Modern Management based on Big Data V
A.J. Tallón-Ballesteros (Ed.)

doi:10.3233/FAIA240273

A Study of the Impact of Digital Transformation on Firms' R&D Internationalization: Mediation Based on Dynamic Capabilities

Yuan Jin and Xujuan Su[1]
School of Economics and Management, Shanghai Maritime University, China
ORCiD ID: Xujuan Su https://orcid.org/0009-0008-6139-8901

Abstract: In the tide of the digital economy, digital transformation of enterprises has been deepening, with far-reaching impacts on their global strategic layout. This study focuses on how digital transformation affects firms' R&D internationalization breadth through the mediating role of dynamic capabilities. Using data from Chinese A-share listed companies in Shanghai and Shenzhen from 2008 to 2021, this paper empirically analyzes the data using a stepwise method regression model. It is found that digital transformation significantly and positively affects firms' dynamic capabilities, including absorptive, adaptive and innovative capabilities. The enhancement of these capabilities helps firms to respond more effectively to changes and challenges in the international market, thus expanding their R&D activities to a wider geographic scope.

Keywords: Digital transformation, dynamic capabilities, R&D internationalization

1. Introduction

Propelled by the ongoing wave of digitization, the digital transformation (DT) of enterprises has turned from an option into an inevitable trend. According to the China Informational Development Report (2023), the digital economy has emerged as a new catalyst for stimulating domestic economic growth. Meanwhile, digital transformation is also profoundly reshaping the global economic landscape. With the popularization and application of advanced information technologies, enterprises have undergone significant changes in their resource allocation and operational capabilities, which have led to fundamental changes in organizational structures, business models, and strategic decisions [1]. For the manufacturing industry in particular, this technological innovation has greatly facilitated the transition from traditional to smart manufacturing, enabling firms to achieve precise positioning and rapid response across a wider range of markets. However, compared to native digital enterprises, the digitalization of the manufacturing sector is not only an enhancement of current processes through digital technology, but also a deep restructuring and strategic reinvention[2]. The R&D

[1] Corresponding Author, Xujuan Su, School of Economics and Management, Shanghai Maritime University, China; Email: suxvjuan_2017@163.com.

internationalization strategy, as one of the key strategic decisions of firms, is clearly also significantly affected by digital transformation[3]. Although in practice many firms have already implemented their international R&D through digital and intelligent means, Academic research investigating how DT influences firms' R&D internationalization behaviors is an area of research that has only begun to receive gradual attention in recent years[1].

In the area of DT, existing research focuses on how it enhances firms' internationalization strategies and competitiveness. By analyzing data from Chinese listed firms, Gao et al. (2022) find that DT significantly enhances the implementation of firms' international strategies and plays a mediating role by fostering firm innovation. Similarly, Pergelova et al. (2021) and Cassetta et al. (2020) both point out that the application of digital technologies reduces cross-border transaction costs and enhances firms' export behavior[1][4][5]. These studies suggest that digital transformation accelerates the internationalization process of firms by optimizing information flow and market response, increasing their activity and efficiency in the global market. These studies provide an important theoretical foundation and reference ideas for digital transformation-related research, but the impact of DT on the internationalization of enterprise R&D and the inherent mechanism have not received enough attention for the time being. Since the R&D internationalization activities of Chinese enterprises have only gradually increased in recent years, there are still relatively few domestic studies on the relationship between digital transformation and enterprise R&D internationalization. Most of the current studies use a binary indicator of whether or not to internationalize R&D to assess the key variable of R&D internationalization [6], an approach that fails to adequately reveal the specific impact of digital transformation on R&D internationalization at different levels. Therefore, based on internationally widely recognized measures [7][8], this study distinguishes between two dimensions of R&D internationalization: breadth and depth. Compared to deepening the depth of R&D internationalization, expanding the breadth of R&D internationalization usually entails higher managerial complexity and risk, providing a broader scope for digital transformation. Therefore, this study focuses on exploring the dynamics of how digital transformation specifically affects the breadth of a firm's R&D internationalization(IRDB).

Based on the analysis of the relationship between digital switching and the IRDB, this paper further adds dynamic capabilities as a mediating variable. Dynamic capability theory emphasizes how firms adapt to changing competitive environments by perceiving environmental changes, grasping opportunities, and reallocating resources in order to maintain and enhance competitive advantages[2]. When firms enter the international market, the external environment they face becomes more uncertain and complex, posing greater challenges to their operations. According to Dynamic Capability Theory, digital transformation enhances a firm's ability to perceive changes in the environment, helps firms to acquire and reconfigure resources to adapt to the ever-changing and competitive international environment, and then supports firms' research and development on a global scale. Therefore, dynamic capabilities theory provides a very suitable theoretical perspective for this study to analyze the interaction between DT and IRDB.

Despite the valuable insights provided by current literature, the specific impact of DT on IRDB, particularly in terms of inherent mechanisms, remains underexplored. While previous studies have highlighted the role of DT in enhancing firms' global competitiveness and streamlining operations, they have not sufficiently addressed the

mediating effect of dynamic capabilities on R&D internationalization strategies. This gap in the literature presents a compelling motivation for this study, which seeks to build on existing knowledge by offering a detailed examination of how DT can influence IRDB through dynamic capabilities. By integrating the theoretical framework of dynamic capabilities with empirical data, this research aims to provide a deeper understanding of the internal mechanisms at play, thereby offering practical insights for businesses looking to navigate the complexities of digital transformation in the global marketplace.

Based on the above analysis, this study takes the data of Shanghai and Shenzhen A-share listed manufacturing enterprises from 2008 to 2021 as a sample, and uses text mining technology to construct an enterprise-level digital transformation index to explore the relationship between DT and IRDB of enterprises. This study has the following potential academic contributions: (1) Through the dynamic capabilities theory, this paper not only explains how digital transformation affects the breadth of R&D internationalization, but also deepens the understanding of this relationship through empirical data, adding a new perspective to the research on DT within the domain of international business. (2) The mediating role of dynamic capabilities between DT and IRDB is explored, revealing the internal mechanism of this process. (3) This paper examines the impact of digital transformation on the breadth of R&D internationalization under different conditions in terms of market and non-market characteristics of firms, thus broadening the understanding of the boundaries of its role. (4) The large-scale panel data adopted in this study enhances the representativeness, precision and scientificity of the study.

2. Theoretical analysis and research hypothesis

2.1. Impact of digital transformation on the breadth of R&D internationalization

Digital transformation(DT) is defined as the fundamental reconfiguration of a company's business model, organizational structure, operational processes, and market strategy through the application of innovative digital technologies [2]. Based on Nambisan's research, these digital technologies can be categorized into three distinct but related categories: digital artifact, digital platform, and digital infrastructure, as shown in Table 1 [9]. The wide application of these digital technologies have profoundly influenced the strategic choices of firms, enhancing their ability to execute R&D internationalization strategies and their practical feasibility. The R&D internationalization strategy determines whether firms are able to enhance their independent R&D capabilities and integrate into global innovation networks. This key strategic choice involves a number of major decisions, including whether to initiate cross-border R&D collaborations overseas and set up overseas R&D centers, etc., and the implementation of this strategy also faces many costs. For example, at the early phase of R&D internationalization, the outsider disadvantage cost due to the difficulty of quickly integrating into the culture and system of the target country and the resistance of its R&D internationalization behaviors by the target country's government and firms makes it more difficult for firms to identify and assimilate the target country's technologies, which leads to a decline in the efficiency of R&D internationalization [10]. The borderlessness and strong interactivity of digital technologies mitigate the cost effects associated with overseas R&D strategies. For

example, existing research shows that DT exerts a substantial impact on reducing the cost of outsider disadvantage faced by firms in the internationalization process [11]. Through digital transformation, enterprises are able to establish digital operation platforms in target countries, use digital twin technology to improve the efficiency of data flow along the entire value chain of products, and promote data interoperability in the innovation chain and supply chain, so as to achieve comprehensive synergy across specialties, organizations, and geographies, and mitigate the outsider disadvantage. So how does DT further affect the breadth of internationalization of enterprise R&D?

Table 1. Classification of digital technologies

categorization	define	account for
digital artifact	A digital artifact is an element of a novel product or service, like an application or media content, that delivers distinct functionality or value to its users. (Ekbia, 2009).	Can exist as independent software or hardware components within physical devices, or as integral parts of a larger ecosystem of products operating on digital platforms. Examples include apps in smart devices, thermostats in home devices, sensors, etc.
digital platform	A digital platform is a framework composed of shared and standardized services and architectures that support complementary products, such as digital artifacts.(Parker et al., 2016).	Architectures that enable applications to run, such as IOS and Android.
digital infrastructure	Digital infrastructure is characterized as a collection of digital technology tools and systems that enable communication, collaboration, and computation.(Nambisan, 2017).	Examples encompass systems and tools for data analytics, interactive platforms, online communities, social media.

R&D internationalization breadth(IRDB), that is, the extent of geographic distribution of R&D sub-institutes set up by firms overseas[8]. First, digital transformation directly expands the geographic and technological scope of firms' R&D by facilitating access to and application of digital technologies. Using advanced digital technologies such as machine learning, firms are able to collect and analyze vast quantities of data globally to identify new R&D opportunities and trends[12]. This data includes market data, consumer behavior, competitor analysis, and technology trends. This information is critical for companies to develop a global R&D strategy, as it provides key insights into which regions may be hotspots for new technology or product development. This data-driven R&D strategy not only enhances a company's responsiveness to global market dynamics, but also enables it to conduct R&D programs in a wider range of countries and regions.

Second, digital transformation enhances the market adaptability of firms, enabling them to quickly adjust their R&D strategies to suit market demands and regulatory environments in different countries and regions. Through real-time market analysis and feedback mechanisms, firms can quickly understand product needs and technological changes in local markets and adjust their R&D direction and innovation priorities accordingly[13]. This flexibility is a direct outgrowth of digital technology, which allows firms to flexibly deploy their R&D resources globally, thereby increasing the IRDB.

In summary, digital transformation has significantly boosted the breadth of internationalization of R&D by improving technology access and market adaptability, enabling enterprises to carry out technological innovation and product development on a broader global scale. This not only brings enterprises greater market opportunities, but also supports their long-term technological competitiveness and market position. Building on the preceding analysis, this paper puts forward Hypothesis 1:

H1: DT has a positive effect on the breadth of internationalization of firms' R&D.

2.2.Analysis of the mechanism of the impact of digital transformation on the breadth of internationalization: the mediating role of dynamic capabilities

While there is evidence that DT has a positive effect on the breadth of firms' internationalization, the specific mechanisms of this effect have not yet been fully explored. Against the backdrop of the increasing integration of digital technologies with the real economy, firms that successfully expand in the global market need to ensure that their resources and capabilities can cope with the dynamic complexity of the international competitive environment. Dynamic capabilities theory suggests that with the aim of securing a sustainable competitive edge, in a dynamic environment, firms must effectively integrate and allocate their resources to cope with rapid changes in markets and technologies[14]. Considering the ever-changing nature of international markets and the complexity of competition, this study will further explore how digital transformation affects firms' dynamic capabilities and, through these capabilities, their internationalization breadth.

Dynamic capability is the ability of a firm to adapt to a rapidly changing environment by integrating, structuring and restructuring both internal and external resources [15]. According to Wang and Ahmed's (2007) theory, dynamic capabilities can be categorized into three basic dimensions: absorptive, adaptive and innovative capabilities[16]. Digital transformation has the following effects on the three dimensions of dynamic capabilities. First, absorptive capacity is defined as a firm's ability to identify the value of external knowledge, incorporate it, and utilize it in business practices. Driven by digitalization, firms are able to reach and absorb external knowledge more effectively through multiple channels and tools. For example, cloud computing technology enables organizations to store and process big data from around the world, while advanced analytics tools help them extract valuable information and trends from this data, improving the quality and speed of decision-making. Social media platforms and professional networks such as LinkedIn and ResearchGate provide a wealth of industry insights and the latest research, enabling organizations to quickly access cutting-edge industry knowledge and technology. In addition, by participating in open innovation and crowdsourcing platforms, companies can access ideas and solutions directly from global innovators, all of which greatly enrich their knowledge base and application capabilities.

Second, adaptive capacity emphasizes the ability of firms to rapidly allocate and reorganize resources when identifying and exploiting market opportunities. Digital transformation enables enterprises to respond quickly to market changes by providing flexible technology infrastructure and tools. Cloud services allow organizations to use computing resources on demand, enhancing the scalability and flexibility of their business. This means that organizations can quickly scale up or down their operations in response to fluctuations in market demand. Digital tools, such as CRM and ERP systems, enable companies to monitor market dynamics and internal operations in real time, allowing them to adjust market strategies and optimize supply chains faster. For example, through real-time data analytics, companies can instantly identify bottlenecks in the supply chain or sudden increases in market demand and quickly make adjustments, such as changing suppliers or adjusting production lines.

Finally, innovativeness is the ability of a firm to create innovative products, launch novel services, or explore emerging markets. Digital technologies provide

powerful support for product development, accelerating everything from automated design to market testing. These technologies enable companies to rapidly iterate on product prototypes, optimize based on consumer feedback, and shorten the time from concept to market. In addition, digital platforms enable companies to tap into global innovation resources and facilitate collaboration among cross-border teams through online collaboration tools and platforms. This collaboration is not limited to internal companies, but also includes cooperation with external partners, universities and research institutions, bringing new ways of thinking and innovation methods to enterprises, thus driving the success of innovation projects.

In summary, the dynamic capabilities of firms that have implemented DT are higher compared to firms that have not implemented DT. In view of this, the following hypotheses are put forward:

H2: DT has a positive impact on firm dynamic capabilities.

H2a: DT positively affects firms' absorptive capacity.

H2b: DT is positively affecting the adaptive capacity of organizations.

H2c: DT is positively impacting the ability of companies to innovate.

The impact of the three dimensions of dynamic capabilities on IRDB is as follows. First, absorptive capacity enables firms to identify, assimilate and apply information and technologies from the global pool of knowledge that are valuable for their innovations. The level of this capability directly affects the efficiency of firms in acquiring and utilizing new knowledge on a global scale. For example, an enterprise can acquire the latest scientific research results and technologies by cooperating with internationally renowned R&D organizations and transform this knowledge into its core competencies. By absorbing this external knowledge, an enterprise can better orient its product development and enhance the relevance and effectiveness of its R&D activities, thus helping it to expand the breadth of its R&D in the global market.

Second, adaptive capacity reflects the ability of an enterprise to quickly adjust its resources and strategies to seize opportunities in the face of market and technological changes. Adaptability is particularly important in the context of R&D internationalization, as it determines the ability of firms to respond effectively to differences in regulations, culture and consumer preferences in different national markets. Firms with high adaptive capacity are able to quickly modify their R&D strategies and product designs to meet the specific needs of different regional markets [11][12]. For example, a firm's success in the European market may not be directly replicated in the Asian market, and thus it needs to adapt its product characteristics to suit the tastes and needs of local consumers through localized research and development. This ability to adapt flexibly not only improves a firm's success rate in entering new markets, but also accelerates its global market expansion and harmonization of technical standards.

Finally, high innovative capacity often implies high R&D investment. Companies with significant R&D expenditure usually have the financial resources to set up R&D centers globally, enabling them to capture strategically important technological and market information in different geographic locations, thus creating a wider geographical distribution. Such a global presence enables firms to respond quickly to technological changes and market demands in markets around the world, enhancing their international competitiveness. Moreover, companies with high innovation capacity usually have close partnerships with multiple R&D networks and research institutions around the world. These partnerships not only provide companies with access to cutting-edge technology and research, but also enable them to access and

share innovation resources around the world. Through these networks, firms are able to screen and identify the most strategic locations for R&D centers globally in order to better integrate and leverage local research and technology resources.

As mentioned above, digital transformation improves the absorptive, adaptive and innovative capacities of firms, i.e. digital transformation enhances the dynamic capabilities of firms. When the dynamic capability is high, enterprises are not only more insightful about international market opportunities, but also more tolerant of risks and uncertainties in multinational expansion. This helps enterprises to obtain R&D resources to carry out R&D internationalization strategies in the dynamic and complex international market, and to realize the dynamic matching between enterprise capabilities and the international competitive environment. Therefore, dynamic capabilities help enterprises explore international market opportunities and conduct overseas R&D more effectively, i.e., DT has an impact on R&D internationalization by shaping enterprises' dynamic capabilities. In summary, dynamic capabilities have a mediating role in the impact of digital transformation on IRDB. Based on the above analysis, the following hypotheses are proposed:

H3: Dynamic capabilities mediate between firms' digital transformation and firms' R&D internationalization breath.

H3a: Absorptive capacity mediates between firms' digital transformation and R&D internationalization breath.

H3b: Adaptive capacity mediates between firms' digital transformation and R&D internationalization breath.

H3c: Innovation capabilities mediate between firms' digital transformation and R&D internationalization breath.

3. Research design

3.1. Data sources and sample selection

In this paper, the listed companies in Shanghai and Shenzhen A-shares in the manufacturing industry from 2008 to 2021 are taken as the research object, and the data are mainly from the database of Cathay Pacific (CSMAR) and Juchao Information Network. The CSMAR database provides a wide range of financial data and information on overseas direct investment of listed companies, which is one of the key data sources to study the overseas investment behavior of Chinese companies. However, since this database does not contain corporate annual reports, this study further supplemented with data from Juchao Information Network to obtain corporate annual reports, which are used to construct corporate digital transformation indicators. Juchao Information Network (http://www.cninfo.com.cn) is a platform for public disclosure of important information such as yearly financial statements of listed companies, social responsibility reports and M&A announcements. After extracting the data through Python crawler technology, this study eliminates the annual report samples that cannot be read due to formatting problems, and after merging them with the data from GuotaiAn, the data are screened based on the subsequent criteria: (1) eliminating the samples of the enterprises that are labeled as ST and PT; (2) eliminating the samples of the missing data; and (3) eliminating samples of the balance sheet ratio that is greater than one. Finally, 8965 observations from 1619 enterprises are obtained.

3.2. Measurement of variables

3.2.1 Explanatory variable: internationalization breadth of R&D (IRDB).

IRDB is generally measured based on the geographic diversity of overseas R&D subsidiaries [7][8], and this paper draws on the treatment of Wang Molin et al. (2022), which expresses the geographic diversity of overseas R&D subsidiaries based on the number of regions and countries covered by overseas R&D subsidiaries owned by the enterprise in the current year as a measure of the breadth of R&D internationalization [17].

3.2.2 Explanatory variable: digital transformation (DT).

Citing the research methodology used by Wu Fei and colleagues (2021), this study constructed a summary chart covering the core terms of digital transformation (see Table 2)[18]. The annual reports of listed companies were crawled from Juchao Information Network through Python and the number of times these core terms appeared was extracted from them. By aggregating the frequency of occurrence of these keywords, the index of enterprise digital transformation was calculated. In view of the "right-skewed" nature of the index, the summed word frequencies were further taken as (+1) and natural numbers to smooth the data distribution [18].

Table 2. List of digital transformation keywords

categorization	byword
artificial intelligence (AI) technology	Artificial Intelligence, Machine Learning, Deep Learning, Neural Networks, Natural Language Processing, Voice Assistants, Speech Recognition, Image Recognition, Data Mining, Intelligent Algorithms, Intelligent Automation, Robotics, Robotic Process Automation (RPA)
big data technology	Big Data Analytics, Data Mining, Data Visualization, Data Governance, Data Warehousing, Data Integration, Data Science
Cloud Computing Technology	Cloud services, cloud platforms, cloud storage, cloud security, virtualization technologies, containerization, cloud architecture
blockchain technology	Distributed ledgers, cryptocurrencies, consensus mechanisms, decentralization, on-chain transactions, digital wallets, blockchain security, tokenization
Internet technology	Mobile Internet, Industrial Internet, Mobile Internet, Internet Healthcare, Internet Finance
Internet of Things (IoT) technology	IoT Platform, Sensors, Smart Devices, Remote Monitoring, Embedded Systems, Connected Cars, Smart Cities, Home Automation, Industrial IoT

3.2.3 Mediating variable: dynamic capabilities (DC)

Utilizing the measurement methods of Yang Lin et al. (2020), the dynamic capabilities of firms are measured in the following three dimensions[19]:

(1) Innovative capacity is measured using a pair of indicators, namely, the intensity of each company's R&D expenditures and the percentage of skilled employees. The specific operation is to implement standardization of these two indicators to ensure the comparability of indicators, and after summing up to get the comprehensive value

of innovation capacity, namely:

$$IC = \frac{X_{RD} - \min_{RD}}{\max_{RD} - \min_{RD}} + \frac{X_{IT} - \min_{IT}}{\max_{IT} - \min_{IT}}$$

(2) Absorptive capacity, calculated through the intensity of R&D expenditure, namely, the proportion of annual R&D expenses to the operating revenues of the sample firms.

(3) Adaptive capacity, the flexibility in resource allocation within the sample companies is indicated by the coefficient of variation across three key expenditures: expenditures of R&D, capital investment and advertising, and then measure the adaptive capacity of the enterprises. To align the value of the coefficient of variation with the adaptive capacity, this study applies the negative value of the coefficient of variation. Consequently, a larger value of the adjusted coefficient indicates a stronger adaptive capacity within the enterprise. Finally, the scores of the three dimensions are standardized and averaged, and the higher the score means the stronger the dynamic ability of the enterprise.

3.2.4 Control variables.

According to related studies, the firm size (Size, the natural logarithm of total assets), growth (Growth, the growth rate of total operating income), gearing ratio (Lev),cash flow (Cash, the proportion of net cash flow from operating activities to overall assets), return on assets (ROA) are selected[20][21]. In addition, the following executive team characteristics variables are added as control variables due to the important influence of the executive team on the firm's R&D internationalization decisions: (6) Equity Concentration (TOP1), which is calculated as the percentage of shares owned by the firm's largest shareholder. (7) Dual (Dual), whether the roles of chairman and general manager are occupied by the same individual. (8) InDep, measured by the percentage of independent directors relative to the total board membership. (9) Overseas background of executives (Overseaback), whether any of the current directors and supervisors have an overseas background (including former and current overseas studies and overseas employment). Furthermore, this study accounts for fixed effects related to Industry and Year. See Table 3 for a description of the main variables.

Table 3. Description of main variables

Variable type	variable name	notation	define
explanatory variable	R&D Internationalization Breadth	*IRDB*	Number of regions or countries covered by overseas R&D subsidiaries owned by the enterprise in the year.
explanatory variable	Digital Transformation	*DT*	Number of keywords related to digital transformation in annual reports of companies (+1) taken as natural logarithms.
intermediary variable	dynamic capability	*DC*	The scores on the three dimensions of absorptive capacity, adaptive capacity and innovative capacity are standardized and averaged out.
	absorptive capacity	*DC_Ab*	Ratio of annual R&D expenditures to operating revenues of enterprises.
	adaptive	*DC_Ad*	Coefficients of Variation of 3 Major Expenditures of Firms on Annual R&D, Capital, and Advertising.
	innovation capacity	*DC_Ino*	Normalized sum of firms' R&D expenditure intensity and share of skilled employees.

control variable	Enterprise size	*Size*	Natural logarithm of total assets for the year.
	return on assets	*ROA*	Ratio of net profit to asset balance.
	growth	*Growth*	Gross operating income growth rate.
	gearing	*Lev*	Ratio of total liabilities to total assets
	cash flows	*Cash*	Ratio of net cash flows from operating activities to total assets.
	shareholding concentration	*TOP1*	Shareholding of the largest shareholder.
	Dual	*Dual*	Whether the roles of chairman and general manager are occupied by the same individual, yes 1, no 0.
	Ratio of sole director	*InDep*	The percentage of independent directors relative to the total board membership.
	Overseas background of executives	*Overseaback*	Whether any of the current directors and supervisors of the high school have an overseas background (including former and current overseas studies and overseas employment), with a value of 1 for yes and 0 for no.

3.3. Modeling

Among the many methods for testing the mediating effect, the stepwise method has been widely used in social science research because of its intuitive and easy-to-use characteristics. Introduced by Baron and Kenny in 1986, the stepwise regression technique is a well-established method for examining mediating effects. It follows a clear, sequential process, starting with the investigation of how the independent variable affects the mediator. Subsequently, it assesses the impact of the mediator on the dependent variable. This methodical approach ensures logical clarity in testing each step of the mediation. Initially, the relationship between the independent and dependent variables is examined (path c). Next, the influence of the independent variable on the mediator is analyzed (path a). Finally, the impact of the mediator on the dependent variable is assessed, while accounting for the influence of the independent variable (path b). Only when the regression coefficients for all three paths are significant can the existence of a mediating effect be recognized. Although this stepwise method has been questioned to some extent, mainly because it is more sensitive to the distributional assumptions of the sample data and may reduce the statistical efficacy of the test when there are more than one mediating variable, the application of the stepwise method is still justified in empirical research. This paper chooses to adopt the stepwise method to test the mediating effect, on the one hand, because this method can provide a simple and intuitive testing procedure for this study, which is easy to be understood and reproduced by readers; on the other hand, in the preliminary data analysis, the stepwise method can provide enough information to assess the reasonableness of the research model and provide a basis for possible model revision. In addition, the results of the stepwise method can also be used as a preliminary reference for other complex tests such as Bootstrap method or Sobel test.

$$IRDB = \beta_1 DT_{i,t} + \sum \beta_m C_{i,t} + \beta_0 + \epsilon_{i,t} \quad (1)$$

$$DC = \beta_1 DT_{i,t} + \sum \beta_m C_{i,t} + \beta_0 + \epsilon_{i,t} \quad (2)$$

$$IRDB = \beta_1 DT_{i,t} + \beta_2 DC_{i,t} + \sum \beta_m C_{i,t} + \beta_0 + \epsilon_{i,t} \quad (3)$$

where β_m is the regression coefficient of the control variable, and β_0 is the intercept of the model, and $C_{i,t}$ is the added control variable, and $\epsilon_{i,t}$ is the random perturbation term. Equation (1) tests the effect of enterprises' DT on the breadth of R&D internationalization, equation (2) tests the effect of DT on enterprises' dynamic capabilities, and equation (3) tests whether dynamic capabilities play a mediating role in the effect of enterprises' DT on the breadth of internationalization. Since some sample firms did not set up R&D subsidiaries overseas, resulting in zero values in the dependent variable, this paper chose to use the Tobit regression model to conduct the analysis. This model is suitable for dealing with restricted dependent variables and can provide unbiased and consistent estimation results, thus reflecting the relationship between variables more accurately[22]. In addition, to avoid the impact of extreme values and outliers on the regression results, the main continuous variables in the model were subjected to 1% shrinkage.

4. Empirical analysis

4.1.Descriptive analysis and matrix of correlation coefficients

The variables listed in the table show that the average value of the Internationalization Breadth of R&D (IRDB) is 0.328, which implies that the average level of international R&D activities of the firms in the sample is relatively low. The mean value of DT is 1.466 with a standard deviation of 1.316, suggesting that there is significant variability in the degree of digital transformation across the companies in the sample. There is a positive and statistically significant relationship between digital transformation (DT) and R&D internationalization breadth (IRDB) and dynamic capabilities (DC), aligning with our hypothesis that as DT and dynamic capabilities increase, their R&D internationalization breadth also increases.

Table 4. Results of descriptive statistics

VarName	Obs	Mean	SD	Min	Median	Max.
IRDB	8965	0.328	0.833	0.000	0.000	12.000
DT	8965	1.466	1.316	0.000	1.386	6.139
DC	8965	0.002	1.007	-0.671	-0.143	54.780
Size	8965	22.335	1.183	19.630	22.202	26.452
ROA	8965	0.048	0.065	-0.373	0.045	0.257
Growth	8965	0.187	0.349	-0.657	0.131	4.024
Lev	8965	0.410	0.181	0.031	0.411	0.907
Cash	8965	0.055	0.063	-0.199	0.052	0.282
TOP1	8965	33.522	14.097	8.087	31.598	75.843
Dual	8965	0.345	0.475	0.000	0.000	1.000
InDep	8965	37.753	5.398	28.570	36.360	60.000
Overseaback	8965	0.668	0.471	0.000	1.000	1.000

Table 5 demonstrates the matrix of correlation coefficients between the main variables. The correlation coefficient between digital transformation (DT) and R&D internationalization breadth (IRDB) meets the criteria for statistical significance, signifying that the level of DT is positively related to the firm's R&D internationalization breadth. Similarly, the correlation coefficient between Dynamic Capability (DC) and Digital Transformation (DT) is significant at the 1% significance level, implying that a higher level of DT is positively associated with a stronger Dynamic Capability. Further looking at the sub-dimensions of dynamic capability, the correlation coefficients between absorptive capability (DC_Ab), adaptive capability (DC_Ad) and digital transformation (DT) are all exhibit significance at the 1% level, but correlation coefficient between innovative capability (DC_Ino) and digital transformation (DT) is not significant.

Table 5. Matrix of correlation coefficients

	IRDB	DT	DC	DC_Ab	DC_Ad	DC_Ino
IRDB	1.000					
DT	0.087***	1.000				
DC	0.104***	0.111***	1.000			
DC_Ab	0.104***	0.111***	1.000***	1.000		
DC_Ad	0.067***	0.077***	0.112***	0.112***	1.000	
DC_Ino	-0.000	0.174***	0.132***	0.132***	0.130***	1.000

4.2. Main and mediating effects tests

Table 6 demonstrates the results of the stepwise regression using the stepwise approach to test for mediating effects. Model (1) is the baseline model that does not include the main explanatory and mediating variables and controls only for the other variables. Model (2) adds digital transformation to model (1), DT has a significant positive effect on IRDB (coefficient of 0.174, $p<0.01$), which supports H1's hypothesis that digital transformation facilitates the breadth of firms' R&D internationalization. Model (3) further considers the effect of DT on dynamic capabilities, and the findings indicate that DT is positively related to dynamic capabilities (coefficient of 0.086, $p<0.01$), which supports the hypothesis of H2, that digital transformation enhances firms' dynamic capabilities. Finally, model (4) is the full model, which considers the joint effect of digital transformation, dynamic capabilities and their effect on IRDB. The findings indicate that digital transformation still has a significant positive effect on IRDB, and the coefficient of digital transformation decreases (coefficient of 0.165, $p<0.01$) and the coefficient of dynamic capabilities is 0.177 and markedly non-zero, which implies that dynamic capabilities partially mediate the relationship between DT and IRDB, which is in line with the expectation of H4.

Table 6 Mediated effects test

VARIABLES	(1) tobit IRDB	(2) tobit IRDB	(3) OLS DC	(4) tobit IRDB
DT		0.174***	0.086***	0.165***
		(0.033)	(0.027)	(0.033)
DC				0.177***
				(0.029)
Lev	-0.997***	-0.921***	-1.520***	-0.659**
	(0.264)	(0.263)	(0.275)	(0.265)
Cash	-1.717**	-1.598**	-0.653	-1.425**
	(0.669)	(0.667)	(0.428)	(0.665)
TOP1	0.004	0.004*	-0.006***	0.005*
	(0.003)	(0.003)	(0.002)	(0.003)
Dual	0.030	0.016	0.053	0.001
	(0.077)	(0.077)	(0.061)	(0.077)
InDep	0.009	0.008	-0.004	0.009
	(0.007)	(0.007)	(0.006)	(0.007)
Overseaback	0.295***	0.285***	-0.048	0.275***
	(0.078)	(0.078)	(0.055)	(0.078)
Constant	-12.250***	-11.502***	-1.321	-11.505***
	(1.137)	(1.137)	(0.827)	(1.132)
Industry	YES	YES	YES	YES
Year	YES	YES	YES	YES
log likelihood	-6841.201	-6827.007		-6809.192
LR chi (2)	905.12	933.50		969.13
R-squared			0.122	
N	8,965	8,965	8,965	8,965

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.3.Mediation effect test for the dynamic capability sub-dimension

Model (2) in Table 6 has demonstrated that the main effect holds, and Models (1) to (3) test the relationship between digital transformation and the three sub-dimensions of dynamic capabilities: absorptive capacity (DC_Ab), adaptive capacity (DC_Ad), and innovative capacity (DC_Ino) (in order to test the second step of the development). The findings indicate that digital transformation maintains a significantly positive impact on both opportunity-awareness ability and environmental adaptation ability, while the relationship on innovation ability is not significant. Models (4) to (6) are tests for the dimensions of dynamic capabilities to play a mediating role between DT and IRDB. With the addition of absorptive capacity, the coefficient of DT on IRDB decreases from 0.174 to 0.165, and the coefficient of absorptive capacity is significant (coefficient of 2.305, $p<0.01$), suggesting that opportunity-perceiving capacity acts as a partial mediator. Wintin the model of adaptive capacity, the coefficient of DT on IRDB decreases from 0.174 to 0.166, and the coefficient of adaptive capacity is significant (coefficient of 0.502, $p<0.01$), again showing its mediating role. In summary, H2a, H2b, H3a, and H3b were validated.

Table 7. Mediation effect test for dynamic capability sub-dimension (sequential test method)

VARIABLES	OLS			tobit		
	(1)	(2)	(3)	(4)	(5)	(6)
	DC_Ab	DC_Ad	DC_Ino	IRDB	IRDB	IRDB
DT	0.004***	0.012***	-0.002	0.165***	0.166***	0.174***
	(0.001)	(0.004)	(0.006)	(0.033)	(0.033)	(0.033)
DC_Ab				2.305***		
				(0.379)		
DC_Ad					0.502***	
					(0.135)	
DC_Ino						0.091
						(0.097)
Constant	0.064***	-0.232	-0.186	-11.624***	-11.294***	-11.475***
	(0.018)	(0.149)	(0.190)	(1.133)	(1.134)	(1.137)
Observations	8,965	8,965	8,965	8,965	8,965	8,965
R-squared	0.122	0.151	0.425			
Log likelihood				-6809.1918	-6820.1024	-6826.5587
control variable	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses,*** p<0.01, ** p<0.05, * p<0.1

4.4. Robustness tests

To further test the robustness of the findings, this paper also lags the explanatory variables for analysis. To address the issue of endogeneity arising from possible mutual causation among the independent variables and the dependent variables, this paper uses the t-period explanatory variables and the t+1-period explained variables to conduct regression analysis, and the regression outcomes are presented in Table 8. The sign and significance of the regression coefficients of DT and the dynamic capabilities are basically consistent with Table 6, indicating that mutual causation is less disruptive to the results of the research.

Table 8. Variable lagged one period test results

	(1) tobit	(3) tobit	(5) OLS	(6) tobit
VARIABLES	F. IRDB	F. IRDB	DC	F. IRDB
DT		0.164***	0.049***	0.145***
		(0.038)	(0.014)	(0.038)
DC				0.312***
				(0.049)
Constant	-11.091***	-10.387***	0.169	-10.434***
	(1.289)	(1.292)	(0.234)	(1.284)
Controls	YES	YES	YES	YES
Observations	7,093	7,093	8,965	7,093
Log likelihood	-5518.1874	-5509.1233		-5489.2726
R-squared			0.122	

4. Conclusion and exploration

In this study, we explore how digital transformation affects firms' R&D internationalization breadth through the mediation of dynamic capabilities. The study shows that with the widespread application and deeper integration of digital technologies, digital transformation brings higher market adaptability and technology access capabilities to firms, which drives the geographic diffusion of R&D activities. In addition, digital transformation enhances firms' dynamic capabilities, including absorptive and adaptive capacities, which provide a solid foundation for international expansion. These capabilities enable firms to better identify opportunities in international markets, respond quickly to market changes, and effectively integrate global innovation resources. The mediating role of dynamic capabilities is particularly significant in the highly competitive and ever-changing international market environment. This transformation not only drives technological innovation, but also helps companies capture market opportunities across borders and optimize resource allocation globally. Therefore, digital transformation strategies and dynamic capability development of enterprises are important for enhancing their international competitiveness and market position.

To bridge the gap between these findings and their practical application, we suggest several actionable strategies for businesses aiming to leverage digital transformation for international R&D expansion. First, firms should invest in technology that enhances data analytics and collaboration tools to improve their absorptive capacity, thereby enabling them to identify and assimilate useful knowledge from global markets swiftly. For instance, adopting cloud-based platforms can facilitate smoother collaboration across international teams, enhancing the integration of diverse knowledge bases and speeding up innovation processes.

Second, to capitalize on the adaptive capacity, firms can implement agile methodologies in their R&D processes. This approach allows businesses to quickly adjust their R&D strategies in response to changes in the international market, ensuring that they remain competitive and can take advantage of emerging opportunities.

Finally, firms should foster an organizational culture that supports continuous learning and flexibility. This can be achieved through regular training programs focused on emerging technologies and market trends, thereby enhancing the dynamic capabilities required for successful internationalization.

Our study provides new evidence on the relationship between digital transformation and the internationalization of R&D and offers practical guidance on how firms can leverage their dynamic capabilities when implementing digital strategies. These findings have significant theoretical and practical value for understanding how digital transformation affects firms' internationalization strategies and global competitiveness, offering a clear pathway for businesses aiming to enhance their global market presence through digital means.

References

[1] Gao F, Lin C, Zhai H. Digital transformation, corporate innovation, and international strategy: Empirical evidence from listed companies in China[J]. Sustainability, 2022, 14(13): 8137. DOI:10.3390/su14138137.

[2] Vial G. Understanding digital transformation: a review and a research agenda[J]. Managing digital transformation, 2021: 13-66. DOI:10.4324/9781003008637-4.

[3] Banalieva E R, Dhanaraj C. Internalization theory for the digital economy[J]. Journal of International Business Studies, 2019, 50: 1372-1387. DOI: 10.1057/s41267-019-00243-7.
[4] Pergelova A, Manolova T, Simeonova-Ganeva R, Yordanova D. Democratizing entrepreneurship? Digital technologies and the internationalization of female-led SMEs[J]. Journal of Small Business Management, 2019, 57(1): 14-39. DOI:10.1111/jsbm.12494.
[5] Cassetta E, Monarca U, Dileo I, Di Berardino C, Pini M. The relationship between digital technologies and internationalization. Evidence from Italian SMEs[J]. Industry and Innovation. 2019, 27(4): 311-339. DOI:10.1080/13662716.2019.1696182.
[6] He A, Zhong Jingwen. R&D internationalization and firms' innovation performance-the moderating role of absorptive capacity and geographic diversity[J]. Southern Economy, 2018, 37(10): 92-112. DOI:10.19592/j.cnki.scje.360728.
[7] Hurtado-Torres N E, Aragón-Correa J A, Ortiz-de-Mandojana N. How does R&D internationalization in multinational firms affect their innovative performance? The moderating role of international collaboration in the energy industry[J]. International Business Review, 2018, 27(3): 514-527. DOI:10.1016/j.ibusrev.2017.10.003.
[8] Hsu C W, Lien Y C, Chen H. R&D internationalization and innovation performance[J]. International business review, 2015, 24(2): 187-195. DOI: 10.1016/j.ibusrev.2014.07.007.
[9] Nambisan S. Digital entrepreneurship: towards a digital technology perspective of entrepreneurship[J]. Entrepreneurship theory and practice, 2017, 41(6): 1029-1055. DOI: 10.1111/etap.12254.
[10] Li Mei, Yu Tianjiao. R&D internationalization and parent firm innovation performance: a review of the literature and prospects for future research[J]. Management Review, 2020, 32(10): 106. DOI:10.14120/j.cnki.cn11-5057/f.2020.10.009.
[11] Yang Z, Hou Y, Li D, Wu C. Equilibrium effects of open innovation networks in the "double cycle" of Chinese firms: An examination based on digital empowerment and organizational flexibility[J]. Management World. 2021, 37(11): 184-205. DOI:10.19744/j.cnki.11-1235/f.2021.0178.
[12] Chen J.L., Zhao Y.X., Lin Song. Can Smart Manufacturing Promote Firms' Innovation Perform ance? [J]. Foreign Economy and Management, 2021, 43(9): 83-101. DOI:10.16538/j.cnki.fem.20 210802.101.
[13] Elia S, Giuffrida M, Mariani M M, Bresciani S. Resources and digital export: an RBV perspective on the role of digital technologies and capabilities in cross border e-commerce[J]. Journal of Business Research, 2021, 132: 158-169. DOI: 10.1016/j.jbusres.2021.04.010.
[14] TEECE D J, PISANO G, SHUEN A. Dynamic Capabilities and Strategic Mangement [J]. Strat egic Management Journal, 1997, 20: 986-1014. DOI:10.1002/(sici)1097-0266(199708)18:7<509::a id-smj882>3.0.co;2-z.
[15] TEECE D J. Explicating dynamic capabilities: the nature and microfoundations of sustainable enterprise performance [J]. Strategic Management Journal, 2007, 28(13): 1319-1350. DOI:10.1002/smj.640.
[16] WANG C L, AHMED P K. Dynamic Capabilities: a Review and Research Agenda [J]. International Journal of Management Reviews, 2007, 9: 31-51. DOI:10.1111/j.1468-2370.2007.00201.x.
[17] Wang M, Song Y, Yan H, Zhang X. A study on the impact of digital transformation on firms' internationalization breadth: the mediating role of dynamic capabilities [J]. Foreign Economics and Management, 2022, 44 (05): 33-47. DOI:10.16538/j.cnki.fem.20211212.204.
[18] WU Fei, HU Hui Zhi, LIN Hui Yan, et al. Corporate digital transformation and capital market performance - Empirical evidence from stock liquidity[J]. Management World, 2021, 37(7): 130-144. DOI:10.19744/j.cnki.11-1235/f.2021.0097.
[19] YANG Lin, HE Xin, GU Hongfang. Executive team experience, dynamic capabilities and corporate strategic mutations: the moderating effect of managerial autonomy[J]. Management World, 2020, 36(6): 168-188. DOI:10.19744/j.cnki.11-1235/f.2020.0093.
[20] Zhan Jun, Liu Ying. Digital Transformation, Dynamic Capabilities, and Servitization of Manufacturing — Based on the Moderating Effect of Business Environment. Economy and Management, 2024, 38(3): 1-9. [Online Journal].http://kns.cnki.net/kcms/detail/13.1032.F.20240428.0901.010.html.
[21] Duan Huayou, Huang Xuebin. Digital Transformation, R&D Innovation, and Corporate Value — Based on Empirical Evidence from Mediating Effects. Statistics and Decision, 2024, 40(07): 167-171. DOI:10.13546/j.cnki.tjyjc.2024.07.029.
[22] Dong Jing, Wang Li, Wu You. Venture capital involvement and the internationalization of entrepreneurial enterprises - an empirical study based on my country's high-tech listed companies [J]. Financial Research, 2017, 43(04): 120-132. DOI: 10.16538/ j.cnki.jfe.2017.04.010.