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Impact of Digital Transformation on the Innovation Capacity of Chinese-Listed Firms: Role of Government Subsidies

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Abstract. As digital transformation progresses, listed Chinese firms are undergoing significant changes in their practices. These changes are crucial for establishing and maintaining a competitive advantage. This research investigates the process by which digital transformation affects firms' capacity to innovate, specifically focusing on the influence of government subsidies. The data was obtained from 1,063 publicly traded in China from 2018 to 2022 with a total of 4,027 data points. A fixed-effects model, stepwise regression analysis, and bootstrapping techniques were employed to construct the models. To address the conventional quantitative constraints and provide a nuanced comprehension of digital transformation's influence, this study uses textual analysis. Research has shown that digital transformation has a substantial positive impact on the ability of companies to innovate. Additionally, government subsidies are proven to have a role in facilitating this process. This paper offers a fresh viewpoint on comprehending the mechanism of government subsidies for digital transformation and corporate innovation capability. It also provides evidence supporting the idea that government subsidies may enhance innovation incentives more effectively.

Keywords: **Chinese-listed firms, digital transformation, government subsidy, innovation, capability, text analysis,**

1. Introduction

As digital transformation progresses, organizations are undergoing significant changes in their manufacturing practices. In today's highly competitive market, firms must undergo digital transformation to achieve a competitive edge (Liang & Li, 2022). Additionally, the digital economy's penetration rate in the secondary industry reached 24%, highlighting the significant role of digital transformation in driving economic development (Wang et al., 2022).

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The significance of innovation capacity, as a crucial measure of the competitiveness of a nation or a company, should not be underestimated (Fan et al., 2023). In very volatile business landscapes, a company's capacity to independently generate innovative ideas becomes the fundamental basis for its continued existence and growth (Li & Pang, 2023). Assessing the innovation capability of firms is a challenging and multifaceted undertaking. It involves examining their innovation activities from various angles and dimensions, with a particular emphasis on the quality of innovation, particularly in terms of firms' patent research and development efforts (Rong et al., 2023; Park et al., 2023).

The industrial policy of China has an important effect on the progress of the economy. One possible mechanism via which industrial policy plays a role is the change of the industrial structure (Chen & Xie, 2019). Government research and development (R&D) subsidies are a significant policy instrument used to encourage innovation. These subsidies have garnered considerable attention because of their ability to promote innovation inside enterprises and facilitate the transformation and upgrading of industrial structures (Yuan & Zhu, 2020). When developing subsidy policies, governments must ensure that subsidies have precise and innovative incentives to produce effective and relevant policy outcomes (Yu & Wang, 2022).

This study aims to analyze the impact of digital transformation on the innovation capacity of Chinese-listed firms and explore the mediating role of government subsidy. The existing studies on the complex relationship between digital transformation (Dx), innovation capacity (InCap), and government subsidies (GovSub) have vital limitations. Some studies such as Xia et al. (2023) and Li et al. (2023) are limited to pharmaceutical firms only and may not reflect current trends as they used data up to 2019-2020. While Xie et al. (2021), Ziyu et al. (2022) and Wang et al. (2023) may not fully measure the relationship between innovation performance and government subsidies due to limited data. Then, Bruggemann and Proeger (2017), Yao (2019), and Gao (2022) challenge the primary assumption of government subsidies on firms' innovation outcomes and R&D investments in the early stage of the firms. Recognizing these limitations and the complexities of quantitatively assessing corporate Dx, this study uses textual analysis as an innovative measurement method that transcends conventional quantitative constraints and provides a nuanced comprehension of Dx's influence. Employing updated data and multifaceted

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analyses, the study endeavors to offer significant contributions to the ongoing discourse surrounding the implications of Dx for the InCap of manufacturing firms.

1.1. Digital Transformation and Innovation Capacity

The theory of technical innovation seeks to elucidate the causes and processes behind the occurrence of technological advancements, their catalysts, their effects on the economy and society, and the mechanisms by which these advancements disseminate and progress (Wei et al., 2023). Simultaneously, the advancement of technical innovation theory also underscores the influence of external elements, such as knowledge management, market change, and social environment, on the process of innovation (Fedulov & Pobedin, 2021). Dx is an intricate process that involves the integration of digital technology into all aspects of a business, resulting in substantial changes to its operations. This approach compels organizations to reassess their innovation efforts by incorporating digital technology into their operations and business model innovation (Zhai et al., 2022; Singh et al., 2021; Verhoef et al., 2021). The focus is on how businesses may use digital technology to strengthen their ability to innovate in the digital economy age (Selimović, 2021).

The interplay between digital and technical skills is crucial for organizations to actively participate in digital innovation (Wang & Li, 2023). Dx facilitates the integration of resources inside companies by offering new technical platforms and tools and increases investment in research and development, hence enhancing companies' ability to innovate (Gupta et al., 2023; Yang et al., 2023). Furthermore, Dx indirectly enhances the innovation performance of businesses by altering their network structure, which includes the expansion of structural holes and the enhancement of network centrality (Hou & Gao, 2022). Digital technology may impact a company's ability to innovate by enabling business model innovation, which in turn influences the company's inventive capacities (Nureen et al., 2023). To summarize, the following theories are put forward:

H1: Digital transformation improves the innovative capacity of firms.

1.2. Role of Government Subsidy

Policy intervention theory is a significant field within economics that examines how governments employ various methods to affect the behavior of individuals or groups to attain certain social and economic objectives. These methods

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include several approaches such as communications, promoting change, advocating for change, imposing penalties for non-compliance, and enhancing the appeal of change (Balch, 1980). Government subsidies are a kind of policy intervention when the government provides direct financial assistance to certain sectors, companies, or people. Subsidies may take the form of direct monetary aid or be provided via mechanisms such as tax exemptions and loan guarantees (Osagiede & Ekhosuehi, 2015).

Government subsidies encourage companies to participate in technology innovation and Dx by offering financial assistance that lowers their research and development expenses and uncertainties (Eslami et al., 2022). Government subsidies in the firm's innovation process serve as a means of signaling, indicating important information about the industry's strategic direction and policy preferences (Wu, 2017). Furthermore, government subsidies have the potential to stimulate corporate innovation by enhancing enterprises' financial condition and mitigating financial limitations (Li et al., 2021). Nevertheless, government subsidies may also include certain constraints and adverse consequences. Government subsidies might potentially hinder the creative activities of non-subsidized enterprises, as shown by Ding et al. (2022). Furthermore, if subsidies are not used effectively, they may fail to fulfill the intended goal of supporting innovation (Bruggemann & Proeger, 2017; Yao, 2019; Gao, 2022). Thus, the following hypothesis is offered based on this foundation:

H2: Government subsidies mediate the relationship between digital transformation and innovation capacity.

2. Methodology

2.1. Data and Samples

Given the particularity of the regulations in the Chinese stock exchange market, a set of criteria for selecting the sample was developed. Firms identified by the Chinese stock market as "ST" (Special Treatment) were excluded. Accordingly, these firms may engage in excessive surplus management to manipulate profits and comply with listing rules (Chi et al., 2020). Firms that lack accounting and financial information were also excluded. The study also applied a filtering process to continuous variables where values below the 1st percentile and above the 99th percentile were omitted. Additionally, this research addresses the issue of possible sample data aggregation features and mitigates the impact

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of heteroskedasticity and autocorrelation concerns by adjusting the standard errors of regression coefficients for clustering at the company level. Thus, a total of 4,027 imbalanced panel datasets consisting of 1,063 A-share manufacturing businesses registered on the stock market from 2018 to 2022 were used.

The data were sourced from the CSMAR database and annual reports of publicly traded companies to gather secondary information. The information is developed based on globally recognized standards and within the framework of China. Additionally, citation studies of data generated for specific projects can offer valuable insights to encourage data sharing and facilitate scientific discoveries (Callaghan, 2014). Annual reports of publicly traded corporations serve as a regularly reported corporate form that offers crucial financial and operational information for various stakeholders (Alduais, 2022).

Table 1 presents the full understanding of the concentration trend, level of variability, and range of data distribution for each variable in the sample.

Table 1 Data description and descriptive statistics

Variable	Obs	Mean	Std	Min	Max
Innovation Capacity	4,027	149.203	407.973	1	3202
Dx	4,027	41.366	10.966	23.694	67.781
Government Subsidy	4,027	17.315	1.449	13.614	21.077
Intangible Assets	4,027	19.331	1.462	15.659	23.210
Tobin's Q	4,027	1.931	1.405	0.701	22.321

Table 2 displays the Variance Inflation Factor (VIF) values obtained from the multicollinearity test conducted on the variables. Based on the basic premise of VIF, a VIF value beyond 10 indicates the potential presence of multicollinearity issues (Kleinbaum et al., 2019). The variables in this research had VIF values ranging from 1.05 to 2.01, indicating the absence of multicollinearity among them.

Table 2. VIF detection values for multicollinearity tests

Variable	VIF	1/VIF
Dx	1.15	0.867
Government Subsidy	2.01	0.499
Intangible Assets	1.88	0.531
Tobin's Q	1.05	0.953
Mean VIF	1.52	

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2.2. Variable Measurement

Table 3 provides a comprehensive overview of the measuring techniques used for all the variables examined in this research. Measuring the extent of corporate Dx using quantitative methodologies is still a topic of current interest in both academic research and commercial implementations (Wu et al., 2023). Crucial information regarding Dx from extensive text data by using sophisticated text mining and natural language processing methods may be efficiently extracted (Ren et al., 2023; Guo & Xing, 2023; Hitham et al., 2023).

Table 3. Variable name and measurement

Variable name	Variable Measurement
Innovation Capacity (InCap)	Number of citations to patents in the year
Digital Transformation (Dx)	The data comes from text-mining (e.g. artificial intelligence, face recognition, driverless, robotics, computer-aided, machine vision, autonomous driving, cloud computing, edge computing, graph computing, internet of things, cloud storage, cloud technology, big data, data mining, virtual reality, augmented reality, network security, information security, data security, O2O, B2B, B2C, intelligent manufacturing, digital marketing, digital management
Government Subsidy (GovSub)	Amount of government subsidies acquired during the year
Intangible Assets Tobin's Q	Closing number of intangible asset items for the year Market capitalization / (Total assets - net intangible assets - net goodwill)

The CSMAR database has published the "Database of Digital Transformation Research of Listed Companies in China". The database was created using pertinent information found in the annual reports, fundraising announcements, qualification certificates, and other announcements made by listed firms. This study employs text analysis to remove the MD&A (Management Discussion and Analysis) content and analyze the frequency of specific keywords. Additionally, it calculates the enterprise digital transformation index by weighing six indicators: strategic leadership, technology drive, organizational empowerment, environmental support, digital achievements, and digital application.

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This research employs a quantitative approach to assess the creative capacity of organizations using data on the number of times firms' patents are cited by others. R&D costs represent the initial financial commitment made by companies towards their innovation initiatives. The number of patents obtained is a subsequent result of these efforts, while patent citations serve as a significant measure of the quality of R&D associated with the patents (Ponta et al., 2021; Bakker, 2016). Furthermore, this research utilizes government subsidies as a mediating variable and adopts an objective evaluation of government subsidies by collecting the quantity of government subsidy details in the annual reports of publicly traded firms (Wang & Zhao, 2023). Among the chosen control variables are intangible assets, growth potential, and Tobin's Q. Intangible assets have a crucial role in the expansion potential and long-term success of companies, particularly those that heavily invest in research and development (Salsa & Erni, 2022). Tobin's Q is a metric that allows investors to evaluate the desirability of investing in a company (Atinc & Simmering, 2021).

2.3. Estimation Models

Fixed effects models (FEM) mitigate the influence of omitted variable bias by accounting for individual characteristics that remain constant over time. This reduces the impact of dynamic misspecification, enhances estimation efficiency, employs adaptive instrumental variable methods, and incorporates bias correction and testing (Haan, 2020). This work developed a multivariate regression model while accounting for individual fixed factors. To assess the impact of Dx on the innovative capacity of manufacturing firms (H1), the following model was constructed:

$$InCap_{i,t} = \alpha_0 + \alpha_1 Dx_{i,t} + \sum \varphi_i Controls_{i,t} + u_i + \varepsilon_{i,t} \quad (1)$$

The Baron and Kenny (1986) method of causal stepwise regression analysis is often used to find primary predictors and identify mediators. To examine the mediating role of government subsidies in the relationship between Dx and innovation capacity (H2), the following models were constructed:

$$GovSub_{i,t} = \beta_0 + \beta_1 Dx_{i,t} + \sum \varphi_i Controls_{i,t} + u_i + \varepsilon_{i,t} \quad (2)$$

$$InCap_{i,t} = \lambda_0 + \lambda_1 Dx_{i,t} + \lambda_2 GovSub_{i,t} + \sum \varphi_i Controls_{i,t} + u_i + \varepsilon_{i,t} \quad (3)$$

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In model 1–3, InCap denotes the number of references to the patents of firm i in year t. Dx denotes the digital transformation index of firm i in year t. GovSub denotes the amount of government subsidies of firm i in year t. α_0, β_0, λ_0 stands for the intercept term α_1, β_1, λ_1 denotes the regression coefficient of the explanatory variables, λ_2 denotes the regression coefficient of the mediating variable, ϕ denotes the regression coefficient of the control variable, denotes fixed effects at the individual firm level, and denotes the residual term.

All analyses, including modeling and hypothesis testing, were conducted using Stata 17.0 software. These methodological procedures played a crucial role in maintaining data integrity, improving the robustness of the statistical findings, and thereby strengthening the scientific validity and credibility of the study.

Additionally, the research employed the bootstrapping method to aid in parameter estimation within statistical models and to facilitate statistical hypothesis testing. This technique involved generating multiple resampled datasets from the original sample, without imposing explicit assumptions about the underlying data distribution (Alfons et al., 2021).

3. Results and Discussion

3.1. The Effects of Digital Transformation on Innovation Capacity

The study hypothesized that Dx improves the InCap of firms. Table 4 provides a comprehensive overview of the outcomes obtained from the FEM.

Table 4. Fixed effects regression results on the effect of digital transformation on innovation capacity

	(Model 1)	(Model 1)
	InCap	*InCap*
Dx	5.448***	5.257**
	(3.36)	(3.26)
Intangible Assets		33.940**
		(3.29)
Tobin's Q		9.493***
		(3.82)
_cons	−26.970	−686.253**
	(−0.42)	(−3.22)
N	4027	4027
R^2	0.270	0.274
F	38.891	28.399

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*Note:***, **, and * denote statistical significance at the 1%, 5%, and 10% levels of significance, respectively. The t-statistics (in parentheses) are based on standard errors adjusted for clustering at the firm level.*

In Model 1, the data shows that the regression coefficient of enterprise Dx and innovation capacity is 5.448 ($p > .001$) when no control variables are included. However, when control variables are included, the coefficient of enterprise Dx and innovation capacity becomes 5.257 ($p > .005$). These findings suggest that the use of digital technology by publicly traded industrial companies in China has a substantial impact on enhancing their capacity to innovate, hence providing more support for H1.

This finding validates the beneficial influence of Dx on the ability of companies to innovate, based on empirical analysis. This finding aligns with the dominant perspective in contemporary academics. The use of new technologies and the enhancement of operational models in organizations, known as Dx, provide novel prospects (Gupta et al., 2023; Yang et al., 2023). Among Chinese manufacturing enterprises that are publicly traded, Dx greatly improves firms' ability to innovate. This discovery has substantial implications for understanding how firms in the digital economy create and engage in innovation.

3.2. Mediating Effect of Government Subsidy in the Relationship Between Digital Transformation and Innovation Capacity

The study also explored the mediating role of government subsidy in the relationship between Dx and InCap firms. Table 5 shows the results of the stepwise regression analysis.

In model 2, the regression coefficient between the Dx of firms and government subsidies is 0.012 ($p > .01$). Nevertheless, it is important to acknowledge that the R-squared value is at 0.049, suggesting that the model has a restricted ability to explain the dependent variable. However, the F-value is 25.664, suggesting that the whole model fits well. The findings in Model 3 indicate that there is a positive correlation, at a significant level of 5%, between the regression coefficient of enterprise Dx and innovation capacity, which is measured at 5.257. The regression coefficient for government subsidies and innovation capacity is -0.143, with a t-value of -0.02. Overall, the Sobel test determines that the mediating impact accounts for 18.39% of the overall effect, and the ratio of the indirect effect to the direct effect is 22.53%.

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Table 5. Regression results for the mediating effect of government subsidy in digital transformation and innovation capacity relationship

	(Model 2)	(Model 3)
	GovSub	*InCap*
Dx	0.012*	5.257**
	(2.42)	(3.26)
GovSub		-0.143
		(-0.02)
Intangible Assets	0.304***	33.974**
	(5.93)	(3.28)
Tobin's Q	0.020	9.489***
	(0.84)	(3.85)
_cons	11.019***	-684.445**
	(11.66)	(-2.92)
N	4027	4027
R^2	0.049	0.274
F	25.664	24.842

*Note:***, **, and * denote statistical significance at the 1%, 5%, and 10% levels of significance, respectively. The t-statistics (in parentheses) are based on standard errors adjusted for clustering at the firm level.*

The results indicate that government subsidies have a role in influencing the connection between Dx and the capacity to innovate. This study highlights the potential benefits of government subsidy programs in encouraging enterprises to engage in innovation. Government subsidies enhance firms' resources by mitigating their R&D expenses and uncertainties, therefore fostering their digitalization and innovation endeavors (Eslami et al., 2022; Li et al., 2021). Nevertheless, the presence of a negative correlation coefficient between government subsidies and innovation capacity highlights the need to ensure the accuracy and efficacy of subsidies to prevent the provision of improper subsidies that lead to a failure in achieving the intended outcome of fostering innovation Yao, 2019; Gao, 2022).

3.3. Robustness test

To enhance the dependability of prior research outcomes and mitigate the impact of measurement inaccuracies and other variables, this study adhered to the methodology outlined by Zhai et al. (2022). It is important to mention that the Bootstrap test yields dependable estimates and conclusions, even in cases

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when the raw data deviates from the assumption of normal distribution. The results of the Bootstrap test are shown in Table 6. The observed coefficient for the indirect effect demonstrates a statistically significant positive impact.

Table 6. Results of bootstrap test

	Observed Coefficient	Bootstrap std. err.	z	P>|z|	Normal-based [95% conf. interval]	
Indirect Effects	1.823	0.234	7.80	.000	(1.365	2.281)
Direct Effects	8.092	0.708	11.42	.000	(6.703	9.480)

The impact remains consistent within the 95% confidence interval, providing further evidence of the importance and statistical significance of the effect, and aligning with the findings of the Sobel test. To summarize, government subsidies provided to listed manufacturing enterprises in China serve as a mediator between Dx and innovative capabilities, hence confirming H2.

Overall, the results suggest the need for specific policy suggestions. It is recommended that the government develop more targeted subsidy programs to guarantee that money is directed towards enterprises that need help for innovation, particularly those that are crucial in driving Dx. Aside from providing direct financial subsidies, governments should allocate resources towards the development of innovation infrastructure, like technological research and development platforms and innovation service centers, to provide companies with more comprehensive assistance for their innovation endeavors.

4. Conclusions

This study examined the impact of Dx on the InCap of Chinese-listed firms while exploring the roles of government subsidy in this dynamic. To achieve this, the study developed an empirical framework for evaluating these relationships, addressing gaps in previous research. Using imbalanced panel data with a total of 4,027 data points from 1,063 A-share manufacturing businesses registered on the stock market from 2018 to 2022, a fixed-effects model was employed to construct the model.

The study concluded that Dx enhances the innovative capacity of organizations. Dx not only alters the methods by which organizations operate but also fosters the collaboration of internal resources and raises the caliber of patent research and development, so substantially enhancing the innovative

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capability of enterprises. This discovery resonates with the prevailing viewpoint in modern academia. The adoption of innovative technologies and the advancement of operational frameworks within organizations, commonly referred to as Dx, offer fresh opportunities (Gupta et al., 2023; Yang et al., 2023).

Both stepwise regression analysis and bootstrapping techniques established that government subsidies indirectly facilitate the relationship between Dx and the capacity to innovate. It implies the government's crucial role in fostering entrepreneurial innovation and facilitating the development of industrial structures. Government subsidies incentivize firms to engage in technology innovation and Dx by mitigating their research and development expenses and uncertainties.

4.1. Implications

This study contributes to the theoretical understanding of Dx's impact on innovation capacity within Chinese-listed firms by developing an empirical framework and addressing research gaps. It reveals that Dx enhances organizational innovation by fostering internal resource collaboration and improving patent research and development quality, aligning with contemporary academic perspectives on the opportunities offered by innovative technologies. Furthermore, the study highlights the indirect role of government subsidies in facilitating the relationship between Dx and innovation, emphasizing the government's crucial role in incentivizing firms to engage in technology innovation and Dx. Practically, these findings offer strategic guidance for firms aiming to leverage Dx for enhanced innovation, while also providing insights for policymakers to design effective subsidy programs to promote innovation-driven growth and enhance competitiveness in the market.

4.2. Limitations

While the study makes valuable contributions, it is constrained by its exclusive focus on listed businesses within China's manufacturing sector, potentially limiting its applicability to other industries or unlisted enterprises. Future research endeavors should address this limitation by expanding the sample to include companies from diverse sectors and varying magnitudes. Moreover, to obtain a more comprehensive understanding, subsequent studies could explore additional multifaceted measures related to Dx. By broadening the scope of analysis and incorporating a wider range of industry contexts and

measurement variables, future research can enhance the depth and breadth of insights into the dynamics of Dx and its impact on innovation capacity.

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