Digital Transformation, Executive Team Heterogeneity and Enterprise Innovation

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Abstract. Digital transformation has become a key factor to enhance the competitiveness of manufacturing enterprises in the background of rapid changes in communication technology and the outbreak of COVID-19.Based on the data of A-share listed manufacturing enterprises in Shanghai and Shenzhen from 2014 to 2021, this paper empirically tested the effect and impact path of digital transformation on enterprise innovation, and tested the moderating role of senior management team heterogeneity in the process of digital transformation driving enterprise innovation. The results show that digital transformation can significantly drive the innovation of manufacturing enterprises, and the heterogeneity of senior management team plays a positive moderating role in this process. Further research shows that compared with the regions with low market informatization, the promotion effect of digital transformation on enterprise innovation is more obvious in the regions with high market informatization.

Keywords: Digital Transformation; Senior Management Team Heterogeneity; Enterprise Innovation; Market Informatization.

1. Introduction

With the development of scientific and technological revolution and the continuous impact of COVID-19 on the real economy, the digital economy has gradually become the driving force of the global economy, playing an irreplaceable role in economic development.Over the past decade, the scale of China's digital economy has expanded from 11 trillion yuan in 2012 to 45.5 trillion yuan in 2022, and its share in GDP has also increased from 21.6% to 39.8%[1].During the 14th Five-Year Plan period, the implementation of the "Intelligence Plus" strategy was one of the strategic goals of China's industrial development, and digital technology has become an important force in enabling industry [2].However, China's manufacturing industry has not taken advantage of the international market by virtue of its resource advantages, but in recent years, due to the extensive development mode, the added value of industrial products is low and the innovation is seriously insufficient.[3]Ye Dingling et al.[4]and Zhang Junqiu et al.[5]believed that digital transformation is one of the important paths of enterprise innovation and development in the information age, and digital transformation is not only a choice but also the only way out for the development of Chinese manufacturing enterprises[6].Therefore, whether digital transformation can effectively promote enterprises to increase innovation input and promote traditional manufacturing enterprises to climb to high-end manufacturing has become a hot spot.

The driving effect of digital transformation on enterprise innovation is not immediate.Some scholars have begun to pay attention to the mechanism of digital transformation on enterprise innovation.First, in terms of value, enterprises can enhance product value on the basis of the original industry and market by re-integrating the value components and value creation process in the Internet value chain[7].Secondly, in terms of cost, the internet platform has a strong resource integration ability to help lower the threshold and reduce the transaction costs of enterprises.[8]According to the Metcalf's law, enterprises reduce their marginal costs by accumulating users, which effectively reduces their innovation costs[43]. Thirdly, in terms of efficiency, under the rapid changes of the new era of telecommunication, the organizational structure of enterprises presents the development trend of flat structure,negotiable decision-making and decentralized ownership,which greatly improves the efficiency of organizational operation[9].Fourth, in terms of innovation capability, digital transformation makes it possible to both front-end excavation and back-end realization of users'

personalized needs, which promotes enterprises to achieve mass customization technology innovation[10].At the same time, under the background of the implementation of "intelligence plus" strategy, scholars have begun to study the mechanism of executive team heterogeneity on enterprise behavior and analyze the impact of executive team heterogeneity on enterprise innovation[11],[12].

Enterprises are the most representative micro subject in the economic system, and the manufacturing industry is the major position of industrial digitalization.Manufacturing enterprises undoubtedly shoulder an important mission in promoting the process of digital industrialization and industrial digitalization.Then,can the digital transformation effectively promote the innovation of manufacturing enterprises?What is the role of executive team heterogeneity in the relationship between digital transformation and innovation in manufacturing enterprises?Based on the above problems, this paper uses the panel data of listed manufacturing enterprises from 2014 to 2021 to conduct empirical analysis, constructs the enterprise digital transformation degree index, and adds the heterogeneity of the executive team as a moderating variable, quantifies the impact of digital transformation on the innovation input of manufacturing enterprises.To provide theoretical support and practical reference for the strategic decision-making of enterprises in digital transformation and the formulation of relevant policies of government departments.

The possible marginal contribution of this paper is to: (1) This paper introduces the concept of degree of digital transformation, and use the method of text recognition to search, match and aggregate the keywords of "digital transformation"in the annual reports of the listed enterprises rather than just judging whether the enterprises introduce information technology, making the conclusions more accurate.(2)Using the heterogeneity of the executive team as a moderating variable to analyze the impact of digital transformation on technological innovation of enterprises, this paper can open the black box of how digital transformation promotes enterprise innovation, provide new empirical guidance for the executive team to make R&D investment decisions, and enrich the existing research.(3)Through heterogeneity analysis, this paper analyzes and compares the characteristics of the impact of digital transformation on enterprise innovation in regions with different degree of market informatization.

2. Literature Review

2.1 Concept Interpretation

2.1.1 Digital Transformation

Digitalization is the cornerstone and core of enterprise informatization, weblification and intelligentization.[13]Digital transformation refers to the use of IT and digital technologies by enterprises to update and transform products, services, business models, strategies and organizational forms, which is specifically manifested as the digitalization of products,services,production processes and management processes,[14] is a response to uncertain technological progress and market fluctuations[15].

2.1.2 Heterogeneity of the Executive Team

The heterogeneity of the senior management team refers to the degree of deviation of demographic characteristics and psychological characteristics among members of the senior management team. Hambrick [16] believes that the demographic characteristics of executives, to some extent, can reflect their psychological characteristics. Some scholars have demonstrated the influences of executive characteristics on corporate behaviors [17]-[20]. The communication, collaboration and decision-making among senior management team members will affect the overall strategy implementation of the senior management team.[21] Therefore, this paper also considers the moderating effect of executive team heterogeneity on the relationship between digital transformation and innovation.

2.1.3 Enterprise Innovation

Schumpeter[22] put forward the disruptive innovation theory which can "realize the recombination of production factors" in *The Theory of Economic Development*, namely when the industry can't survive profit level,enterprises will spontaneously make a breakthrough in innovation,by breaking the market equilibrium, reforming the inefficient production pattern,introducing efficient technology, optimizing the structure and workflow comprehensively,so as to form a new economic growth engine for the industry[23].

2.2 The Impact Path of the Degree of Digital Transformation on Manufacturing Enterprises

Chen Liping and Liu Liang believed that traditional manufacturing enterprises have problems to be solved, such as outdated traditional production organization mode, serious lack of R&D investment and slow industrial form renewal[24].And the emergence of digital transformation is expected to alleviate these problems.The existing research analyzes the effect of digital transformation of manufacturing enterprise from the following aspects: from the angle of production,Zhu Jianliang,Wang Tingcai et al.argues that digital transformation can improve the production of traditional supply chain, so the flow of goods and information, and the resource use efficiency will be improved[25];Zhang Hengmei,Li Nanxi et al.found that manufacturing enterprises can use the Internet of Things to improve the efficiency of customized production, significantly reduce the cost of customized production, and carry out visual monitoring management of products and production equipment[26].From the perspective of services, Peng Zhao proposed that digital transformation can drive the development of relevant producer services such as big data storage, software services, system integration services and cloud computing in manufacturing enterprises[27];At the same time, enterprises can accelerate the information construction of commodity circulation, so as to improve the level of after-sales service[10].From the perspective of sales, Jiao Yong et al. believe that enterprises can make full use of cloud computing algorithms and big data resources to promote the informatization process of manufacturing sales and procurement channels, so as to reduce information asymmetry and meet the needs of specific users[1];Online trading platforms also allow for a freer choice of trading venue and time, and the reduction of middlemen also speeds up trading[28]In terms of organizational resources, digital transformation is not only about technological change, but also about management[29] Jin Jun et al. believe that top management can influence the digitalization process of enterprises to a large extent, and organizational cooperation resources are critical to the digitalization transformation of enterprises, which can make up for the limitation of organizational resources[30], expand the proportion of collaborative innovation in enterprise innovation, and improve innovation capability and efficiency;In addition, Qi Yudong and Cai Chengwei et al. also found the existence of the digital paradox, that is, due to the mismatch between the original organization or management structure and the newly introduced digital business model, the improvement of enterprise performance caused by the digital transformation of most manufacturing enterprises is offset by the imbalance of management cost[31]. From the R&D perspective, consider that R&D ambidexterity is a key organizational ambidexterity in enterprise innovation and product development[32] Zhao Fuchun and Ling Hong et al. pointed out that the application of IT can promote the process ambidextrous competence and flexibility of enterprises, so as to improve the R&D ambidextrous competence.[33] Huang Hao pointed out that the diffusion of digital technology also enables different industries to have a common technical basis and promote industrial integration, so as to promote technology research and development in line with market demand[34].

Most of the existing literature on the impact of digital transformation on enterprise innovation is theoretical qualitative analysis,and most of the empirical tests on the innovation driving force of digital transformation are from the meso and macro perspective, and few empirical tests are from the perspective of micro enterprise innovation.Secondly, there is a lack of relevant mechanism tests on how digital transformation affects enterprise innovation.In addition, some scholars have proposed that the heterogeneity of top management team has a certain impact on enterprise innovation.[35]

However, there is still a lack of empirical studies examining the specific relationship between digital transformation and firm innovation.

3. Research Analysis and Hypotheses

3.1 Analysis on the Mechanism of Digital Transformation Driving Enterprise Innovation

In essence, digital transformation is a process of deep integration of digital technology and production, sales and management [24]. Digital transformation is also through these channels to effectively improve the efficiency of enterprise innovation, the main performance is as follows: first, in production activities, the use of MES, PLM, SCM and other systems can help manufacturing enterprises to dynamically track, record and control workshop data[36].On the one hand, the enterprise can timely operate and maintain the production line, improve the utilization rate of machinery and equipment, improve the production capacity and efficiency of the enterprise, automation equipment also makes the mass production of personalized products possible;On the other hand, digital transformation can effectively reduce the degree of information asymmetry, help enterprises achieve the optimal allocation of resources, and further make breakthroughs in product research and development innovation.In addition, the business model of the Internet reduces the distance between enterprises and consumers, and consumers also have the opportunity to participate in the process of product production.Second, in sales activities, manufacturing enterprises can standardize and centrally manage key data such as procurement, inventory, warehouse and channel with the help of analysis cloud platform, which provides strong data support for product sales[37].At the same time, the analysis cloud platform can also fully tap the value of data, help the R&D department to carry out accurate upgrading of product lines, and effectively improve the innovation willingness of manufacturing enterprises.Third, in management activities, manufacturing enterprises use digital technology to replace the work function of middle-level management to transmit information[8]through the application of ERP system. Thus, it compresses and optimizes the power structure of enterprises, reduces the cost of management and coordination in the long run, and expand the boundaries of enterprises [38], which makes enterprises willing and able to increase investment in product R&D and innovation. Accordingly, this paper proposes:

H1: Digital transformation can drive innovation in manufacturing enterprises.

3.2 Moderating Effect Analysis of Top Management Team Heterogeneity

This paper analyzes how the comprehensive heterogeneity of senior management team moderates enterprise innovation from four aspects: gender, age, occupational background and educational background.(1) The larger the gender heterogeneity index of the senior management team, the more female executives there are.On the one hand, due to the passive and cautious psychological characteristics of women, female executives generally pursue stability. As a new thing, digital transformation has a high risk coefficient, and the risk-averse tendency of female executives may inhibit the progress of enterprise digital transformation.On the other hand, female executives' sensitivity to market segments enables them to promote enterprise innovation with the help of professional experience, way of thinking and emotional preference[39].(2) Executives of all ages have different attitudes, visions and values due to the different social, political and economic environments they experience[40], thus providing a wide range of cognitive resources for enterprises.Young executives are more willing to be ahead of the curve, responding to the country's call for digital transformation, increasing R&D spending and implementing innovative strategies.However, older executives prefer conservative strategies due to physical and psychological changes brought about by aging, which produce complementary effects within the team, and also enhance the ability of enterprises to resist risks and provide innovation driving force for enterprises.(3) The heterogeneity of career background means different observation perspectives, and diversified talents can conduct differentiated review and careful reflection on the strategic direction of the enterprise[41]Senior management teams with complex backgrounds are often able to collect

information from multiple ways and interpret information from multiple perspectives, so they have a strong ability to accept the digital transformation of new things.They are also able to formulate plans at multiple levels and evaluate strategies in multiple directions, so they can more keenly capture the driving effect of digital transformation on enterprise innovation.(4) The heterogeneity of the educational background of the senior management team has its own contradictions.On the one hand, the digital technology itself has certain barriers, and the difference of educational background may lead to poor communication between teams, which is not conducive to enterprises to fully explore and utilize the driving role of digital transformation in innovation, and reduce the efficiency of R&D investment.On the other hand, senior management teams with different educational backgrounds tend to have strong environmental adaptability and action tendency[42]Different thinking angles and behavior patterns also improve the effectiveness of innovation decisions of enterprises.Accordingly, this paper proposes that:

H2: In the process of digital transformation of manufacturing enterprises, the heterogeneity of top management team has a significant moderating effect on enterprise innovation.

4. Research Design

4.1 Data Sources and Sample Processing

In this paper, A-share listed manufacturing enterprises in Shanghai and Shenzhen from 2014 to 2021 were selected as research samples, and the following treatments were carried out: (1) Enterprises with missing key data were excluded;The enterprises marked with ST and ST* were excluded;(3) The continuous variable is winsorized, and the tail shrinkage object is the upper and lower value 1% seen.After the data processing, 2304 sample observations were obtained.

4.2 Variable Selection

4.2.1 Explained Variables

The explained variable of this paper is enterprise innovation (RD).The existing literature mainly measures enterprise innovation from the perspective of input or output. From the perspective of input, in order to avoid data distortion, this paper selects the proportion of enterprise R&D investment in year-end operating revenue to represent enterprise innovation.

4.2.2 Explanatory Variables

Table 1. Structural features of enterprise digital transformation

The underlying technology	Artificial intelligence technology	Artificial intelligence, Business intelligence, Image understanding, investment decision aid systems, Intelligent data analytics, Intelligent robotics, Machine learning, deep learning, Semantic search, biometrics, face recognition, speech recognition, identity verification, autonomous driving, Natural Language processing
	Cloud Computing Technology	Cloud computing, stream computing, graph computing, memory computing, multi-party secure computing, brain-like computing, green computing, cognitive computing, converged architecture, multi-billion concurrent, EB-level storage, Internet of Things, information physical systems
	Big Data Technology	Big data, data mining, text mining, data visualization, heterogeneous data, credit investigation, augmented reality, mixed reality, virtual reality
	Blockchain Technology	Blockchain, digital currency, distributed computing, differential privacy technology, smart financial contracts
The specific application	The mobile Internet, Internet, mobile Internet, Internet medical, e-commerce, mobile payment, the third party payment, NFC payment, intelligent energy, B2B, B2C, C2C, O2O, snatched, intelligence, wisdom, dressing agriculture, intelligent transportation, intelligent medical, intelligent, smart home, intelligent service for shun, smart, intelligent, environmental protection, intelligent power grid, the wisdom Can marketing, digital marketing, unmanned retail, Internet finance, digital finance, Fintech, financial technology, quantitative finance, open banking	

Since the types and quantities of digital technologies introduced by different enterprises, as well as the degree of effort, vary greatly, this paper introduces the concept of degree of Digital transformation (EDT) to improve the accuracy of the research conclusions. This paper draws on the practice of Wu Fei et al [43], the frequency of keywords related to digital transformation in the annual report of listed enterprises is used to describe the degree of digital transformation of enterprises. The specific practices are as follows: ①Generate database. Based on the web Crawler technology, the paper obtained the annual reports of Shanghai and Shenzhen A-share listed manufacturing enterprises from 2014 to 2021, then converted them into TXT format to form a database for screening keywords of digital transformation. ②Confirm the keywords. The key words of digital transformation are determined from the four underlying technologies of digital transformation and the specific application of digital technology, as shown in Table 1. Calculate the word frequency of keywords. The index of digital transformation degree was obtained by searching, matching and summing the generated keywords.

4.2.3 Moderating Variables

In this paper, executive team heterogeneity (Heter) was selected as the moderating variable. This paper refers to the practice of Li Duansheng and Wang Xiaoyan et al. [44] The heterogeneity of the four indicators of age, gender, educational background and occupational background was comprehensively investigated. The heterogeneity of each indicator was calculated by the HHI index method, and the mean value of the four indicators was calculated to represent the comprehensive heterogeneity of the senior management team. The specific formula is as follows: $H = 1 - (\sum_{i=1}^{n} P_i)\text{^}2$,

H∈ [0,1]. Among them, the p_i^2 represents the proportion of type-i members to all members of the senior management team. n represents the number of members in each category.The higher the value of H, the more heterogeneous this indicator is in the executive team.

The group assignment of each indicator of the heterogeneity of the executive team is based on the practice of Li Xiuping et al.[45]The specific rules are as follows: age: there are five groups: below 30 years old =1, 31-40 years old =2, 41-50 years old =3, 51-60 years old = 4,61 years old and above =5; Gender: there were two groups, male =1, female =2; Educational background: there are five groups: technical secondary school and below =1, junior college =2, undergraduate =3, master =4, Doctor or above =5; Professional background: nine groups: production =1, R&D = 2, design =3, human resources =4, management =5, Marketing =6, finance =7, finance =8, law =9.

4.2.4 Control Variables

Referring to relevant literature, this paper selected the enterprise size, enterprise age, proportion of independent directors, ownership concentration, asset-liability ratio, current ratio and other control variables.Specific definitions are shown in Table 2.

Table 2. Definition of control variables

The variable name	Variable symbol	Variable definitions
The scale of enterprise	size	Take logarithm of total assets of the business at year-end
Age of enterprise	age	Year of study minus year of establishment
Independent director ratio	indb	Independent directors as a percentage of total board members
Ownership concentration	top1	Shares held by No.1 shareholder
Asset-liability ratio	lev	Total liabilities divided by total assets
Current ratio	current	Current assets divided by current liabilities

5. Model Building

Model 1 is used to test hypothesis H_1.The subscripts I and t represent individual companies and years respectively.The coefficient β of EDT is used to judge the impact of digital transformation on

enterprise innovation of listed manufacturing companies, $\delta\sum X_{i,t}$ represents other control variables, μ_i represents individual fixed effects, θ_t represents the time fixed effect, $\varepsilon_{i,t}$ is the random error term.To prove hypothesis H_2, Model 2 adds the moderating variable of executive team heterogeneity, $EDT_{i,t}$*$heter_{i,t}$ is the interaction term of the degree of digital transformation of manufacturing enterprises and the heterogeneity of the executive team. This paper focuses on the coefficient β_3 of the intersection term.In addition.In order to avoid multicollinearity caused by interaction terms, the variables are centralized in advance.

Model 1: $rd_{i,t} = \alpha_0 + \beta_1 edt_{i,t} + \delta\sum X_{i,t} + \theta_t + \mu_i + \varepsilon_{i,t}$

Model 2: $rd_{i,t} = \alpha_0 + \beta_1 edt_{i,t} + \beta_2 heter_{i,t} + \beta_3 heter_{i,t} \times edt_{i,t} + \delta\sum X_{i,t} + \theta_t + \mu_i + \varepsilon_{i,t}$

6. Empirical Test and Result Analysis

6.1 Descriptive Statistics

Table 3. Descriptive statistics of relevant variables

	The mean	The standard deviation	The minimum value	The maximum
rd	6.2357	5.6841	0	76.3500
edt	3.0069	5.0437	1	82
heter	0.4398	0.1203	0	0.6719
size	22.1280	1.2110	20.0202	25.9684
age	17.5178	5.6574	3	61
indb	54.1716	16.9360	28.5714	142.8571
top1	32.5168	14.2248	7.4500	72.8800
lev	0.3918	0.1810	0.0574	0.8292
current	2.6466	2.3131	0.5728	14.7915

It can be found from Table 3 that the digital transformation degree index and enterprise innovation level of 1003 manufacturing enterprises sampled in this paper show the characteristics of small mean and large standard deviation, indicating that the digital transformation degree of Chinese manufacturing enterprises is generally not high, but the difference is great.The standard deviation of the heterogeneity index of the executive team is small, indicating that there is a certain heterogeneity in the executive team of Chinese manufacturing enterprises and the degree of heterogeneity is similar.the sample range, and there is no outlier interference, which is in line with statistical significance.

6.2 Correlation Analysis

Table 4. Pearson correlation coefficient between variables

variable	rd	edt	heter	top1	indb	size	age	current
rd	1							
edt	0.1704 *	1						
heter	0.1903 *	0.0135	1					
top1	0.1289 *	0.0576 *	0.0228	1				
indb	0.0619 *	0.0135	0.0543 *	0.0238	1			
size	0.1991 *	0.0258	0.2278 *	0.0280	0.1529 *	1		
age	0.1003 *	0.0640 *	0.1869 *	0.0253	0.0457 *	0.1969 *	1	
current	0.2522 *	0.0040	0.1722 *	0.0209	0.0850 *	0.3753 *	0.1045 *	1

According to Table 4, the correlation coefficient between RD and EDT is 0.1704, which is significant at the level of 10%, indicating that digital transformation of manufacturing enterprises can significantly and positively affect enterprise innovation, which preliminarily supports hypothesis 1.In addition, RD is significantly correlated with EDT, Heter, TOP1, INDB, SIZE, AGE, and Current at

the 10% level, and the correlation coefficients among all variables are less than 0.5, indicating that there is no serious multicollinearity problem.

6.3 Baseline Regression Results

6.3.1 The Impact of the Degree of Digital Transformation of Manufacturing Enterprises on Enterprise Innovation

Observe the first column of Table 5, Model 1 reports the impact of digital transformation on innovation of manufacturing enterprises.After the year and industry are double fixed, the coefficient of enterprise digital transformation (EDT) is 0.1362 at the 1% level of significance, which indicates that digital transformation will increase the willingness of manufacturing enterprises to increase R&D investment. Therefore, the rationality of hypothesis H1 is verified.In addition, the control variables SIZE, AGE, TOP1, Lev and current are all significant at the 1% level, which is consistent with the expectation. Indb has no significant impact on enterprise innovation.

6.3.2 Moderating Effect of Senior Management Team Heterogeneity

Model 2 added the heterogeneity of the executive team on the basis of Model 1 to perform the regression, and the results are shown in the second column of Table 5.After adding the moderating variable, the coefficient of EDT increases and remains significant, indicating that the addition of the heterogeneity of the executive team can enhance the impact of the digital transformation of manufacturing enterprises on enterprise innovation to a certain extent.In Model 2, the coefficient of the interaction term EDT × Heter is significantly positive at the level of 5%, indicating that the heterogeneity of the executive team plays a positive moderating role in the driving effect of digital transformation on enterprise innovation. The stronger the heterogeneity of the executive team, the stronger the willingness to innovate. Manufacturing enterprises tend to invest more research and development funds. Hypothesis 2 is verified.

Table 5. Digital transformation, Executive team Heterogeneity and firm innovation

	(1)	(2)
edt	0.1199 * * *	0.1209 * * *
	(2.8747)	(3.1368)
top1	0.0322 * * *	0.0333 * *
	(4.1581)	(4.2883)
indb	0.0073	0.0080
	(1.3352)	(1.4616)
size	0.4749 * * *	0.4246 * * *
	(5.2084)	(4.6506)
age	0.0673 * * *	0.0605 * * *
	(3.6628)	(3.3222)
current	0.4168 * * *	0.4076 * * *
	(3.8018)	(3.7205)
heter		2.3022 * * *
		(2.6628)
Edt*heter		0.5129 * *
		(2.4755)
Constant	17.9098 * * *	15.7602 * * *
	(8.5077)	(7.2527)
Year fixed effects	control	control
Industry fixed effects	control	control
R-squared	0.2436	0.2480
N	2301	2301

(Note: ***, ** and * indicate significant at the 1%, 5% and 10% levels, respectively; standard errors in parentheses.)

6.4 Robustness Test

6.4.1 Replace the Dependent Variable

This article previously uses the proportion of r&d input of enterprises operating income as explanatory variables of enterprise innovation, but scholars Xu Yingmei et al. also put forward that the enterprise innovation performance can be measured through the indexes of patent application and authorization [46], therefore this article also takes the logarithm of the number of patent applications of enterprises and plus1 to measure the degree of influence of the digital transformation of manufacturing enterprises on the innovation of enterprises.The results are shown in the first column of Table 6.

6.4.2 Change the Model Settings

Considering that time-varying differences in different industries (such as potential differences in industrial policies and development cycles in different periods) may affect the benchmark regression results, this paper constructed model 3 and included "industry-time" interactive fixed effects for regression. The results are shown in the second column of Table 6.

Model 3: $\mathrm{rd}_{i,t} = \alpha_0 + \beta_1 edt_{i,t} + \delta \sum X_{i,t} + \gamma_{\mathrm{ind}} \times year_t + u_{it}$

6.4.3 Change the Study Period

In order to avoid the test results of the extreme behavior impact of economic shocks on enterprise innovation input during the COVID-19 pandemic in 2020, this paper shortened the sample period to 2014-2019 and conducted the regression test again. The results are shown in the third column of Table 6.

All the above test results verify the above hypothesis and prove the robustness of the conclusion of this paper.

Table 6. Robustness test results

	(1)	(2)	(3)
	lnpatent	rd	rd
edt	0.0302 * *	0.0666 * * *	0.0950 * * *
heter	0.0867	1.4247	2.3691 * * *
interact	0.0681 *	0.2784 *	0.6198 * * *
Control variables	control	control	control
Year fixed effects	control	control	control
Industry fixed effects	control	control	control
R-squared	0.0619		0.2378

6.5 Endogeneity Test

Manufacturing enterprises with a high level of innovation may have a higher demand to promote digital transformation to continuously maintain and improve innovation capability, so that enterprise innovation and the degree of digital transformation are mutually causal, leading to the endogeneity problem.In order to avoid the influence of endogeneity caused by bidirectional causality on the conclusions,the degree of digital transformation with a lag of 1 period was selected as an instrumental variable in this paper, and the two-stage least squares method was used for regression. The results are shown in Table 7.After testing, the minimum eigenvalue statistic of the instrumental variable L.DT is 1463.52. According to Staiger and Stock (1997), as long as the value is larger than 10, weak IV is not considered to exist, ensuring the validity of the instrumental variable.The first-stage regression results showed that L.EDT was positively correlated with EDT, which was consistent with the expectation.In the second step, the coefficient of the degree of digital transformation remains positive at the 1% significance level, indicating that the research conclusion of this paper is still valid after considering the endogeneity problem.

Table 7. Endogeneity test results

	2SLS estimation based on instrumental variables	
	The first stage	The second stage
	edt	rd
edt		0.2219 * * *
		(3.88)
L.edt	0.8323 * * *	
	(10.74)	
Control variables	control	control
Year fixed effects	control	control
Industry fixed effects	control	control
R-squared	0.5832	0.1146

6.6 Further Tests

This paper constructs a model of "digital transformation-executive team heterogeneity". Considering that interaction effects may mask the role of main effects, and the focus of this paper is mainly on the innovation-driven role of digital transformation, further supplementary tests are carried out: According to the proportion of enterprises with e-commerce transactions in each region from CSMAR, it is used as the standard to measure the degree of market informatization in the province (region, city) where the enterprise is registered, with 50% quantile as grouping boundaries, divided into two categories, high and low market information level area and keep the rest of the explained variable, control variable amount of legal person, the range of inspection.The results of the grouped regression are shown in Table 8.

It can be found that after grouping according to the degree of market informatization, digital transformation has a significant positive impact on the innovation of manufacturing enterprises in both groups.Among them, the coefficient of EDT in the high market informatization group is larger and the significance is stronger, indicating that digital transformation plays a greater role in promoting enterprise innovation in the region with high market informatization level.Enterprises in regions with high market informatization level can make better use of the results of digital transformation, and promote enterprise innovation by using more robust online platforms and digital infrastructure, richer experience in e-commerce transaction management and more efficient resource allocation efficiency.In addition, low information barriers also provide strong support for the collection, interpretation and output of information and technology related to digital transformation, helping enterprises to find the optimal path and improve the success rate of technological innovation.On the contrary, the role of digital transformation in promoting enterprise innovation is not obvious in regions with a low level of market informatization.

Table 8. Supplementary test results

variable	Low market informationization group	High market informationization group
edt	0.0601 * *	0.2129 * * *
heter	1.1998	4.4476 * * *
interact	0.4237 *	0.1164
Constant term	21.2711 * * *	5.3878 * * *
Control variables	control	control
Year fixed effects	control	control
Industry fixed effects	control	control
N	1371	925
R-squared	0.2144	0.3400

The moderating effect of executive team heterogeneity is different in the regression results of the two groups. In the low market informatization group, the heterogeneity of executive team can positively moderate the driving effect of digital transformation on firm innovation, but in the high

market informatization group, it has insignificant negative moderating effect. From the information decision theory, Qie Haituo et al. believe that the heterogeneity of the functional background of the senior management team is conducive to breaking the information barrier and giving play to the integration advantage of resources and knowledge [47], while regions with low information barrier have lower requirements on the heterogeneity of senior management. At the same time, the technology and risk of digital transformation may lead to cognitive conflicts among senior management team members, which increases the communication cost of innovation decision-making of enterprises, and may lead to the lack of significant positive moderating effect of senior management team heterogeneity on the high market information group.

7. Research Conclusion and Implications

7.1 Research Conclusion

This paper constructs A theoretical model of manufacturing enterprises driving enterprise innovation with the help of digital transformation. Using the data of A-share listed manufacturing enterprises in Shanghai and Shenzhen from 2014 to 2021, this paper analyzes the impact path of digital transformation on enterprise innovation and conducts in-depth exploration.To verify its impact on the relationship between enterprise digital transformation and enterprise innovation.Through empirical analysis, the conclusions of this paper are as follows:(1)Digital transformation can effectively drive the innovation of manufacturing enterprises.(2)The comprehensive heterogeneity of gender, age, occupational background and educational background of the senior management team can positively moderate the promoting effect of digital transformation on enterprise innovation in manufacturing enterprises.(3) The heterogeneity test shows that the digital transformation of manufacturing enterprises has a more significant driving effect on enterprise innovation in regions with a higher degree of market informatization.

7.2 Practical Implications

For manufacturing enterprises, first of all, decision-makers should cultivate the thinking of digital transformation and realize that digital transformation is not only a technological update and change, but also a change in organizational structure, internal operation and management mode. Secondly, manufacturing enterprises should strengthen the internal training and external introduction of digital technical talents, and cultivate a team of talents with digital concept.Enterprises should not only increase the introduction of high-tech talents, but also give front-line employees more opportunities to participate in systematic innovation activities, so as to tap their digital creativity.At the same time, enterprises should accelerate the construction of information infrastructure, smart factories and digital factories, etc., to provide the necessary development conditions for enterprises to successfully carry out digital transformation.Finally, manufacturing enterprises should pay attention to the positive moderating effect of executive team heterogeneity on enterprise innovation in the process of digital transformation.On the one hand, the gender and age composition of the senior management team should be reasonably adjusted to realize the complementary advantages of young and middle-aged executives, male and female executives, and ensure the smooth development of digital transformation.On the other hand, we should comprehensively plan the cultivation of compound executive team, make full use of the cognitive conflicts between executives with different occupations and educational backgrounds, pool our wisdom, accelerate the adaptation to the new thing of digital transformation, and effectively improve the innovation ability of enterprises.

For the government, it can increase the intensity of financial support for the digital transformation of enterprises, such as increasing the upper limit of technical transformation reward, providing a certain proportion of technical transformation funds for digital transformation, improving the cycle of incentive funds so as to adapt to the digital technology transformation project, and guide the manufacturing enterprises to carry out digital transformation.At the same time, the government can promote the process of market informatization, vigorously develop e-commerce, expand and upgrade

information consumption, further promote the process of digital economy, so as to motivate enterprises to carry out digital transformation, and provide an inexhaustible source of innovation for enterprises.The improvement of the degree of market informatization cannot be separated from a good basic environment. Therefore, the government should strengthen the construction of digital infrastructure and lay a solid foundation for the development of new digital technology.In addition, in order to better play the leading role of the digital economy, the government needs to formulate supportive policies related to the development of the digital economy and its specific forms of business, and promote the effective integration of the digital economy and manufacturing enterprises.

7.3 Limitations and Prospects

This paper deeply studies the impact of digital transformation on innovation input of manufacturing enterprises and the moderating role of executive team heterogeneity. To some extent, this paper complements the research on digital transformation and enterprise innovation, but there are still the following limitations to be improved: (1) The research samples in this paper are all manufacturing enterprises listed in Shanghai and Shenzhen A-shares. Whether the conclusion can be extended to enterprises in other industries and non-listed enterprises needs to be empirically tested by expanding the research context.(2) The data in this paper are from the text data of the annual report, which may have measurement bias, making the results inaccurate.In the future, we can use questionnaire and interview to obtain primary data for further testing.(3) This paper analyzes the impact path of digital transformation on enterprise innovation, but does not cover the specific impact of the subdivision process of digital transformation (digitization of resources, digitization of psychology, digitization of structure, etc.) on enterprise innovation, which still needs to be further explored by means of case studies in the future.

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