiveness through continuous innovation, so as to promote the realization of high-quality and sustainable development of enterprises. From the perspective of actual innovation output, the average innovation output level of enterprises is not high. Most enterprises in China are in the growth mode driven by traditional factors, and fewer enterprises rely on modern technology to enable innovation, and there are relatively few innovative enterprises in the real sense. How to increase the actual innovation achievements of various enterprises in China has become an important problem that enterprises need to solve. Figure 1 reports the changing trend of digital transformation in Chinese enterprises. It can be found that the degree of digital transformation of enterprises has increased year by year, and the advantages of digital transformation driving forces have become increasingly prominent. Researchers have explored the impact of enterprise digital transformation from the aspects of resource allocation and corporate governance (Hass, Tarsalewska & Zhan, 2016; Frynas, Mol & Mellahi, 2018; Graetz & Michaels, 2018; Lin, Xie, Hao & Wang, 2020; Ma, Li & Wang, 2023), obtained fruitful research results, which laid a good theoretical foundation for this paper. Enterprise digital transformation can alleviate the financing constraints of enterprises, improve the market competitiveness of enterprises, become an important means to promote enterprises to achieve curve overtaking, and provide a solution for enterprises to solve the problem of insufficient innovation. However, few studies have focused on how enterprise digital transformation promotes enterprise dual innovation. In view of this, this paper, based on the theory of dual innovation, Based on the data of A-share listed companies from 2007 to 2022, this paper analyzes the theoretical logic of dual innovation driven by digital transformation from the micro enterprise level by using the two-way fixed effect model, and explores the heterogeneity of enterprises affected by different operating efficiency and different regions. Compared with the existing researches, the contributions of this paper are as follows: (1) It enriches the research results on the impact of enterprise digital transformation from the perspective of enterprise two-way innovation; (2) Reveals the internal theoretical logic of dual innovation driven by digital transformation.

The follow-up structure of this paper is as follows: The second part is literature review; The third part is theoretical analysis and research hypothesis; The fourth part is data source, variable design and model setting. The fifth part is characteristic facts and datum regression; The sixth part is mechanism test and heterogeneity analysis. The seventh part is the conclusion and enlightenment.

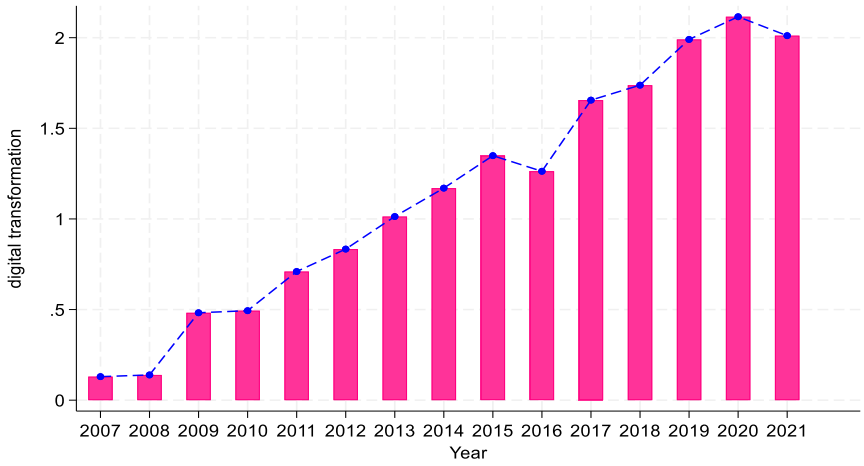

Figure 1. Trend chart of enterprise digital transformation

Notes: Drawn by stata15.0, same as below.

Literature review

Research status of enterprise digital transformation

Connotation and characteristics

The transformation is systematic, strategic and phased, and it is a crucial route for businesses to establish new competitive advantages and seek new economic growth points. Enterprise digital transformation is a high-level transformation aimed at realizing a new business model of digitalization, informatization and intelligence (Song & Song, 2023). From the technology-driven perspective, some scholars believe that digital technology is the core content of modern enterprise transformation. Enterprises invest a lot of money in the introduction and development of new technologies, which can make them more competitive than enterprises that spend the same amount of money (Tang, 2021). In today's fierce market competition, enterprises need to combine business and strategic goals to update digital technology in a timely manner and create a new technological foundation. This business transformation process will change the traditional value creation mode of enterprises, improve business processes, production and operation management, etc. (Smirnov & Antropova, 2022). From a data-driven perspective, some scholars believe that the collection and sorting of data resources is the key to enterprise transformation, and enterprise digital transformation is a strategy to support enterprise upgrading through sorting and analyzing various data resources. As intangible assets of enterprises, data is considered as the core resource of enterprises. Enterprises summarize experience, discover rules and predict development trends through data information, so as to provide decision information for managers. From the perspective of organizational change, enterprise digital transformation is one of the processes of organizational change, and this process is sustainable (Lozić, 2023). Enterprises reconstruct organizational culture, business model and organizational structure through the digital process, which will flatten the organizational structure of enterprises,

build digital core values and behavior patterns, and make resource allocation more reasonable.

Influencing factors

It mainly includes three aspects: management, organization and environment. In terms of management, the process and efficiency of transformation are affected by the level of enterprise management. As the strategic decision makers of enterprises, corporate executives are the leaders in the process of transformation (Wrede, Velamuri & Dauth, 2020) . Executives have different risk preferences and decision-making levels. At present, enterprises lack systematic transformation plans and strategic goals, and most managers fail to plan in all aspects, and only focus on how to introduce digital technologies. The dynamic capabilities of enterprises are different, which affect the transformation process and promote the business model and process innovation of enterprises(Jiao, Yang, Wang & Li, 2021; Matarazzo, Penco, Profumo & Quaglia, 2021); In terms of organization, the enhancement of fault zone of the senior management team can improve the decision-making level of the management, improve the integration ability of enterprise resources, and promote the management to improve the risk appetite and increase the investment in transformation. On the environmental front, the government will adopt a series of industrial policies to achieve certain economic goals and objectives. Among them, government subsidies and tax incentives provide policy power and institutional support for enterprise transformation (He & Qiu, 2023).

Major obstacles

The digital transformation process and efficiency are mainly focused on data security issues, digital technology talent shortage, financial barriers, and insufficient management capacity. Data security issues are one of the main obstacles to transformation. The transformation process involves a large amount of data, and there is a great risk of disclosure in the process of sharing and interworking of enterprise data. The privacy of employees cannot be guaranteed, and the rights and responsibilities are not clear (Li & Chen, 2023). Therefore, there is hesitation and hesitation in the enterprise and its employees. A shortage of digital skills is another major obstacle. Digital technology talent is a new important resource to promote digital transformation. Enterprises need not only management personnel with digital management experience, but also a variety of technical personnel in the fields of computer science, information science and automation. At present, enterprises are insufficient to introduce talents and lack systematic digital technology training for enterprise employees, China 2023 enterprise digital transformation ability report shows that 57% of enterprises lack digital training for relevant personnel, 23% of enterprises have never had the corresponding training. Financial barriers are the third major obstacle. The transformation process requires a lot of money to update equipment, collect data and train talent, and some companies may have financial barriers. Small and medium-sized enterprises are short of funds and have poor ability to bear financial risks (Chen & Chen, 2023). Management capacity is the fourth

major obstacle. Enterprise managers need to make decisions based on the information they have and make overall arrangements for the digital management process, which requires managers to have a comprehensive digital knowledge background and choose appropriate digital technologies according to their own advantages to combine with their own production and operation process. However, for traditional enterprises, decision-making is more difficult.

Effect of utility

The effectiveness of digital transformation mainly includes improving resource allocation and corporate governance. In terms of resource allocation, the researchers pointed out that enterprises undergoing digital transformation transmit signals of strong financial strength and broad development prospects to the outside world, which can help enterprises attract high-quality talents and provide human resources for the development of the company. Digital technology applications can optimize human resources by replacing and supplementing highly repetitive, low-skilled jobs with cheaper capital (Graetz & Michaels, 2018). At the same time, the improvement of the level of enterprise informatization will restrain the violation of corporate information disclosure (Ma, Li & Wang, 2023), increase the trust of external investors in enterprises, and increase the possibility of investment. In addition, digitization can reduce unnecessary capital requirements and reduce the inefficient operation of financial resources (Frynas, Mol & Mellahi, 2018). In terms of corporate governance, business process informatization can improve the transparency of enterprises in production links, internal management links, research and development links and financial control links, restrain managers' short-sighted behaviors, alleviate principal-agent problems, strengthen internal supervision, increase the fairness and effectiveness of decision-making, and improve the internal governance environment of enterprises (Hass, Tarsalewska & Zhan, 2016). And help improve the organizational environment, governance structure and checks and balances, so as to form a community of interests for information sharing and common governance (Lin, Xie, Hao & Wang, 2020).

Research status of dual innovation

Connotation and characteristics

March J.G. (March, 1991) divided enterprise innovation activities into exploratory innovation and exploitative innovation for the first time, thus forming the idea of organizational dual innovation. Since then, scholars have continuously enriched and improved the connotation of dual innovation on this basis. Exploratory innovation is a fundamentally old and new behavior, which focuses on long-term and larger innovation activities, aiming at producing brand new products or services, opening up new markets and marketing methods to attract new customers (Sun, Liu & Ding, 2020); Exploitative innovation is a progressive innovation behavior that focuses

on the expansion of existing technologies , its goal is to improve product functions and improve service quality, so as to meet the needs of customers (Ling & Yang, 2023). The two types of innovation activities have different resource demands, risk bearing and income improvement. Both kinds of innovation activities require resource input, and resources are scarce. Based on innovation heterogeneity, Yingbing Jiang et al. found that different enterprises have different investment in exploratory innovation and utilization innovation (Jiang, Xu & Ban, 2022). As different enterprises have different target orientation, risk preference and resource reserve structure, enterprises will focus on different types of innovation according to their own conditions (Guo, Liu & Zhang, 2019). In addition, the collaborative development of dual innovation can not only help enterprises maintain their long-term competitive position in the existing market, but also open up potential markets for enterprises to help occupy a dominant position in new markets, which will bring sustainable development benefits to enterprises.

Influencing factors

Market environment, organizational characteristics, resource acquisition and so on have an impact on enterprise innovation. In terms of market environment, people's services and demands for products continue to diversify. Customers buy commodities in order to obtain the use value of commodities, and enterprises in order to obtain profits. In a dynamic and competitive environment, enterprises need to continuously improve the allocation of innovation resources, balance their own innovation capabilities, balance two kinds of innovation activities, and take into account the current and future competitive advantages. In terms of organizational characteristics, Lin et al. large scale enterprises have strong risk tolerance and are suitable for the collaborative development of dual innovation(Lin, Yang & Demirkan, 2007) . Xiaodi Zhang et al. believe that enterprises that change rigid habits and consciousness are more able to promote the development of dual innovation(Zhang, Tian, Song & Zhao, 2021). In terms of resource acquisition, some researchers have analyzed how the enterprise resource acquisition ability affects the dual innovation ability.

Research trends review

First, existing literature has analyzed the connotation and characteristics of enterprise digital transformation in detail from the perspectives of technology-driven, data-driven and organizational change. At the same time, with the development of the dual concept, some scholars have begun to combine the dual theory with innovation, such as: dual innovation synergy, equity incentive and dual innovation, dual innovation capability, dual innovation input connotation and characteristics, etc., while few papers have studied exploratory innovation and utilization innovation from the level of dual innovation performance. Second, existing literatures have studied the factors affecting the overall level of dual innovation from the aspects of management, organization and environment, but there is a lack of relevant studies from the aspect of

transformation. Third, the theoretical research on digital transformation has been deepened, mainly focusing on the connotation and characteristics, influencing factors, transformation obstacles, and utility impact. Through the transformation, enterprises can realize the reorganization of technology, business process and knowledge, break through the technical barriers, and provide a new perspective for improving the performance of enterprises' dual innovation.

Theoretical Analysis

Digital transformation and dual innovation

The transformation is systematic, strategic and phased, which can help enterprises to seek new economic growth points. Enterprise digital transformation is a high-level transformation of enterprises through improving business processes, improving organizational structure, and transforming management mode to achieve a new business model of digitization, information and intelligence. Enterprises inject digital technology into business processes, and rely on digital technology to enable them to identify underutilized human resources, internal and external resources, and help enterprises reduce resource redundancy and improve resource utilization (Wen & Zhong, 2022). The injection of digital technology into the production process can improve the flexibility and expansibility of the new product design process (Ferreira, Fernandes & Ferreira, 2019), broaden the channels for enterprises to obtain resources, and increase the paths for enterprises to solve problems. As the basic unit of production development, enterprises meet the needs of consumers by transforming the means of production into products, services, systems, etc. In order to meet the increasingly diversified product demand of consumers, enterprises need to continuously produce more new products and increase the achievements of enterprise dual innovation. Enterprise innovation results are the new products, new services and new systems developed by enterprises through research and development, design, construction and other innovative activities. Whether enterprises can achieve innovation results is restricted by many factors, among which the important factors include financing constraints and human capital quality. Enterprise digital transformation can not only alleviate the information gap between banks and enterprise subjects, but also increase the attractiveness of enterprises to talents. Through technical support for enterprise employees, talents' skills can be fully utilized and enterprises' dual innovation results can be increased. Digital transformation mainly improves the effectiveness of dual innovation through the following two ways. The theoretical model is shown in Figure 2.

First, it will help enterprises ease financing constraints. From the perspective of risk management, enterprise digitalization is strengthening enterprise resilience, enabling enterprises to withstand pressure and recover quickly in the face of adverse scenarios (Chen, Hao & Yi, 2023), reducing corporate financial risks, operational risks and other risks, and thus reducing corporate debt financing costs. From the perspective of information market, enterprise informatization can increase the information transparency among enterprises, make the connection between stakeholders closer, promote information sharing and resource complementarity among

enterprises, improve commercial credit, expand commercial credit financing channels, and alleviate financing constraints (Li, Li & Li, 2023). The investment cycle of enterprise innovation activities is long and the funds are needed. Due to the high resource requirements of innovation activities, companies need to have strong financial strength to increase the intensity of innovation activities. Most enterprises can not rely on their own financial strength to provide funds for innovation activities, more rely on a variety of channels of financing. Therefore, corporate financing constraints directly affect the output of innovation achievements. The improvement of the digital level of enterprises enables external investors to follow up the progress of innovation projects in a timely manner and supervise the financial status of enterprises, thus improving the dual-innovation ability and dual-innovation efficiency of enterprises.

Secondly, it helps enterprises to improve the quality of human capital. Based on the substitution effect, digital technology enables enterprises to invest in lower-cost machines to complete repetitive and procedural work, replace part of low-skilled manpower, and reduce the proportion of redundant human resources. Based on the creation effect, the transformation will change the production structure of enterprises, which will provide new employment opportunities such as algorithm development and smart device maintenance. At the same time, the complementarity of capital skills in the production process will enable enterprises to increase the capital investment of highly skilled talents and attract high-quality labor force (Xiao, Sun, Yuan & Sun, 2022). The substitution effect reduces the low-skilled manpower, while the creation effect increases the high-skilled manpower. This process will increase the proportion of high-quality labor force. Compared with other business activities, enterprise dual innovation activities are more professional, longer cycle and greater uncertainty. Therefore, researchers involved in dual innovation activities must have sufficient knowledge reserves, rich imagination and perseverance. Through digital transformation, enterprises can provide the necessary talent base for the dual innovation activities, so as to promote the dual innovation.

The innovation results of exploratory innovation are new products or new services, while exploitative innovation is to improve on the basis of original products or services, so as to achieve the effect of innovation. The two kinds of innovation activities are different in risk and return, and there are differences in technology and financial support. Compared with exploitative innovation, exploratory innovation has higher risks and uncertainties. At the same time, once exploratory innovation is successful, new products or services will play a huge competitive advantage and bring greater benefits to enterprises. Because exploratory innovation requires old and new, it often requires higher capital investment, higher technology, and greater financing constraints. Therefore, exploratory innovation is more urgent than exploitative innovation in terms of talent and financing constraints. Faced with the benefits that the success of exploratory innovation will bring to the enterprise, the enterprise is willing to carry out exploratory innovation activities, but faced with the high-tech talents and funds required for exploratory innovation, it is the barrier to the success of exploratory innovation activities. Through digital transformation, enterprises can enhance the technical support for innovative R&D activities, improve the quality of human capital, increase the possibility of successful R&D, and financial institutions will be more willing to cooperate with enterprises, and the financing constraints will be eased. When the "urgent conditions"

required for exploratory innovation are improved, enterprises are more willing to increase investment in exploratory innovation activities in the face of greater benefits, which has a more significant impact on the performance of exploratory innovation. Based on this, this paper proposes the following research hypotheses

H1a: The improvement of the degree of digital transformation can significantly improve the level of exploratory innovation of enterprises.

H1b: The improvement of the degree of digital transformation can significantly improve the level of exploitative innovation of enterprises.

H1c: Digital transformation has a more significant impact on enterprise exploratory innovation.

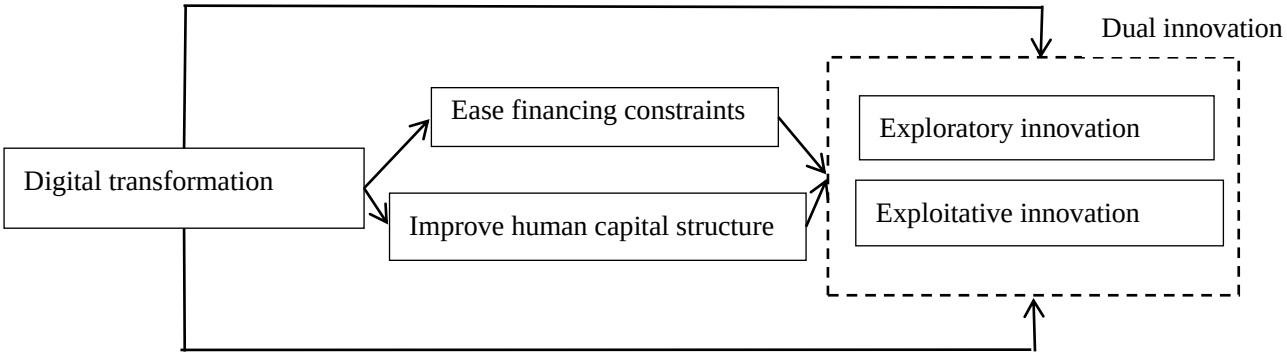

Figure 2: The impact of digital transformation on dual innovation

Heterogeneity of business efficiency

Enterprise operation efficiency is the concentrated performance of enterprise profitability and risk level, which can reflect the ability of enterprises to concentrate social resources, maintain social resources and make full use of limited social resource. In the digital economy environment, enterprises with higher operating efficiency are more likely to concentrate resources to gain insight into market demand, and their entrepreneurs have higher acumen, so they can take the lead in grasping opportunities , abandon worthless resources, reduce unreasonable investment, provide sufficient cash flow for innovation activities, and adjust organizational personnel allocation and product development requirements in a timely manner, so as to promote enterprise dual innovation. Enterprise innovation activities will be accompanied by new changes and new risks. In enterprises with high operating efficiency, the accuracy of risk identification is higher, the corresponding risk control system is more perfect, the enterprise can track and deal with potential risks in time, respond to new changes in time, make full use of resources to solve problems, give play to the advantages of digital technology, promote the process of enterprise digitization, and achieve the purpose of improving the output of dual innovation. Specifically, enterprises with higher operating efficiency have stronger profitability and anti-risk ability . Therefore, in the face of uncertain costs and benefits, enterprises with high operating efficiency are also willing to rely on new technologies to invest more resources in continuous innovation, and can make full use of resources to

significantly improve the level of dual innovation results. In order to prevent business risks, enterprises with low operating efficiency dare not risk investment and innovation, and firmly set the focus of development on innovation activities. Based on this, this paper proposes the following research hypothesis:

H2a: The role of digital transformation in promoting exploratory innovation in enterprises is more significant in enterprises with high operational efficiency.

H2b digital transformation's promotion of exploitative innovation in enterprises is more significant in enterprises with high operational efficiency.

Regional heterogeneity

China is divided into three parts according to the region: middle, east and west, and there are gaps in the level of economic development, regional digital policies, digital infrastructure construction and so on. There is an imbalance in regional economic development in China, and the demand for products in the eastern region is diverse and strong, which promotes enterprises in the eastern region to implement the product diversification strategy, and the product diversification strategy guides and supports enterprises to produce new products from the policy perspective (Jiang, Xie & Liu, 2023). There is an imbalance in the agglomeration level of innovation elements in various regions, and the innovation elements such as capital, talent, and knowledge are more concentrated in the eastern region, followed by the innovation factors and market demand in the central and western regions. According to the comparative advantages of each region, China's regional policy arrangements are different, the central and western regions focus on the integration of data and reality in key areas, the eastern developed regions give priority to development, aiming at cutting-edge science and technology. At the same time, the digitalization policy in the eastern coastal region is more perfect. The implementation of digitalization-related policies can reduce the cost burden of transformation and effectively stimulate the transformation momentum of enterprises. Systematic policy support can improve the local innovation ecological environment (Wang, Zhao & Li, 2023), promote the agglomeration of innovative talents and capital, and form a knowledge spillover effect. The construction of digital infrastructure is a strong support for enterprise transformation, which can improve the efficiency of transformation and deepen the application process, and thus significantly promote enterprise innovation, while the digital infrastructure in the eastern region is more complete. Based on this, this paper proposes the following theoretical hypotheses:

H3a: The role of digital transformation in promoting exploratory innovation in enterprises is most significant in the eastern region.

The promotion effect of H3b digital transformation on enterprise exploitative innovation is the most significant among enterprises in the eastern region.

Data Specification, Variable Design and Model Settings

Data Specification

Taking 2007-2022 as the sample period, this paper takes the degree of digital transformation and ambidextrous

innovation achievements of all A-share listed companies in China as the research object, and performs the following processing on the initial data: (1) Remove the samples of enterprises in the financial industry; (2) Delete the type of accounting statements of the parent company, and only retain the sample of consolidated accounting statements; (3) Delete the sample of patent application abroad; (4) Keep only the samples that have applied for patents (5) delete the samples that have no information, (6) delete the samples that do not match, and finally contain 2580 samples. Among them, data such as digital transformation and patent applications obtained by listed companies in the digital economy come from the CSMAR database and the Wind database.

Variable Design

Explained variables

Exploratory innovation (EI) and exploitative innovation (DI) were designed as explained variables respectively. This paper takes technological innovation behavior of enterprises as the standard: new products or new services are classified as exploratory innovation performance, and the number of invention patent applications is used to quantify; Product process improvement, quality control improvement, addition of product functions and reduction of production costs are classified as exploitative innovation. The number of utility model applications and the number of design applications are summed up by addition, and the result is regarded as the new level of exploitative innovation (Benner & Tushman, 2003).

Core explanatory variables

The degree of enterprise digital transformation (Dgt) is the core explanatory variable. This paper draws on the practice of Wu Fei et al to measure variables (Wu, Hu, Lin & Ren, 2021). The measure includes five categories: artificial intelligence (AI), cloud computing (CC), blockchain (BC), Big Data (BD), and Digital technology Applications (DTA). Since the sample data is "biased", the word frequency of the five categories of enterprises is specifically summed up, and on this basis, the logarithmic processing is carried out.

Model Settings

The panel fixed effect model is used to eliminate industry characteristics and time characteristics. OLS method was used to estimate parameter values, and regression coefficient was used to test the causal relationship between digital transformation degree and dual innovation. In order to test the theoretical hypothesis H1a and H1b mentioned above, model (1) and model (2) are constructed:

$$EI_{\mathrm{it}} = a_0 + a_1 Dgt_{it} + \sum a_j Control_{it} + \mathrm{Ind}_{\mathrm{k}} + Year_t + \varepsilon_{it} \quad (1)$$

$$DI_{\mathrm{it}} = a_0 + a_1 Dgt_{it} + \sum a_j Control_{it} + \mathrm{Ind}_{\mathrm{k}} + Year_t + \varepsilon_{it} \quad (2)$$

Where i represents the enterprise, t represents the year, k represents the industry, and ε is a random disturbance

term. If a_1 is significantly positive, hypothesis H1a and hypothesis H1b can be supported .

Control variables

This paper refers to the practice of mainstream literature, The main variables are defined in Table 1.

Table 1. Main variable definitions

Variable symbol	Variable name	Calculation method
EI	Exploratory innovation	Number of invention patent applications
DI	Exploitative innovation	Number of utility model applications + number of design applications
Dgt	Digital Transformation (second)	Dgt=Ln(AI+CC+BC+BD+DTA+1)
Size	Enterprise size (Yuan)	Ln (ending total assets +1)
Age	Enterprise age	Ln (Company's current age - listing age +1)
Lev	Asset-liability ratio	Total liabilities/total assets
MB	Book-to-market ratio	Total assets/Market value A
Roa	Return on assets	Net profit/average total assets
Z	Financial distress index	Download from CSMAR database
TQ	Tobin's Q value	Market capitalization A/ Total assets
Ind	Industry code	Industry dummy variable
Year	Year to which it belongs	Year dummy

Notes: Data were obtained by stata.15.0 analysis, as shown in the following table.

Empirical Test

Description Statistics

The statistical results are shown in Table 2. The empirical test included a total of 2580 sample data. The value range of variable EI is [0,1631], and the value range of variable DI is [0,1920], indicating that the number of binary innovation achievements is significantly different. Specifically, enterprises' utilization-type innovation results are slightly higher than exploration-type innovation results. The median values of EI and DI are 11 and

12,most companies have fewer ambidextrous innovation outcomes. The range of the variable Dgt is [0, 6.282] and the standard deviation is 1.507, indicating that the mean is representative. The average Dgt was 1.436 and the median was 1.099, indicating that the digital transformation of domestic enterprises is still in the exploratory stage.

Table 2 Descriptive statistics of main variables

Variable Name	Sample size	Mean	Standard deviation	Minimum	Median	maximum
EI	2580	31.32	78.07	0	11	1631
DI	2580	32.97	92.43	0	12	1920
Dgt	2580	1.436	1.509	0	1.099	6.282
Age	2580	1.365	0.998	0	1.386	3.466
Size	2580	21.66	1.030	19.56	21.48	26.16
Lev	2580	0.333	0.193	0.0110	0.308	0.984
Roa	2580	0.0490	0.0880	-2.834	0.0500	0.604
TQ	2580	2.275	1.657	0.782	1.763	27.34
MB	2580	0.559	0.221	0.0370	0.567	1.279
Z	2580	6.771	9.182	-9.291	4.196	160.9

Characteristic facts

Figures 3 and 4 report the characteristic facts of the research hypothesis in this paper. It can be found that the slopes of the fitting curves in Fig. 3 and Fig. 4 are positive, which preliminarily verifies the research hypothesis of this paper. However, it is worth noting that since the scatter plot does not exclude the influence of any confounding factors, and can only reveal the correlation between the two variables, the research hypothesis needs to be further empirically tested.

Baseline regression

Table 3 shows the benchmark regression results of this paper. The results show that after control variables and fixed effects are added successively, the estimated regression coefficients of Dgt for EI and DI gradually decrease, while the goodness of fit R2 gradually increases. From column (5), the regression coefficient of Dgt on EI is 5.9764***, which proves that digital transformation significantly improves enterprise exploratory innovation, and thus hypothesis H1a can be verified. From the perspective of economic significance, when the degree of digital transformation increases by 1 unit, the enterprise exploratory innovation increases by 19.08% on average; From column (6), the regression coefficient of Dgt on DI is 4.1855***, indicating that digital transformation significantly improves exploitative innovation, and hypothesis H1b can be verified.

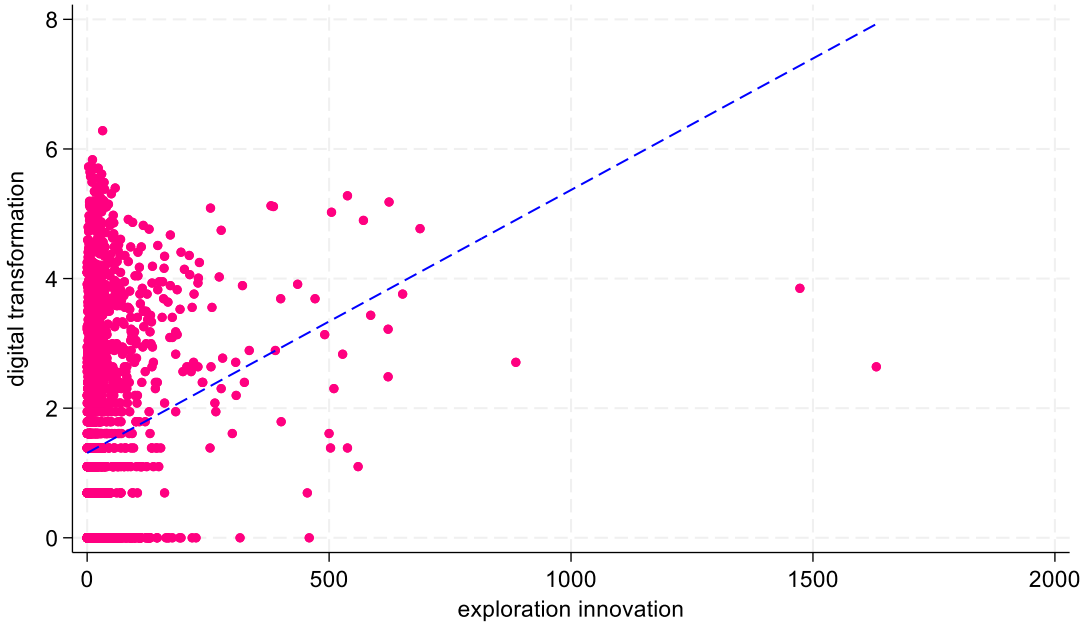

Figure 3. Correlation between digital transformation and exploratory innovation

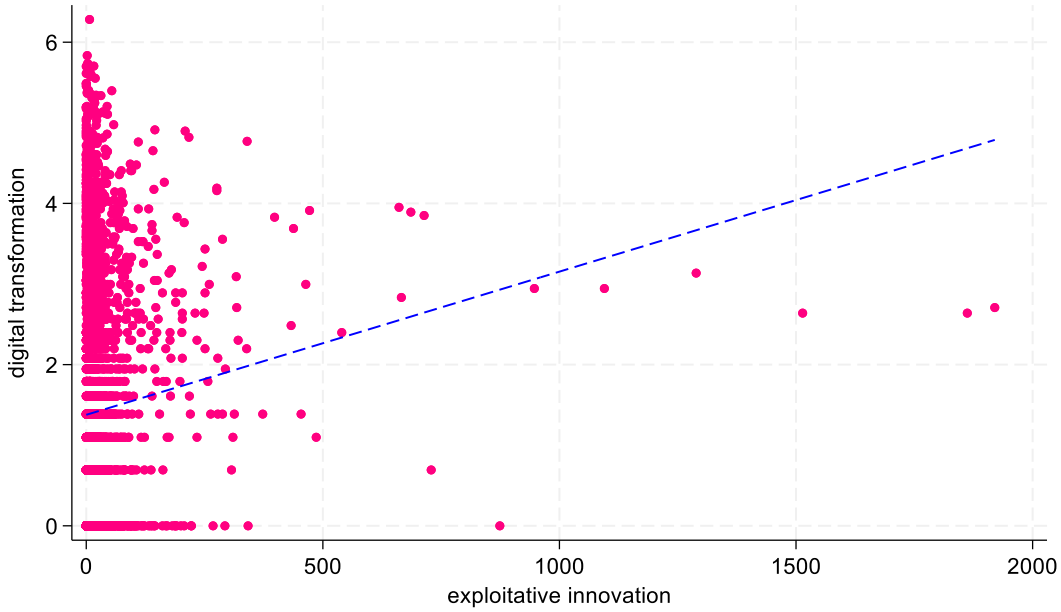

Figure 4. Correlation between digital transformation and exploitative innovation

From the perspective of economic significance, when the degree of digital transformation increases by 1 unit, the average increase of enterprise exploitative innovation is 12.69%, which is less than the increase of exploratory innovation, indicating that digital transformation has a greater effect on the improvement of enterprise exploratory innovation, and hypothesis H1c can be verified.

Table 3 Baseline regression results

Variable	EI	DI	EI	DI	EI	DI
	(1)	(2)	(3)	(4)	(5)	(6)
Dgt	10.8677***	6.6676***	7.6560***	5.2040***	5.9764***	4.1855***
	(1.310)	(1.195)	(0.991)	(1.066)	(1.080)	(1.062)
Age			-10.7175***	-1.5241	-10.6826***	-0.7621
			(2.200)	(1.947)	(2.742)	(2.530)
Size			34.5618***	20.8594***	39.8434***	25.7830***
			(3.359)	(2.569)	(3.720)	(2.870)
Lev			-8.9410	32.3089***	-8.5371	16.0237
			(13.518)	(9.369)	(13.894)	(10.542)
Roa			-15.2682	63.8992**	-19.1312	59.2214***
			(13.685)	(26.757)	(13.994)	(21.028)
TQ			3.1264*	-1.8391	2.7278*	-2.6702**
			(1.640)	(1.175)	(1.589)	(1.144)
MB			-45.1579***	-44.1771***	-49.6196***	-47.5441**
			(11.962)	(14.366)	(13.957)	(18.963)
Z			-0.5277***	-0.3617**	-0.4392***	-0.1881
			(0.146)	(0.148)	(0.147)	(0.126)
Constant	15.7139***	23.3941***	-688.1169***	-406.6892***	-835.0996***	-568.0761***
	(1.268)	(1.335)	(69.255)	(50.114)	(80.593)	(60.605)
R^2	0.044	0.012	0.186	0.080	0.248	0.159
Year	No	No	No	No	Yes	Yes
Ind	No	No	No	No	Yes	Yes
Obs	2,580	2,580	2,580	2,580	2,580	2,580

Note: In brackets is robust standard error, ***, ** and * respectively indicate significant at the significance level of 1%, 5% and 10%, as shown in the following table.

Robustness test

Considering that the binary innovation is a counting variable, the results estimated by OLS may be biased. In this paper, Poisson regression model is used for robustness test, and the test results are listed in Table 4. In the Poisson regression model, the regression coefficients are all positive and significant, so the baseline regression conclusion is robust.

Table 4 Regression results of robustness test

Variable	EI	DI	EI	DI	EI	DI
	(1)	(2)	(3)	(4)	(5)	(6)
Dgt	0.3015***	0.1838***	0.2281***	0.1592***	0.1456***	0.1170***
	(0.025)	(0.025)	(0.021)	(0.025)	(0.023)	(0.025)
Control	No	No	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes
Ind	No	No	No	No	Yes	Yes
Obs	2,580	2,580	2,580	2,580	2,580	2,580

Note: Limited by space, the control variables are the same as in Table 3 and the following table.

Mechanism test and heterogeneity test

Mechanism test

Financing constraint mechanism

In this paper, SA index is calculated according to Hadlock & Pierce's measurement method (Hadlock & Pierce, 2010)[1],The absolute value of SA is taken to measure financing constraint FC, and the test results of financing constraint mechanism are shown in Table 5.

Table 5 Test results of financing constraint mechanism

Variable	FC	EI	DI
	(1)	(2)	(3)
FC		-75.3380***	-45.6388***
		(24.090)	(15.689)
Dgt	-0.0047**		
	(0.002)		
C	Yes	Yes	Yes
Year	Yes	Yes	Yes
Ind	Yes	Yes	Yes
R^2	0.857	0.250	0.159
Obs	2,580	2,580	2,580

The regression coefficient of Dgt to FC is -0.0047**, indicating that digital transformation can significantly

[1] SA=-0.737*$Size_1$+0.043*$Size_1$^2-0.040*Age, where $Size_1$=ln(total assets at the end of the period (unit: million yuan),Age is the company's listed years.

reduce financing constraints. Meanwhile, the regression coefficients of financing constraints on dual innovation are -75.3380*** and -45.6388***, respectively, indicating that easing financing constraints can significantly promote dual innovation. In summary, financing constraint is one of the mechanisms for digital transformation to enhance enterprise dual innovation.

Human capital structure

Referring to the study of Tusheng Xiao et al. (Xiao, Sun, Yuan & Sun, 2022), the human capital structure was quantified by using Educ_ratio as a substitute variable. The test results of human capital structure mechanism are shown in Table 6. The regression coefficient of Dgt to Educ_ratio is 0.0356***, indicating that the improvement of the degree of digital transformation will significantly improve the human capital structure of enterprises. At the same time, Educ_ratio regression coefficients for dual innovation are 57.5268*** and 33.5227*, respectively, indicating that human capital structure is positively correlated with dual innovation. To sum up, human capital structure is one of the mechanisms for digital transformation to promote dual innovation.

Table 6 Test results of human capital structure mechanism

Variable	Educ_ratio (1)	EI (2)	DI (3)
Educ_ratio		57.5268*** (10.607)	33.5227* (17.885)
Dgt	0.0356*** (0.004)		
Control	Yes	Yes	Yes
Year	Yes	Yes	Yes
Ind	Yes	Yes	Yes
R^2	0.544	0.302	0.171
Obs	1,701	1,701	1,701

Heterogeneity test

Heterogeneity of operational efficiency

Business efficiency is measured by total factor productivity (TFP). With reference to the studies of Blundell and Bond (Blundell & Bond, 1998) and Xiaodong Lu and Yujun Lian (Lu & Lian, 2012), this paper uses GMM

method to measure the total factor productivity [2] . Meanwhile, define that enterprises with total factor productivity greater than or equal to the mean are high operating efficiency, otherwise low operating efficiency. The heterogeneity test results of operating efficiency are shown in Table 7. For enterprises with high operating efficiency, the regression coefficient of Dgt on EI is 5.5792***, and the regression coefficient of Dgt on DI is 3.8603**. For enterprises with low operating efficiency, the regression coefficient of Dgt on EI is only 1.7919**, and the correlation between Dgt and DI is not significant. Therefore, the digital transformation of enterprises with higher operating efficiency has a more significant effect on the improvement of enterprises' dual innovation. The hypothesis H2a and H2b were verified. Therefore, it is necessary to optimize the business environment, reduce taxes and fees, and improve the operation efficiency of enterprises.

Table 7 Test results of operating efficiency heterogeneity

Variable	EI		DI	
	High operating efficiency	Low operating efficiency	High operating efficiency	Low operating efficiency
	(1)	(2)	(3)	(4)
Dgt	5.5792***	1.7919**	3.8603**	0.5949
	(1.980)	(0.898)	(1.833)	(0.943)
Control	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes
R^2	0.423	0.308	0.368	0.192
Obs	903	1,107	903	1,107

Regional heterogeneity

To test regional heterogeneity, the study samples were divided into three groups according to the region, and each group was returned separately. Table 8 shows the results of regional heterogeneity test. In the eastern samples, the regression coefficient of Dgt for EI was 6.1815***, and the regression coefficient of Dgt for DI was 3.1879***. In the samples from central and western regions, Dgt had no significant effect on dual innovation. Thus, hypotheses H3a and H3b can be tested. Therefore, digital policy support should be given to the central and western regions to improve the digital ecological environment; We will promote cross-regional

[2] $y_{it} = \varpi_t(1-\rho) + \rho y_{it-1} + \beta l_{it} + \gamma k_{it} - \rho\beta l_{it-1} - \rho\gamma k_{it-1} + \eta_{it}$

Where y_{it} represents the logarithmic form of output; l_{it} represents the logarithmic form of labor input; k_{it} represents the logarithmic form of capital input; ϖ_{it} is part of the residual.

talent flow, strengthen digital infrastructure, and accelerate the development of the digital economy.

Table 8 Results of regional heterogeneity test

	EI			DI		
Variable	east	Middle	west	east	Middle	west
	(1)	(2)	(3)	(4)	(5)	(6)
Dgt	6.1815***	3.1604	7.1745	3.1879***	1.8922	9.3142
	(1.133)	(2.864)	(7.015)	(1.097)	(2.388)	(5.858)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.242	0.403	0.408	0.164	0.373	0.371
Obs	1,960	377	238	1,960	377	238

Conclusion and Revelation

Conclusion

Transformation is the way for enterprises to explore new value creation models, which is conducive to enterprises to innovate. Based on the sample of Chinese listed enterprises from 2007 to 2022, this paper selects relevant word frequency to quantize digital transformation, theoretically analyzes and empirically examines the impact of digital transformation on enterprises' dual innovation. Conclusions are drawn: (1) Digital transformation significantly improves the level of dual innovation, and has a greater impact on the establishment of old and new enterprises. Improving employee structure and easing financing constraints are two mechanisms of action. The synergistic effect of digital transformation, talent and capital stimulates the dual innovation vitality of enterprises. (2) The effect of digital transformation is reflected in the higher operating efficiency of enterprises in the eastern region, which makes the comprehensive innovation of enterprises enter a virtuous circle.

Enlightenment

Based on the above conclusions, the following policy implications are proposed: First, enterprises should clarify transformation goals and promote enterprise digitalization. The essence of digital transformation is an innovation process using digital technology, which has the characteristics of long-term and directional, and belongs to strategic decision-making. First of all, business executives must fully realize the importance of digital transformation to the high-quality development of enterprises, and understand and grasp how to transform from the height of enterprise development strategy. Secondly, the relevant knowledge of digital

technology is the key premise, and business executives must fully learn the relevant knowledge, fully grasp the current situation of enterprise development, and combine their own resources, capabilities and industry characteristics in a timely manner to combine digital technology with their own management process. Finally, the goal of enterprise digital transformation should be subdivided into specific functional departments to form a specific implementation plan to promote enterprise digital reform from top to bottom. Second, strengthen the construction of digital infrastructure to facilitate the digital transformation process of enterprises. First of all, as a government investment, infrastructure construction has the characteristics of diminishing marginal returns, so infrastructure construction can not be "one-size-fits-all", there must be a master and a secondary, the government's infrastructure construction can be moderately inclined to the central and western regions. Secondly, we can further optimize the business environment, reduce taxes and fees, and effectively increase the tax burden of enterprises, so as to fully develop the positive effect of digital transformation of enterprises and improve the operation efficiency of enterprises. Third, improve the market supervision system. On the one hand, relevant government departments should give policy support to digital transformation enterprises, encourage enterprise transformation, and strengthen supervision to ensure the timeliness and effectiveness of financial subsidies and preferential policies given by the government. On the other hand, in order to more fully stimulate the enthusiasm of enterprises to implement digital strategies, practical policy support can be provided by sharing the cost of enterprise transformation with the government. Led by the government, the government and enterprises jointly contribute to the establishment of a special fund to reward those enterprises that have made achievements in digital transformation. Fourth, promote the agglomeration of dual innovation factors at multiple levels to promote the improvement of regional dual innovation capability. Promoting the integrated development of production, university and research, and establishing a multi-dimensional long-term mechanism of talent cultivation and introduction are conducive to promoting talent agglomeration, leading to factor agglomeration, and promoting the improvement of regional dual innovation ability. First of all, we should respect talents and promote the free and full flow of talents throughout the country by reducing the obstructing effect of policy barriers on the flow of talents. Secondly, strengthen the linkage of elements in the eastern and central regions through the flow of talents, and finally achieve the joint improvement of the national innovation ability in the agglomeration.

Limitations and prospects

The limitation of this paper is that it is limited to the availability of data and does not discuss the impact of digital platform construction on two-way innovation, which is the direction of further research.

Declaration

Acknowledgment: First of all, I would like to thank my school, which regularly invites well-known researchers to give lectures at our school, so that I can understand the academic frontier and related research progress.

Secondly, I would like to thank my supervisor for providing me with the valuable opportunity to conduct research at the Institute of Innovation and Development of Hunan University of Science and Technology, allowing me to be guided and inspired. Finally, I would like to thank the reviewers for their constructive suggestions for this article, which has greatly improved the quality of the article. Without the support of these people, this work would not have been possible. I would like to express my sincere gratitude to all the scholars and staff who contributed to this article.

Funding: The research presented in this work was supported by two sources:
Self-funded: Most of the funding for the study comes from self-funding, including data processing, material costs, and travel costs.
Hunan University of Science and Technology: Thanks to the database resources subscribed by Hunan University of Science and Technology, the literature resources and data sources of the articles are guaranteed, which greatly promotes the research process.

Conflict of interest: The authors declare no conflicts of interest**.**

Authors contribution: Research topic: I am responsible for determining the topic of the article. Research Framework: I am responsible for developing the research framework, including the development of research content and the selection of research methods. Research data: I am responsible for the collection, processing, export, analysis and storage of data, and ensure the rigor of the research in a quantitative way. Essay Writing: I wrote the main body of the dissertation, including the various parts of the essay. Thesis revision: I have made significant contributions to the editing and revision of papers. Overall, my contribution to this dissertation covers all stages of the research process.

Data availability: The datasets used and analyzed during the current study are publicly available.

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