Research article

How digital transformation enhances corporate innovation performance: The mediating roles of big data capabilities and organizational agility

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ABSTRACT

Digital transformation has emerged as a key driver of high-quality enterprise development and an essential tool in forging an innovation-driven paradigm.Existing studies fail to delve into the specific mechanisms of their impact on firms' innovation performance, and views on their impact are divergent. Some studies suggest that digital transformation can enhance innovation performance, while others point out that it may have negative impacts, and cannot clearly answer how big data capabilities and organisational agility play a role in the digital transformation process. Therefore, based on dynamic capability theory and systems engineering theory, this study adopts the logical framework of "strategy-behaviour-performance" to systematically explore the process of digital transformation that enhances firms' innovation performance through the enhancement of big data capability and organisational agility. By empirically analysing the survey data of 476 manufacturing enterprises in China, the study reveals the chain-mediated effects of big data capability and organisational agility, and confirms the key roles of both in the transformation process. The findings suggest that digital transformation significantly improves firms' innovation performance, and that the dual mediating effects of big data capability and organisational agility are important links in its influencing mechanism. These findings not only provide empirical support for the theoretical model of digital transformation, but also provide practical guidance for enterprises to formulate strategies and optimise resource allocation in the digital era. We suggest that enterprises should strengthen the cultivation of big data capabilities and organisational agility while promoting digital transformation to better adapt to and lead market changes.

1. Introduction

Nowadays, the digital technology represented by big data, the Internet, artificial intelligence has set off a "digital revolution" in the global economy, and the digital economy has become an important engine to drive global economic growth [1]. From a macro point of

view, according to the China Academy of Information and Communication Research, in 2020, the digital economy of 47 countries in the world will reach 32.6 trillion U.S. dollars, accounting for 43.7 % of the proportion of GDP, with a nominal growth rate of 3 %, far exceeding the average growth rate of the world of that year −3.363 %. From the enterprise level, the 2022 UNIDO report shows that manufacturing enterprises using high levels of digital technology also perform much better than other enterprises in terms of monthly sales, annual profits, employment and many other economic indicators [2]. As a global manufacturing powerhouse with a full range of industries, a massive user base and leading digital technology enterprises, China has a unique path advantage in digital transformation. The Chinese government attaches great importance to the important role of data as an emerging production factor to empower the real economy and promote high-quality development. In the report of China's 20th National Congress, high-quality development is explicitly mentioned as the primary task of building a modern socialist country in a comprehensive manner, and digital transformation is identified as one of the important ways to achieve this task. The release of the 14th Five-Year Plan for the Development of the Digital Economy signalled that China's digital economy is moving towards a new stage of deepening application, standardised development and universal sharing. 2023 State Council Government Work Report also clearly proposed the vigorous development of the digital economy, with special emphasis on the importance of digital transformation of traditional industries and small and medium-sized enterprises (SMEs). This series of policy signals clearly indicates that the Chinese government has established the development of digital economy as a major strategic choice to cope with the new development stage, and the digital transformation of enterprises is not only an effective starting point for the country to promote economic transformation, but also as an important hand for green development and sustainable development [3]. The essence of digital transformation is to change the business model, process and culture of enterprises through the integration of digital technology to improve efficiency, flexibility and innovation [4], which is not only a core element of the development strategy of the digital economy, but also becomes the core driving force to stimulate the innovation vitality of enterprises and promote the economic quality upgrading, efficiency reform, as well as the power of change [5]. By deepening digital transformation, enterprises are able to redesign and optimise their business models [6], product development and market strategies [7], significantly enhancing their innovation capabilities. This transformation not only enhances the competitiveness of enterprises themselves, but also enables them to play a leading and empowering role in the digital economy, driving technological upgrading and innovation activities in other industries [8]. Therefore, actively promoting digital transformation is a key path for enterprises to respond to market changes, promote high-quality economic development and implement innovative development.

Does the digital transformation of an enterprise affect innovation performance in the context of digitalisation? Existing studies have not yet reached a unified conclusion, and the main views can be divided into two categories: the first category believes that digital transformation has a positive effect on innovation performance. The first view is that digital transformation has a positive effect on innovation performance. Digital transformation reduces the cost of information search, reconstructs the business model of the enterprise, improves the enterprise's resource integration capability and operational efficiency, helps the enterprise better integrate internal and external resources, manages the innovation process more effectively, and directly promotes the enterprise's process and product innovation to improve the enterprise's innovation performance [9]. Studies have shown that enterprise digital transformation can enhance enterprise innovation performance through the path of integrating into innovation networks [5], enhancing IT capabilities [10], improving human capital levels [11], alleviating financing constraints [12], and flexible organisation [13]. The second group of views argues that digital transformation of enterprises negatively affects enterprise innovation performance, and even derives a non-linear characteristic relationship between the two based on the heterogeneity of the research object. For example, in the process of digital transformation, enterprises may pay too much attention to the technological possibilities of products rather than deeply understand customer needs, making it difficult for enterprises to successfully change their business models through digitalisation [14]; at the same time, there is a lag in digitalisation investment, and in the longer term, the effects of digitalisation face the dual constraints of organisational structure and management, and the benefits brought by digitalisation will be offset by the management costs derived from it [15]. It has also been found that as digitisation inputs increase, the unit benefit gained by the firm gradually decreases and eventually approaches zero [16]. Digital transformation promotes firm innovation when the level of digitisation is below the inflection point, while it inhibits firm innovation when the level of digitisation is above the inflection point [17]. Excessively high digitisation levels may lead to information overload, crowding out the mismatch between the enterprise's human capital investment and the enterprise's existing resource conditions and capability base, resulting in the enterprise's inability to either continue to support the in-depth implementation of digital transformation, or to quickly adjust itself to external environmental changes [18].

As a result, we can see that existing research has yet to provide insights into how digital transformation specifically affects firms' innovation performance, while there is disagreement on the assessment of its impact. While it is widely recognised that digital transformation plays a key role in driving or inhibiting firm innovation, there is still a dearth of research on its mechanisms of action and its specific effects in different contexts. This analytical gap highlights the urgent need for more systematic and nuanced research to clearly define the specific effects of digital transformation on innovation performance in different business environments and to identify the key drivers that facilitate or inhibit such effects. Data plays an important role as a core strategic resource in the digital transformation process. Firms should leverage and integrate high correlation with other resources, such as labour, capital, and technology, based on access to data resources, to enhance flexibility in the face of market dynamics, thereby improving innovation performance and creating more competitive advantages. Therefore, this paper argues that big data capabilities and organisational agility are important transmission mechanisms between digital transformation and innovation performance. On the one hand, effective big data analytics capabilities enable organisations to identify patterns and trends hidden in complex data, so that digital transformation can play a better role in supporting organisations to make more accurate market forecasts and risk assessments, and provide reliable data support for innovation activities [19]. On the other hand, organisations with agility are able to respond quickly to changes in the market and technology, and flexibly adjust their strategies and operating models [20]. This agility is not only reflected in the ability to make quick decisions, but more importantly, the ability to quickly implement and adapt to innovative changes,

enabling organisations to maintain competitiveness in changing market environments, and to capture and utilise innovation opportunities in a timely manner in order to gain a greater competitive advantage.

Firstly, this study selects manufacturing enterprises in the Chinese region as the research object to explore how digital transformation affects the innovation performance of enterprises. Second, we analyse how big data capabilities and organisational agility in digital transformation act as key mechanisms to influence firms' innovation performance from the logical framework of "strategy-behaviour-performance". Through this study, we aim to answer the following core questions: (1) Does digital transformation facilitate or inhibit firms' innovation performance? (2) How does digital transformation impact on firms' innovation performance? (3) What role do big data capabilities and organisational agility play in this process?

The contributions of this study are mainly in the following aspects. First, unlike the existing literature, this study is based on 476 empirical data, which clearly confirms that digital transformation has a positive impact on corporate innovation performance, and provides empirical evidence to address the divergent views. Second, this study adopts the "strategy-behaviour-performance" theoretical framework to systematically analyse the mechanism of digital transformation, especially the mediating role of big data capability and organisational agility in this process, and provides a basis for how digital transformation impacts on firms' innovation performance. It also provides a basis for how digital transformation affects the innovation performance of enterprises. Finally, this study also pays attention to the robustness of the study and ensures the reliability of the findings by examining potential endogeneity issues. Overall, this study not only fills a gap in existing research, but also provides clear and valuable evidence-based guidance for policymakers and business managers.

2. Literature review and research hypotheses

2.1. Digital transformation and corporate innovation performance

Digital transformation will have an impact on enterprise manufacturing, operation management, organisational change, human resource management, etc. [21], as well as affecting the enterprise's ability to obtain information, resource allocation, etc. [22], which in turn will bring about a significant improvement in the enterprise's innovation performance. Firstly, the application of digital technologies such as big data and cloud computing significantly reduces the information asymmetry within the enterprise and outside the market, and improves the efficiency of information collection, collation and transmission [23]. This enables enterprises to quickly match and accurately dock supply and demand, greatly enhancing market response speed and decision-making quality. Second, in terms of organisational structure, digital transformation has triggered internal organisational changes [24]. The traditional vertical management model has been replaced by a flatter network structure, which not only improves organisational flexibility and coupling, but also enhances the strategic flexibility of the enterprise. By means of digitalisation, firms are able to integrate internal resources more effectively and promote inter-departmental synergies, thus accelerating the implementation of product and operational innovations. At the same time, digital transformation frees up more capital and resources to support innovation activities by reducing search costs, replication costs, communication costs, and matching and integration costs [25]. This increased cost efficiency provides more room for firms to invest in research and development of new products, services, and solutions, thus enhancing their market competitiveness and innovation capabilities. Finally, firms have also fostered an innovation-orientated culture through digital transformation implementation [26]. This culture encourages risk-taking, experimentation and organisational learning, providing fertile ground for innovation. Enterprises are able to adapt faster to market changes and technological advances, and continuously promote the expansion of innovation boundaries.

Hypothesis 1. Enterprise digital transformation can significantly enhance innovation performance.

2.2. The mediating role of big data capability

Big data capability is seen as a unique and unrepeatable resource for enterprises, which is not only about the collection and storage of data, but more importantly involves the analysis, understanding and application of data. Digital transformation will inevitably contribute to the enhancement of big data capabilities, which is reflected in the investment and attention of enterprises in data-driven activities [27]. , including the enhancement of data processing technologies, analytical mechanisms, and innovative ideas. With the increase in data resources, analysts, and technological tools, the data analysis capabilities of enterprises are significantly enhanced. Big data capabilities enable enterprises to predict market trends and user behaviour more accurately and accelerate the innovation and decision-making process [28], thus significantly improving their competitiveness and innovation performance in the market. On the one hand, enterprises have significantly improved their ability to identify and assimilate external knowledge through the application of big data technologies [29]. Big data analyses enable firms to rapidly access key market and technology trend information, which not only expands the scope of access to knowledge and resources needed by firms in their innovation activities, but also increases the diversity of knowledge resources [30]. In addition, the application of this technology shortens the cognitive distance between technology and market and promotes the integration of cross-domain knowledge, thus directly enhancing the innovation capability of enterprises. On the other hand, the further application of big data technologies improves the efficiency of enterprises in processing and analysing internal data [31]. Using efficient data processing tools such as cloud computing and machine learning, enterprises have not only improved the speed and accuracy of information processing, but also been able to deeply analyse massive amounts of data in a shorter period of time [32]. This fast and accurate data analysis provides enterprises with in-depth business insights and supports data-based decision making [33]. With the continuous improvement of big data capabilities, enterprises are able to identify innovation

opportunities from complex datasets faster, significantly shorten the product development cycle, and accelerate the market response speed, thus enhancing their market competitiveness.

Hypothesis 2. Big data capabilities play a mediating role in the impact of digital transformation on firms' innovation performance.

2.3. The mediating role of organizational agility

Organisational agility is the ability of a firm to adapt and react quickly to changes in an unpredictable and constantly changing environment [32]. This definition emphasises an organisation's adaptability and ability to evolve itself in response to dynamic and complex internal and external environments.Organisations undergoing digital transformation can significantly improve organisational agility. By introducing advanced digital technologies such as cloud computing, big data analytics, and artificial intelligence, orga- nisations are able to shift from a fixed mode of operation to a highly interconnected, dynamically adaptive network [33]. Enterprises can rapidly access critical information and technical support from this network, which drives them to update in tandem with market changes, strengthens their responsiveness and adaptive strategies, and motivates them to rapidly adapt and optimise their operational processes, thereby enhancing overall organisational agility [34]. In terms of the external environment of the firm, organisational agility enables firms to be more flexible in adapting to market demands and technological changes. Agile firms are able to access key resources and information from stakeholders, such as customers, suppliers, and partners, more quickly [35]. This rapid pooling of resources and absorption of external knowledge provides rich inputs for the firm's innovation activities, thus accelerating the process of developing new products and services. From an internal governance perspective, increased organisational agility allows firms to adjust their management and operational strategies more flexibly [36]. In the face of rapid changes in markets and technologies, agile firms are able to implement decisions quickly and optimise processes and structures to support new innovation projects [37]. This efficient decision-making and fast execution not only improves the firm's responsiveness to new opportunities, but also reduces the time from idea to product realisation, and enhances the firm's ability to innovate and adapt to the market in the face of fierce competition.

Hypothesis 3. Organisational agility plays a mediating role in the impact of digital transformation on firms' innovation performance.

2.4. The chain mediating effect of big data capability and organizational agility

Digital transformation makes firms' innovation processes more efficient by enhancing big data capabilities and organisational agility. This transformation enables firms to quickly access and analyse large amounts of market and consumer data at lower costs, and target product innovation to customer needs, thereby creating a unique competitive advantage [38]. At the same time, enhanced data processing capabilities and organisational flexibility reduce cross-departmental resource mismatches [39], facilitate effective inte- gration of internal resources, and encourage more innovation [40], thus directly enhancing innovation performance. On the one hand, by utilising big data technologies such as data warehouses, online analytical processing, data visualisation tools and data mining tools, firms are able to capture timely changes in demand from within the firm, customers and suppliers [41]. This timely acquisition and processing of information enables enterprises to make rapid decision-making adjustments through effective information transfer in the supply chain, thus enhancing organisational agility. On the other hand, the application of big data technology promotes the flattening of internal organisational structure, improves organisational flexibility and adaptability, and enhances the agility of enterprises in responding to environmental changes [42], which makes the organisational design of enterprises based on digital technology and agile structure, and enables them to quickly adapt to the opportunities and threats brought by the environment. This organisational change facilitates the establishment of an open and collaborative innovation culture, making the firm more adaptable to the rapidly changing market environment and facilitating the effective integration of internal and external knowledge.
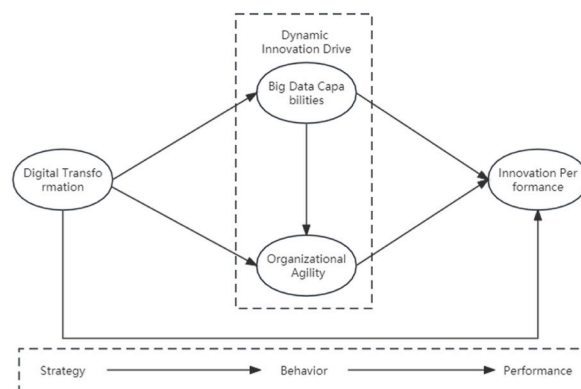

Fig. 1. Theoretical framework.

Hypothesis 4.   Digital transformation positively affects firms' innovation performance through the chain mediation of big data capabilities and organisational agility.

The theoretical framework, as depicted in Fig. 1.

3. Research design

3.1. Research sample

The data used in this study was obtained through a survey of manufacturing enterprises in the Chinese region, and the target group was middle and senior managers and those in charge of big data-related work in manufacturing enterprises, who were required to have been in their positions for more than one year, and at the same time, the number of employees in the enterprise was more than 20. The sample covers 24 provinces in China, both in the east and west, and is representative of the level of socio-economic development and geographical distribution. The survey first selected five enterprises for preparatory tests, and the questionnaire was revised and finalised after face-to-face communication with the relevant personnel of the enterprises.The questionnaire was distributed from October to December 2023.Out of 550 distributed questionnaires, 476 valid responses were received, yielding a recovery rate of 86.54 %.Among respondents, 70.07 % were male, and 54.93 % held a bachelor's degree.Among the sampled enterprises, 44.08 % were established for over 8 years; 60.20 % were private, 33.55 % state-owned, with foreign and joint ventures comprising the remainder.

3.2. Variable measurement

To ensure reliability and validity, the study adapted and refined established scales and theoretical frameworks from global sources, aligning them with business practices.Scoring employed a Likert five-point scale, ranging from "strongly disagree (1)" to "strongly agree (5)".

3.2.1. Independent variable: digital transformation
Due to diverse definitions of digital transformation in academia, standardized measurement methods are lacking [43]For a robust digital transformation scale, this study integrates systems integration theory and the findings of Hess, Huang et al.[[25,44]],incorporating digital transformation practices in Chinese enterprises. The scale comprises 11 items on digital technology adoption, data-driven decision processes, and corporate culture digitisation.

3.2.2. Dependent variable: Innovation Performance
Acknowledging limitations of using only patent counts, this study focuses on product and process innovation. Based on Bell and Ritter [45,46],the scale with 5 items addresses product and process innovation, and industry standards setting.

3.2.3. Mediating variables: big data capability, organizational agility
The big data capability scale, based on Shahriar Akter [47], includes 5 items on data collection, analysis, application, and governance.Organizational agility measurement, drawing on Ramamurthy K R [48],consists of 5 items on market response speed, process flexibility, and innovation capabilities.

3.2.4. Control variables
Enterprise innovation performance is affected by many factors, drawing on existing literature research [49–51], this study selected the age of the firm and the size of the firm as control variables to deal with in this study.(1) Enterprise age categories: under 3 years, 3–5 years, 6–8 years, over 8 years, scored 1 to 4; (2) Enterprise size based on employee count: 1–100, 101–500, 501–1000, over 1000, each scored 1 to 4.

3.3. Model construction

To validate the proposed hypotheses, this study constructs the following model.
The baseline model, focused on the direct impact of corporate digital transformation on innovation performance, is as follows:

$$Inno = \alpha_0 + \alpha_1 DT + \sum_m \alpha_m controls + \varepsilon \tag{1}$$

In this model, 'Inno' denotes corporate innovation performance, 'DT' indicates the level of corporate digital transformation, 'Controls' refers to the control variables set, and ε represents the random error term.
Expanding on regression model (1), the mediating effect model is constructed as follows:

$$MID = \beta_0 + \beta_1 DT + \sum_m \beta_m controls + \varepsilon \tag{2}$$

$$Inno = \beta_0 + \beta_1 DT + \beta_2 MID + \sum_m \beta_m controls + \varepsilon \tag{3}$$

Equation (2) models the relationship between the explanatory variable DT and the mediating variable MID, while equation (3) models the relationship between DT, MID, and the dependent variable CT.MID encompasses big data capability and organizational agility, with other variables defined as in equation (1).

Additionally, using equations (1) and (2), a chained mediating effect model, equations (4) and (5), is constructed for validation.

$$OA = c_0 + c_1 DT + c_2 DC + \sum_m c_m controls + \varepsilon \tag{4}$$

$$Inno = d_0 + d_1 DT + d_2 DC + d_3 OA + \sum_m c_m controls + \varepsilon \tag{5}$$

4. Empirical analysis

4.1. Measurement of common method bias

This study utilized Harman's single-factor test to assess common method bias.Exploratory factor analysis was conducted on all items from the four variables, revealing that the first factor accounted for less than 50 % of the variance, suggesting that common method bias is not a significant concern in this study.

4.2. Reliability and validity analysis

Prior to hypothesis testing, reliability and validity of the scales were assessed.Reliability tests for digital transformation, corporate innovation performance, big data capability, and organizational agility were conducted.Table 1 shows Cronbach's α values for each variable exceeding 0.7, and Composite Reliability (CR) values above 0.7, indicating strong internal consistency.Structural validity was examined through convergent and discriminant validity analyses.Standardized factor loadings for each item exceeded 0.6, and Average Variance Extracted (AVE) was above 0.5, demonstrating high convergent validity.Discriminant validity was further assessed using Confirmatory Factor Analysis (CFA), detailed in Table 2.The results indicate an excellent fit for the four-factor model: the $\chi 2/df$ value is 2.028, well below the threshold of 3, suggesting a robust model fit.Additionally, CFI (0.954) and NFI (0.913) values surpass the 0.9 standard, and the RMSEA value is 0.058, below 0.08, indicating a well-fitting model with a small error estimate.Overall, the four-factor model demonstrates both theoretical and practical robustness, affirming significant discriminant validity among the variables.

4.3. Correlation analysis

This study quantified the relationships between research variables using the correlation coefficient method.Table 3 shows significant positive correlations among the variables.Specifically, digital transformation is significantly positively correlated with

Table 1
Results of reliability and validity test.

Variable	Items	factor loadings	Cronbach'Alpha	CR	AVE
Digital Transformation	DT1	0.805	0.932	0.918	0.563
	DT2	0.620			
	DT3	0.704			
	DT4	0.717			
	DT5	0.644			
	DT6	0.784			
	DT7	0.713			
	DT8	0.639			
	DT9	0.716			
	DT10	0.747			
	DT11	0.721			
Big Data Capability	DC1	0.792	0.905	0.896	0.634
	DC2	0.828			
	DC3	0.834			
	DC4	0.764			
	DC5	0.759			
Organizational Agility	OA1	0.794	0.929	0.884	0.606
	OA2	0.793			
	OA3	0.796			
	OA4	0.812			
	OA5	0.690			
Corporate Innovation Performance	CI1	0.753	0.903	0.868	0.57
	CI2	0.686			
	CI3	0.713			
	CI4	0.788			
	CI5	0.827			

Table 2

Results of CFA model fit test.

Model	Factor	χ^2	df	χ^2/df	NFI	CFI	IFI	RMSEA
Four-Factor Model	DT; Inno; DC; OA	561.76	277	2.028	0.913	0.954	0.954	0.058
Three-Factor Model	DT; Inno + DC; OA	963.96	280	3.443	0.851	0.889	0.889	0.090
Two-Factor Model	DT; Inno + DC + OA	2250.24	296	7.602	0.640	0.745	0.746	0.135
Single-Factor Model	DT + Inno + DC + OA	2647.925	299	8.825	0.590	0.617	0.619	0.161

corporate innovation performance (r = 0.433, p < 0.01), big data capability (r = 0.340, p < 0.01), and organizational agility (r = 0.488, p < 0.01).Likewise, corporate innovation performance is significantly positively correlated with big data capability (r = 0.376, p < 0.01) and organizational agility (r = 0.470, p < 0.01), and there is a significant positive correlation between big data capability and organizational agility (r = 0.394, p < 0.01).These findings offer preliminary empirical support for the study's hypothesized relationships.

4.4. Hypothesis testing

A structural equation model, developed based on the theoretical hypotheses, was constructed and evaluated. The data results are detailed in Table 4, and the Model Estimation Results are depicted in Fig. 2.Digital transformation significantly influenced big data capability (β = 0.504, p < 0.001), organizational agility (β = 0.529, p < 0.001), and corporate innovation performance (β = 0.338, p < 0.001), supporting Hypotheses 1.Additionally, big data capability positively affected organizational agility (β = 0.278, p < 0.001) and corporate innovation performance (β = 0.298, p < 0.001).Organizational agility significantly impacted corporate innovation performance (β = 0.232, p < 0.001).These results further support the study's hypotheses, affirming the crucial role of digital transformation, big data capability, and organizational agility in enhancing corporate innovation performance.Moreover, the significant path coefficients indicate the indirect effects of digital transformation on corporate innovation performance via enhanced big data capability and organizational agility, setting the stage for further analysis of mediating effects.

To validate the mediating roles of big data capability and organizational agility, this study employed a 95 % confidence interval and conducted 5000 Bootstrap resamples for enhanced reliability.Table 5 presents the mediation effect test results using the Bootstrap method.The confidence intervals of the mediation paths did not include zero, indicating clear mediation effects.Specifically, big data capability's mediation effect between digital transformation and corporate innovation performance was 0.150, with a 95 % confidence interval of [0.085, 0.209], excluding 0.This confirms big data capability's partial mediation in this relationship, supporting Hypothesis 2.The mediation effect of organizational agility was 0.123, with a 95 % confidence interval of [0.053, 0.219], also excluding 0.This supports organizational agility's partial mediation role between digital transformation and corporate innovation performance, affirming Hypothesis 3.The combined mediating effect of big data capability and organizational agility was 0.033, with a 95 % confidence interval of [0.011, 0.068], also excluding 0.This indicates that digital transformation positively influences corporate innovation performance via the sequential mediation of big data capability and organizational agility, supporting Hypothesis 4.

4.5. Robustness test

Considering that this study uses cross-sectional data and the variables take values in the range of [1,5], in order to further determine the robustness of the results, the logit model and probit model were used respectively, and it was found that the findings after changing the regression method were consistent with the original test. The results show that digital transformation shows a significant positive impact on big data capability, organisational agility, and corporate innovation performance, which can prove that the results of the main effect of this study have a high degree of confidence. The mediating effects of big data capability and organisational agility were further tested using stepwise regression. After adding the mediator variable big data capability, the coefficient of the mediator variable is significant, and the regression coefficient of the effect of digital transformation on corporate innovation performance is significantly positive and this coefficient is reduced, indicating that big data capability plays a partial mediating role between digital transformation and corporate innovation performance. Meanwhile, after adding the mediator variable organisational agility, the coefficient of the middle mediator variable is significant, the regression coefficient of the impact of digital transformation on enterprise innovation performance is significantly positive, and the coefficient is reduced, indicating that organisational agility plays a partially mediating role between digital transformation and enterprise innovation performance.

Table 3

Correlation coefficients results.

Variable	Digital Transformation	Big Data Capability	Organizational Agility	Innovation Performance
Digital Transformation	(0.563)			
Big Data Capability	0.340**	(0.634)		
Organizational Agility	0.488**	0.394**	(0.606)	
Innovation Performance	0.433**	0.376**	0.470**	(0.570)

**indicates p < 0.01, values in parentheses are the square roots of AVE.

Table 4
Hypothesis testing results.

| Path	Standardized Path Coefficient	Unstandardized Path Coefficient	S.E.	C.R.	P
Digital Transformation → Big Data Capability	0.504	0.488	0.056	8.664	***
Digital Transformation → Organizational Agility	0.529	0.538	0.059	9.068	***
Big Data Capability → Organizational Agility	0.278	0.292	0.058	5.024	***
Digital Transformation → Corporate Innovation Performance	0.338	0.313	0.061	5.117	***
Big Data Capability → Corporate Innovation Performance	0.298	0.285	0.055	5.149	***
Organizational Agility → Corporate Innovation Performance	0.232	0.211	0.061	3.436	***

*** indicates $p < 0.001$.
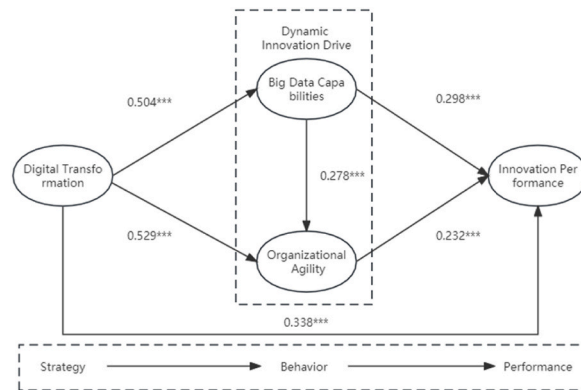
Fig. 2. Model estimation results.

Table 5
Bootstrap mediation effect test analysis results.

Path	Standardized Effect	Unstandardized Effect	95 % Confidence Interval	
			Lower	Lower
Direct Effect	0.338	0.313	0.182	0.439
Digital Transformation → Big Data Capability → Corporate Innovation Performance	0.150	0.139	0.085	0.209
Digital Transformation → Organizational Agility → Corporate Innovation Performance	0.123	0.114	0.053	0.219
Digital Transformation → Big Data Capability → Organizational Agility → Corporate Innovation Performance	0.033	0.030	0.011	0.068
Total Indirect Effect	0.306	0.283	0.196	0.394
Total Effect	0.644	0.596	0.481	0.709

5. Discussion

First, the empirical evidence in this study confirms that digital transformation significantly enhances firms' innovation performance, which is consistent with the findings of previous empirical studies [12,22], which suggest that by effectively integrating advanced digital technologies, firms not only accelerate the development of new products and services, but also shorten the innovation cycle, thus adapting faster to market changes. These findings support the application of dynamic capabilities theory, whereby firms achieve competitive advantage by enhancing their capabilities to sense and respond to rapidly changing environments. Although some studies have pointed out that digital transformation can cause information overload and resource mismatch [15,52], our data show that by enhancing big data capabilities and organisational agility, these challenges can not only be effectively managed, but can also be transformed into forces that drive innovation. That is, under the appropriate managerial and technological frameworks, digital transformation can significantly improve firms' innovation performance.

Second, to explore how digital transformation affects firms' innovation performance through multiple mechanisms, we specifically examine the mediating role of big data capabilities and organisational agility. The study shows that big data capabilities and organisational agility not only affect innovation performance independently, but their joint effect further strengthens this effect. Specifically, big data capabilities provide the necessary information and insights, while organisational agility ensures that firms are able to respond quickly to the opportunities presented by these insights, which is in line with the findings of previous studies [28,37], but further emphasises the integrated role of these mediating variables in transformational success through the detailed portrayal of chain reactions. Compared to the existing literature [40,53], our study provides a more refined framework of understanding,

suggesting that the overlapping effects of mediators cannot be ignored in the execution of digital strategies.

Another interesting finding of this study is that big data capabilities play a more significant role in driving firms' innovation performance compared to organisational agility. This difference reveals that big data capabilities may play a more critical role than organisational agility at different stages and in different domains of digital transformation. While existing studies generally agree that organisational agility is critical for coping with rapid change, this study finds that big data capabilities play a more prominent role in data-driven, data-intensive manufacturing environments. This finding challenges the conventional view [54] and highlights the need to pay particular attention to the development and utilisation of data capabilities when developing digital strategies. Such data-based insights and decision-making capabilities enable manufacturing organisations to more accurately predict market trends and create products that are more in line with market and consumer needs, thereby gaining an edge in the fierce global competition, as shown in Fig. 3.

6. Conclusions

6.1. Implications to theory

This study presents three important theoretical contributions. First, it addresses the controversy over the impact of digital transformation on innovation performance. Through empirical analyses of 476 Chinese manufacturing firms, this study confirms that digital transformation significantly improves firms' innovation performance and that digital capabilities can be effectively transformed into firms' competitive advantages under appropriate managerial and technological frameworks. This finding is not only consistent with previous studies, but also resolves the academic controversy about whether digital transformation has a positive or negative impact on innovation performance. Second, by systematically integrating the various components of digital transformation and clarifying how these components work together to drive innovation performance, we reveal how two specific organisational capabilities, namely big data capability and organisational agility, independently and synergistically drive innovation performance, and provide a new theoretical perspective for understanding how firms can realise innovation through technological and organisational change. Finally, a "strategy-behaviour-performance" research framework was developed. The development of this framework provides future researchers with a reliable theoretical and practical model for analysing and designing more effective digital strategies. The proposed framework extends the resource-based perspective and dynamic capabilities theory, increasing their explanatory power and scope of application by applying them to the field of digital transformation.

6.2. Implications to practice

With the global advancement of digital transformation, digital technologies are reshaping the operations and competitive landscapes of businesses. These technologies not only enhance decision-making and operational efficiencies within companies but also transform interactions with customers, suppliers, and other business partners. In this context, digital transformation has become crucial for enhancing innovation capabilities and market adaptability, particularly in rapidly developing economies like China, where it plays a pivotal role in the long-term development and competitive strength of enterprises. Thus, it is essential for businesses to integrate digital strategies into their core strategic planning to align with national policies like China's "14th Five-Year Plan" and digital economy strategies, thereby driving economic restructuring and high-quality growth. This necessitates strategic investments in
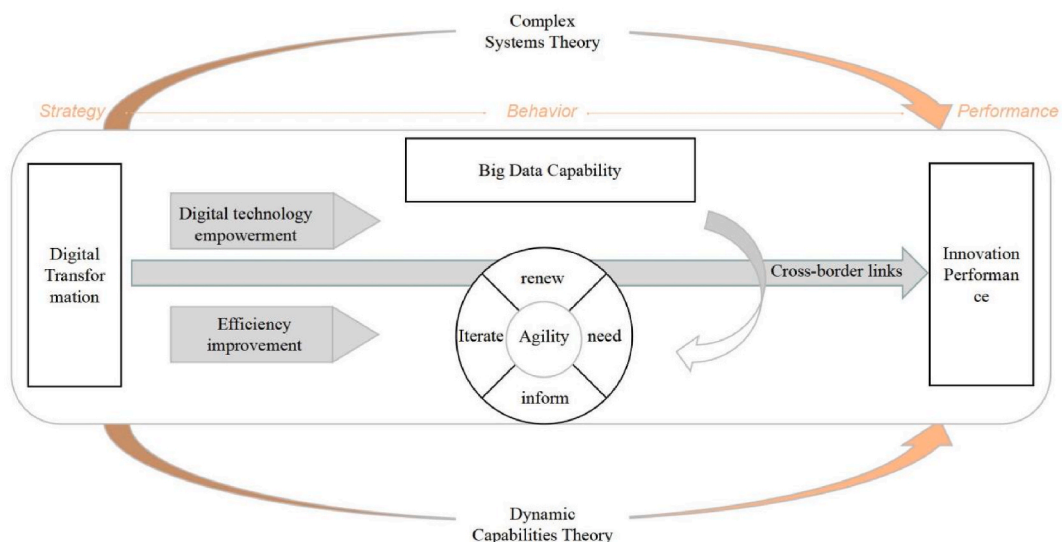

Fig. 3. The mechanism and evolution path model of digital transformation driving innovation performance.

emerging technologies, reforms in corporate culture and organizational structure, and innovation in business models to adapt and lead in changing market conditions.

Therefore, this study proposes the following policy suggestions. Firstly, Enhance Strategic Planning and Build a Digital Transformation Ecosystem. As national digital economy strategies unfold, integrating digital transformation into strategic planning is crucial for businesses to maintain their digital transformation. First, Enhance Strategic Planning and Build a Digital Transformation Ecosystem. Strategic planning should encompass investments in emerging technologies, cultural and organizational reforms, and business model innovation. Businesses should also foster a collaborative ecosystem involving various stakeholders like supply chain partners and academic institutions, promoting resource sharing and joint ventures. Businesses should also foster a collaborative ecosystem involving various stakeholders like supply chain partners and academic institutions, promoting resource sharing and joint technology exploration. Simultaneously Enhance Big Data Capabilities and Organizational Agility. Critical to the digital transformation journey, big data capabilities and organisational agility enable businesses to quickly adapt to market changes and deeply understand customer needs. Developing a robust data infrastructure is crucial, involving investments in advanced data processing tools and establishing data governance. Developing a robust data infrastructure is crucial, involving investments in advanced data processing tools and establishing data governance policies. Similarly, adopting agile methodologies such as Scrum and Kanban enhances project management and operational efficiency, fostering a culture that supports rapid adaptation to new challenges through collaboration and innovation. innovation.

6.3. Key lessons learnt

Firstly, this study demonstrates the importance of theoretical integration. By applying a combination of systems engineering theory and resource-based theory to the analysis of digital transformation, this study demonstrates the power of theoretical integration in explaining complex business phenomena. This point suggests that future research can enhance the explanatory power and breadth of application of theoretical models through cross-theoretical integration. In addition, this innovative use of theory provides management practices with new perspectives to examine problems from multiple dimensions. Second, this study obtains data-driven decision making. This study highlights the central role of big data in driving firms' innovation, especially in predicting market trends and optimising product development processes. This lesson suggests that firms should rely more on data-driven decision making when formulating strategies. For future research, this highlights the need to further explore mechanisms and tools for effectively integrating and utilising big data to support the decision-making process. Finally, this study found an association between agility and innovativeness. Organisational agility plays a key role as a mediating variable in the success of digital transformation. What this lesson means for practice is that while pursuing technological innovation, firms need to continuously optimise their internal structures and processes in order to maintain a high level of agility and responsiveness. For future research, this reveals the potential value of exploring the ways in which agility is realised and its effects in different types and sizes of firms.

6.4. Limitations of the study

There are certain limitations of this study that need to be explored further. Firstly, the limitations of the sample in terms of geography and industry. This study focuses on manufacturing companies in China, especially in more economically developed regions. There are significant differences in digital maturity, industrial structure, and policy environment in different regions of China, which may not fully represent the challenges and opportunities that all regions may encounter in digital transformation. For example, firms in less developed regions may face different technical infrastructure and policy support issues, and these differences may lead to different transformation effects and innovation performance. Second, there are limitations in the timeliness of the cross-sectional data. The cross-sectional data used in this study, while convenient for analysing the current state of the data, fails to capture long-term trends and cyclical fluctuations, which may mask the complexity and evolution of the interactions between variables. For example, the initial stages of digital transformation may be characterised by a decrease in productivity or an increase in costs, and this short-term negative effect may shift over time. Finally, while we have explored the mediating role of big data capabilities and organisational agility, there is still a lack of depth as to whether there are other variables that interact with, and influence, business operations and management activities.

6.5. Recommendations for future research

Future research should expand to regions with different levels of economic development and different industries to examine whether the impact of digital transformation exhibits different characteristics in different cultural and economic contexts. In addition, consideration could be given to include non-manufacturing areas such as the service industry to explore the differences and applicability of digital transformation across different industries. Second, it is strongly recommended that future studies adopt longitudinal data to track the same enterprises at different stages of the digital transformation process and analyse the changing trends and long-term impact of the transformation effects. This approach can help researchers more accurately understand and explain the true impact of digital transformation on innovation performance. Finally, further research is recommended to investigate the interactions between big data capabilities and organisational agility with other potential variables (e.g., corporate culture, internal innovation climate, employee skills and technology acceptance, etc.). In particular, it is important to explore how these mediating variables play a role at different managerial levels and strategy implementation, and how these mechanisms can be used to optimise a firm's overall innovation strategy and performance.

Data availability statement

Data will be made available on request.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with.

Informed consent

Informed consent was obtained from all individual participants included in the study.

CRediT authorship contribution statement

Minghao Xu: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Yufei Zhang:** Writing – review & editing, Methodology, Conceptualization. **Haoran Sun:** Writing – original draft, Methodology, Conceptualization. **Yuanxiu Tang:** Visualization, Software, Formal analysis. **Junjun Li:** Writing – original draft, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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