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MANAGEMENT OF DIGITAL TRANSFORMATION ON INNOVATION PERFORMANCE IN CHINESE ENTERPRISES: AN EMPIRICAL ANALYSIS

УПРАВЛІННЯ ЦИФРОВОЮ ТРАНСФОРМАЦІЄЮ ЩОДО ІННОВАЦІЙНОЇ ЕФЕКТИВНОСТІ КИТАЙСЬКИХ ПІДПРИЄМСТВ: ЕМПІРИЧНИЙ АНАЛІЗ

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With the rapid rise of the digital economy, digital transformation has become crucial for enterprise development. R&D enterprises face growing innovation pressures and efficiency demands, requiring effective process diagnostics and tailored optimization models. This paper develops a systematic framework for diagnosing R&D processes and proposes an optimization model based on literature analysis and case studies. Using empirical methods, it explores the link between digital transformation and innovation, analyzing data from Chinese A-share listed companies (2018–2023). Findings show digital transformation enhances innovation by optimizing processes and improving efficiency, allowing enterprises to allocate more resources to innovation. This effect is stronger in large enterprises. Despite widespread adoption, patent application analysis suggests room for improvement in innovation performance. This study offers insights into digital transformation's role in enterprise innovation, guiding firms in enhancing competitiveness.

Keywords: digital transformation, innovation, chinese enterprises, management, technology adoption, competitiveness, organizational change, empirical analysis, strategy, digital economy.

З розвитком технологічної революції та стрімким зростанням цифрової економіки цифрова трансформація стала критичним фактором розвитку підприємств. Особливо це стосується компаній, що займаються науково-дослідними та дослідно-конструкторськими (R&D) роботами, оскільки вони стикаються зі зростаючим тиском інновацій і підвищеними вимогами до ефективності. Це зумовлює необхідність розробки дієвих методів діагностики процесів і оптимізаційних моделей, що дозволяють удосконалити управління інноваціями та підвищити конкурентоспроможність. Метою цього дослідження є розробка системної рамки для діагностики R&D-процесів і пропозиція моделі оптимізації на основі аналізу наявної літератури та практичних кейсів. Використовуючи емпіричні методи дослідження, у статті вивчається взаємозв'язок між цифровою трансформацією та інноваційною діяльністю підприємств, спираючись на дані китайських публічних компаній A-share за період 2018–2023 років. Результати показують, що цифрова трансформація суттєво підвищує інноваційну продуктивність через оптимізацію бізнес-процесів, удосконалення виробничої ефективності та раціональніший розподіл ресурсів. Це дозволяє підприємствам активніше інвестувати в інноваційні розробки, що, своєю

чергою, сприяє підвищенню їхньої ринкової вартості та довгостроковій стійкості. Зокрема, позитивний ефект цифрової трансформації на інноваційну діяльність більш виражений у великих підприємствах, які мають кращий доступ до цифрових технологій і можливості масштабування. Попри те, що більшість китайських компаній уже реалізували певні етапи цифрової трансформації, аналіз поданих патентних заявок свідчить про значний потенціал для подальшого зростання загальної інноваційної ефективності. Недостатнє використання сучасних цифрових технологій, таких як штучний інтелект, великі дані та автоматизація, обмежує можливості підприємств щодо досягнення максимальної продуктивності. Таким чином, це дослідження надає цінні теоретичні та практичні висновки щодо впливу цифрової трансформації на інноваційну діяльність підприємств у Китаї. Запропоновані рекомендації можуть бути корисними для керівників, які прагнуть посилити конкурентоспроможність своїх компаній через ефективні цифрові стратегії.

Ключові слова: цифрова трансформація, інноваційна ефективність, китайські підприємства, стратегії управління, впровадження технологій, конкурентоспроможність бізнесу, організаційні зміни, емпіричний аналіз, стратегічне управління, цифрова економіка, технологічні інновації, автоматизація, штучний інтелект.

Formulation of the problem in general. In the era of rapid technological advancements, digital transformation has become a crucial strategy for enterprises seeking to enhance competitiveness, optimize operational efficiency, and drive innovation. Emerging technologies such as cloud computing, big data, and artificial intelligence have significantly altered traditional business models, enabling enterprises to explore new growth opportunities and improve customer engagement. However, despite the recognized benefits of digital transformation, its direct impact on enterprise innovation output remains a critical issue requiring further empirical analysis.

Enterprises of different sizes and ownership structures may experience varying effects of digital transformation on innovation due to differences in resource availability, risk tolerance, and strategic focus. While large enterprises possess greater financial and technological resources to support digital transformation, small and medium-sized enterprises (SMEs) may face constraints that limit their capacity to leverage digital tools effectively. Additionally, the relationship between digital transformation and innovation output may be influenced by external factors such as market competition, regulatory policies, and industry-specific challenges.

Given these complexities, it is essential to examine the extent to which digital transformation contributes to enterprise innovation, the underlying mechanisms driving this relationship, and the moderating factors that may influence its effectiveness. This study aims to address these gaps by investigating the impact of digital transformation on innovation output, using empirical data from Chinese A-share listed companies. Through this analysis, the study seeks to provide insights into how enterprises can optimize their digital transformation strategies to enhance innovation performance and achieve long-term sustainable development.

Analysis of recent research and publications. Recent studies highlight the growing significance of digital transformation in enhancing enterprise innovation output. Qiu Yangdong [3] empirically analyzed the impact of the digital economy on enterprise innovation and found that digital transformation significantly increases the proportion of invention patents. Similarly, Luo Jinlian, Wang Xianglu, and Geng Xin [4] confirmed that digital transformation positively affects innovation output within a certain intensity range, reinforcing its role in driving technological advancements. Liu Bingbing and Liu Aimei [5] further demonstrated that digital transformation enhances the efficiency of technological innovation by optimizing the allocation of labor, capital, knowledge, and technology. Zhang Kuangwei et al. [6] conducted an empirical study using provincial panel data in China, revealing a linear relationship between digital transformation and innovation, particularly in high-tech industries.

Research on enterprise size and digital transformation suggests that larger enterprises benefit more significantly from digital initiatives due to their financial and technological resources. Duan Huayou, Yang Xingliu, and Dong Feng [7] examined how enterprise size influences the impact of digital transformation on innovation, concluding that state-owned and large enterprises experience a stronger positive effect compared to SMEs. However, challenges such as technological risks, market uncertainties, and organizational restructuring complicate the transformation process, especially for smaller firms.

Despite the consensus on the positive impact of digital transformation, gaps remain in understanding its long-term effects and the mechanisms driving innovation. Studies primarily focus on technological innovation, with limited

exploration of non-technological aspects, such as business model innovation and organizational adaptability. Moreover, the methodologies used to measure digital transformation, such as keyword analysis in corporate reports, may not fully capture the depth of digital adoption. Future research should explore the role of leadership, digital skills, and external factors like regulatory frameworks in shaping the effectiveness of digital transformation on enterprise innovation.

Unresolved parts of the common problem. While digital transformation is widely recognized as a driver of enterprise innovation, the extent and mechanisms through which it influences innovation output remain insufficiently explored. The varying impact of digital transformation on large enterprises versus SMEs raises questions about resource accessibility and strategic implementation. There is a lack of consensus on whether digital transformation directly increases patent applications or merely enhances operational efficiency without significantly affecting innovation output. The role of external factors, such as industry regulations and market competition, in shaping the effectiveness of digital transformation on innovation remains unclear. Existing research does not fully address how different stages of digital transformation influence innovation intensity and quality. The measurement of digital transformation through keyword analysis in corporate reports may not accurately reflect the depth and effectiveness of technological integration. Empirical studies often focus on short-term effects, leaving uncertainty about the long-term sustainability of digital transformation's impact on innovation. The extent to which digital transformation fosters radical versus incremental innovation within enterprises is not well understood. The influence of digital transformation on non-technological innovation, such as business model changes and organizational innovation, remains underexplored. Additionally, the role of leadership, corporate culture, and workforce digital capabilities in maximizing the benefits of digital transformation for innovation output requires further investigation.

The purpose of the article to conduct an empirical study on the impact of digital transformation on innovation output in Chinese enterprises, providing theoretical support and practical guidance for enterprises to formulate effective innovation strategies in the context of the digital economy.

Presenting main material. The Fourth Plenary Session of the 19th Central Committee of the Communist Party of China first proposed to incorporate data as a separate production factor into the national income distribution sequence. The "14th Five-Year Plan" explicitly states, "Accelerate the construction of the digital economy and drive the transformation of production methods through overall digital transformation."

The rise of cutting-edge technologies such as cloud computing, big data, and artificial intelligence has prompted enterprises to deeply recognize that digital transformation is not only a necessary path to enhance market competitiveness and optimize operational efficiency but also a key to innovating business models and opening new growth avenues. At the same time, the strong demand from the younger generation for digital experiences and services has become a powerful external driver for enterprises to accelerate transformation. Faced with the fierce competition in the global market, enterprises urgently need to leverage digital means to strengthen brand influence and expand market share.

Digital transformation is not only a strategy for enterprises to cope with challenges but also a core engine for stimulating innovation vitality. Digital transformation can enhance an enterprise's ability to understand customer needs, procure and retain customers, and provide products and services tailored to different customers [1]. It can also break through existing limitations by effectively integrating digital resources and capabilities, expanding the digital industry chain, and promoting the collaborative development of digital ecosystems, thereby constructing intelligent ecosystems [2].

This transformation not only meets existing customer needs but also further explores potential customer demands, opening up new paths for enterprise development, such as precision services based on big data and flexible subscription economies. These emerging models not only bring broader market opportunities to enterprises but also build an unreplicable competitive advantage, helping enterprises maintain a leading position in a rapidly changing market environment and achieve stable and sustainable development. Therefore, digital transformation is not only an inevitable choice for enterprise development but also an important source of innovation-driven and sustained growth. Based on this, this paper conducts an empirical study on the relationship between digital transformation and innovation output of enterprises, building

on existing research and combining practical situations.

The Impact of Digital Transformation on Enterprise Innovation Output. Digital transformation refers to the process of transforming traditional manufacturing technologies and creating new manufacturing models through the use of modern manufacturing technologies represented by digital and intelligent manufacturing. Qiu Yangdong empirically tested the impact of the digital economy on enterprise innovation from multiple dimensions [3]. The results show that the development of the digital economy can significantly increase the proportion of invention patents of enterprises. Moreover, the increase in the number of invention patents has an important promoting effect on the improvement of the innovation structure of enterprises. Luo Jinlian, Wang Xianglu, and Geng Xin deeply explored the substantive impact of digital transformation on the effectiveness of enterprise innovation output and its internal operating mechanisms [4]. Their research findings clearly indicate that within a certain intensity range, the positive effect of digital transformation on promoting enterprise innovation output is significant, fully verifying the effectiveness of digital transformation in promoting enterprise innovation output. Liu Bingbing and Liu Aimei also empirically concluded that digital transformation can enhance the efficiency of technological innovation by improving the allocation efficiency of labor, capital, knowledge, and technology among enterprises [5]. Zhang Kuangwei and others conducted empirical research using provincial panel data in China to analyze the linear relationship between digital transformation and high-tech industry innovation, revealing that digital transformation has a positive impact on innovation output [6].

Digital transformation of enterprises can significantly promote innovation output.

Large enterprises typically possess more resources, giving them an advantage in digital transformation. These resources can support large-scale technological investments, R&D innovations, and the construction of digital infrastructure. In contrast, small and medium-sized enterprises may face resource limitations, resulting in slower capacity and speed for digital transformation. Therefore, enterprise size may affect the degree and effectiveness of digital transformation, thereby influencing innovation output. Digital transformation also involves certain risks, such as technological risks, market risks, and organizational change risks. Large enterprises usually have a stronger risk tolerance and can bear larger investments and experimentation costs. They can explore multiple fields to seek new innovation opportunities. Small and medium-sized enterprises, on the other hand, may be more sensitive to risks and tend to adopt lower-risk innovation paths during digital transformation. Duan Huayou, Yang Xingliu, and Dong Feng examined the impact of digital transformation on the level of technological innovation and its path mechanisms, analyzing the impact of enterprise size on innovation output, concluding that the promoting effect of digital transformation on technological innovation is more prominent in state-owned enterprises and large enterprises [7].

Compared to small and medium-sized enterprises, larger enterprises exhibit a more pronounced effect of digital transformation on innovation output.

This study uses A-share listed companies in Shanghai and Shenzhen from 2018 to 2023 as samples to examine the impact of digital transformation on enterprise innovation. The digital transformation data is sourced from the "Research Report on the Evaluation of Digital Transformation Index of Chinese Listed Companies" published by Guangdong University of Finance. Patent data, used to measure enterprise innovation, comes from the Innovation Patent Research Sub-database of the China Research Data Service Platform (CNRDS). Other financial and corporate governance data are sourced from the CSMAR database. The original sample is processed as follows: (1) Exclude financial industry samples; (2) Exclude ST, PT, and insolvent samples; (3) Exclude samples with data anomalies and missing main variables. To eliminate the potential influence of extreme values, this study also applies Winsorization to the main continuous variables at the upper and lower 1%, resulting in a final sample of 15,748.

Innovation Output (Patent). Referencing the research of Tan Hongtao and Chen Yao, this study measures the level of innovation output by the total number of patents applied for by the company in the current year [8]. In the CNRDS database, the total number of patents applied for by the company is used as the dependent variable, represented by the natural logarithm of the total number of patent applications.

Digital Transformation Index (Digital). The data is sourced from the measurements of enterprise digital transformation by Wu Fei et al. [9], derived from the "Research Report on the Evaluation of Digital Transformation Index

of Chinese Listed Companies." It identifies the total number of keywords related to "digital transformation" in the annual report texts of listed enterprises through big data analysis, followed by calculating the logarithm of the total word count.

To reduce the interference of omitted variables on the relationship between digital transformation and enterprise innovation and to minimize regression coefficient bias, this study introduces the following control variables: Enterprise Age (Age), Enterprise Size (Size), Debt-to-Asset Ratio (Lev), Return on Equity (ROE), Enterprise Growth (Growth), and Tobin's Q (TobinQ). The variable definitions are shown in Table 1. To test whether digital transformation promotes enterprise innovation, the following multiple regression model is established:

$$Patent_{i,t} = \beta_0 + \beta_1 * Digital_{i,t} + \Sigma \beta_k * controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$Patent_{i,t} = \beta 0 + \beta 1 * Digital_{i,t} + \beta 2 * Size + \beta 3\, Digital_{i,t} * Size + \Sigma \beta k * controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

Where $Patent_{i,t}$ represents the innovation output level of enterprise i in year t;$Digital_{i,t}$ indicates the digital transformation index of enterprise i in year t; $controls_{i,t}$ includes several control variables; $\beta 0$ is the constant term; $\beta 1$ measures the effect of the digital transformation index on the level of innovation output; βk represents the coefficients of control variables; and $\varepsilon_{i,t}$ is the random error term.

Table 2 presents the descriptive statistical results of the main variables. The results indicate that the mean and median of the variables differ minimally, suggesting that the sample is normally distributed. The natural logarithm of the mean patent application volume is 2.533, indicating that the innovation output efficiency of Chinese enterprises is not high. There is a significant gap between enterprises with high and low patent application volumes, with the maximum and minimum values differing by 9.358. The digital transformation index shows significant variation, with a mean of 30.575, indicating that most Chinese enterprises have undergone some degree of digital transformation.

Table 3 shows the correlation analysis results among various variables, where the correlation coefficient between innovation output (Patent) and digital transformation (Digital) is 0.124, significant at the 1% level, preliminarily indicating that digital transformation can enhance innovation output levels. The correlation coefficient between enterprise size (Size) and innovation output (Patent) is 0.267, also significant at the 1% level, suggesting that larger enterprises tend to have higher innovation output. Additionally, other correlation coefficients are generally less than 0.5, indicating that there is no multicollinearity present in the regression model.

Table 1

Variable Definitions of Digital Transformation Related Domain Information

Variable Type	Variable Symbol	Variable Name	Measurement Method
Dependent Variable	Patent	Innovation Output	Total number of patents applied by the enterprise
Independent Variable	Digital	Digital Transformation Level	Frequency of keywords related to digital transformation in the enterprise's reports
Control Variables	Age	Enterprise Age	Number of years since the enterprise was established, with listing years computed as current year – listing year + 1
	Size	Enterprise Size	Natural logarithm of total assets
	Lev	Debt-to-Asset Ratio	Total liabilities / total assets at year-end
	ROE	Return on Equity	Net profit / average owner's equity balance
	Growth	Enterprise Growth	Current year operating income / previous year operating income - 1
	TobinQ	Tobin's Q Value	(Market value of circulating shares + non-circulating shares * net asset per share + book value of liabilities) / total assets

Data source: CSMAR database, Juchao Information Network

Table 2

Descriptive Statistics of Variables

Variable	Mean	SD	Min	Max	p50
Patent	2.533	1.432	0	9.358	2.485
Digital	30.575	45.301	0	206	13
Age	1.836	0.936	0	3.367	1.946
Size	22.168	1.234	19.676	26.086	21.948
Lev	0.386	0.19	0.052	0.894	0.379
ROE	0.065	0.128	-0.636	0.354	0.076
Growth	0.135	0.327	-0.573	2.213	0.093
TobinQ	1.94	1.154	0.855	7.78	1.575

Data source: CSMAR database, Juchao Information Network

Table 3

Correlation Analysis

Variable	Patent	Digital	Age	Size	Lev	ROE	Growth	TobinQ
Patent	1							
Digital	0.124**	1						
Age	0.036**	-0.081**	1					
Size	0.267**	-0.028**	0.453**	1				
Lev	0.133**	-0.027**	0.381**	0.483**	1			
ROE	0.118**	-0.037**	-0.176**	0.102**	-0.268**	1		
Growth	0.046**	-0.018**	-0.082**	0.055**	0.035**	0.288**	1	
TobinQ	-0.006	0.044**	-0.019**	-0.311**	-0.208**	0.065**	0.111**	1

Data source: CSMAR database, Juchao Information Network

*Note: * and ** denote significance at the 5% and 1% levels, respectively.

Table 4 (1) presents the model's goodness of fit, with an R^2 value of 0.110, indicating a certain accuracy in explaining the relationships among variables. The regression analysis results show that the coefficient of the digital transformation index is 0.004, which is significant at the 1% level.

This result supports the hypothesis H1 of this study, indicating that digital transformation has a significant positive impact on innovation output, specifically that an increase in the digital transformation index leads to a corresponding increase in innovation output. Additionally, the coefficient for enterprise size is 0.350, also significant at the 1% level, demonstrating a significant positive correlation between enterprise size and innovation output, meaning that larger enterprises tend to have higher innovation output.

Standard errors in parentheses. **p < 0.01, *p < 0.05.

To further analyze the moderating effect of enterprise size in the process of digital transformation promoting innovation, this study divides the sample into two groups based on the median size (22.168): those exceeding this threshold are classified as large enterprises, while those below are classified as small enterprises. Data from Table 5 show that in large enterprises, the promoting effect of digital transformation on innovation output is more pronounced, demonstrating stronger innovative promotion effectiveness, thereby reinforcing the positive impact of digital transformation on innovation outcomes in large-scale enterprise environments, confirming hypothesis H2.

Standard errors in parentheses. **p < 0.01, *p < 0.05.

To ensure the reliability of the conclusions, this study validated the robustness of the regression results using variable substitution methods. It is important to note that the total number of patent applications may not accurately measure a company's innovation output. Therefore, the logarithm of the total number of patents granted was substituted into

Table 4

Multiple regression results

VARIABLES	/b1 /Patent	/b2 / Patents
Digital	0.004**(16.852)	0.004**(15.536)
Age	-0.189**(-13.499)	-0.199**(-14.438)
Size	0.350**(29.797)	0.358**(31.182)
Lev	0.474**(6.682)	0.370**(5.383)
ROE	1.019**(10.389)	0.717**(7.709)
Growth	-0.093**(-2.614)	-0.212**(-6.168)
TobinQ	0.064**(6.366)	0.062**(6.278)
Constant	-5.369**(-22.138)	-5.581**(-23.560)
Observations	15748	16172
R-squared	0.110	0.102

Data source: CSMAR database, Juchao Information Network

Table 5

Results of grouping by firm size

VARIABLES	/ Patent / Large Enterprises	/ Patent / Small Enterprises
Digital	0.003**(10.853)	0.004**(13.156)
Age	-0.304**(-4.319)	-0.483**(-11.015)
Size	0.311**(14.802)	0.317**(12.814)
Lev	0.664**(5.366)	0.305**(3.691)
ROE	1.093**(6.429)	1.186**(10.550)
Growth	-0.172**(-2.926)	0.020**(0.460)
TobinQ	0.136**(7.660)	-0.024*(-2.106)
Constant	-4.209**(-8.451)	-3.270**(-6.152)
Observations	6727	9026
R-squared	0.076	0.067

Data source: CSMAR database, Juchao Information Network

the model, replacing the logarithm of the total number of patent applications (Patent) with the logarithm of the total number of patents granted (Patents). The specific regression results are shown in Table 4 (2). The correlation between digital transformation and corporate innovation output remains statistically significant, with a regression coefficient of 0.004. This indicates that digital transformation has a positive impact on corporate innovation output. The results of the two regression analyses did not show substantial changes, indicating that whether using the number of patent applications or the number of patents granted, the facilitating effect of digital transformation on corporate innovation output is robust at the enterprise level.

Conclusions. Based on data from A-share listed companies in Shanghai and Shenzhen from 2018 to 2023, this study empirically reveals the significant positive impact of digital transformation on corporate innovation. The results indicate that digital transformation not only facilitates the conversion and output of corporate innovation achievements but also has a more pronounced effect on innovation output in larger enterprises. Additionally, the study found that although the average digital transformation index of Chinese enterprises reached 30.575, indicating a certain degree of digital transformation activity, the natural logarithm of the number of patent applications is relatively low, reflecting a need for improvement in innovation output efficiency.

Our recommendations are as follows: establish digital transformation goals closely aligned with corporate strategy to provide clear direction for innovation activities, increase R&D

investment, and optimize resource allocation to enhance the quality and efficiency of innovation, particularly in patent applications and technological innovation. At the same time, actively seek diversified financing channels to reduce financing costs and ensure stable funding support for innovation projects. Utilize data analysis tools to gain deep insights into customer needs and respond quickly to market changes, driving product and service innovation centered around customers. Finally, evaluation and feedback mechanisms for innovation outcomes should be established to ensure that innovation activities remain aligned with market and corporate goals, achieving continuous optimization and improvement. Through these measures, enterprises can enhance innovation capabilities, strengthen competitiveness, and achieve long-term sustainable development in the digital age.

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