R&D INVESTMENT, INNOVATION EFFICIENCY, VALUE CREATION AND DIGITAL TRANSFORMATION OF LARGE ENTERPRISES IN CHINA— —A MODERATED MEDIATION MODEL

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Abstract

In recent years, the R&D investment and innovation efficiency of China's large enterprises have different development. It is of great significance for the high-quality development of China's large enterprises to study the relationship between the two and analyze the mechanism and degree of their influence on enterprise value creation under different levels of economic development. Through literature review, this paper puts forward some theoretical assumptions about the relationship among R&D investment, innovation efficiency , and enterprise value creation of large enterprises at the present stage and the adjustment of digitalization degree. On this basis, the provincial panel data from 2011 to 2020 were used to construct a model to test these hypotheses. The results show that R&D investment is beneficial to improve firm value creation, and innovation efficiency plays a part in the mediating variable between R&D investment and value creation due to the positive correlation between R&D investment and innovation efficiency. The degree of digitization positively regulates the first half path of the mediation process, but the regulation effect of the second half path and the direct path is not obvious at this stage.

Keywords: R&D Investment, Innovation Efficiency, Enterprise Value, Digital Transformation

Introduction

Large enterprises play a backbone support role in technological innovation and entrepreneurial development. After the Chinese government launched the white paper "Made in China 2025" in 2015, the goals and tasks of industrial enterprises were further defined, and their innovation-driven and entrepreneurial incubation effects are the results of the implementation of the national strategy of "innovation-driven development". Large companies rely on their resource endowments, technological advantages, and innovation capabilities to drive various forms of R&D investment activities within and outside their organizational boundaries. In recent years, with the introduction of the national Industry 4.0 industry paradigm, major provinces and cities have started to attract the inflow of high-tech talents and driven by the policy, the R&D investment of enterprises has shown an upward trend. Figure 1 presents the value of R&D investment in China, rising from RMB

868.7 billion in 2011 to RMB 236.38 billion in 2020. The increase in R&D investment can bring into play the innovation-driven effect of large enterprises, improve the innovation efficiency of the enterprises themselves through their resource endowment, technological advantages, and innovation capabilities, and drive the innovation and entrepreneurship development of the surrounding upstream and downstream enterprises through the business incubation effect. At the same time, R&D investment activities of large companies can also show negative effects such as organizational rigidity and innovation inertia, which are not conducive to the efficiency of corporate innovation.

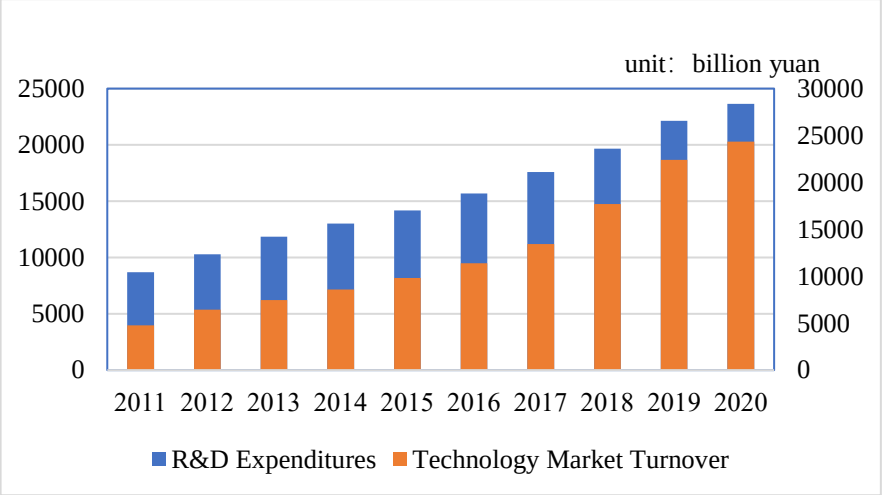


Figure 1: China's R&D expenditure and technology market turnover from 2011 to 2020

While R&D investment is increasing, the issue of corporate innovation efficiency in China cannot be ignored. As can be seen from Figure 1, the technology market turnover shows the growth of the total amount year by year, but due to the different levels of economic development at the provincial level and the uneven spatial distribution of large enterprises, resulting in large variability of innovation efficiency. At the same time, there is no overall but significant linear relationship between firms' R&D expenditure and technology market efficiency at the micro-level. Therefore, figure 1 can be divided into three stages: the first stage is a linear relationship between R&D expenditure of enterprises and technology market efficiency in 2011-2017, which basically grows in parallel. Phase 2: in 2017-2019 the gap between corporate R&D funding investment and technology market efficiency becomes smaller, with technology market turnover increasing faster and rapidly equalizing with R&D funding investment. Phase 3: In 2019-2020, the technology market turnover is slightly higher than the R&D funding investment.

Large firms' upfront R&D investment and innovation efficiency are closely related to firm value creation. It is better at improving innovation than at disruptive, disruptive innovation. However, along with the impact of emerging technology developments such as digital transformation and national policy changes, corporate entrepreneurship has begun to undergo a fundamental shift in

organizational form and strategic behavior. Large enterprises are constantly trying to promote various forms of corporate entrepreneurial activities inside and outside organizational boundaries based on technological innovation. Moreover, large enterprises with a central position can play a key leading role in related entrepreneurial activities. This process inevitably brings differentiation and lags in value creation but is growth-oriented in overall performance. Figure 2 presents the cumulative new product sales revenue and the number of R&D invention patents for large Chinese companies between 2011 and 2020. As can be seen from the graph, both have trend growth from 2011-to 2020, but after 2015 the growth is more pronounced for both, especially for new product sales revenue.

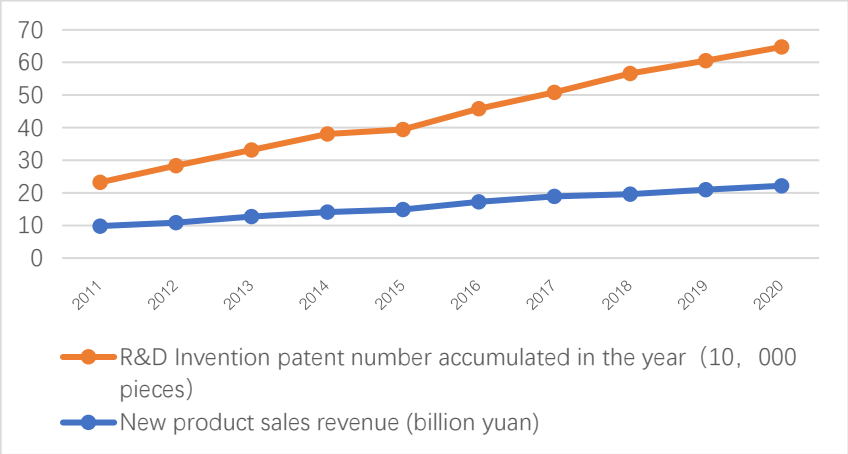


Figure 2: New product sales revenue and R&D patents from 2011 to 2020

In summary, this paper uses provincial panel data and applies a moderated mediating effect model to analyze the enabling effect of digitalization degree on innovation efficiency of large enterprises and incorporates innovation efficiency into the study of the relationship between R&D input and value creation to explore the mechanism of the role of digitalization degree in enabling innovation efficiency and value creation of large enterprises from the mediating and moderating effects. Compared to the existing studies in the literature, the contribution of this paper mainly lies in. First, a mediated quantitative empirical analysis of the relationship between R&D investment and value creation in large enterprises is conducted in the context of China's new normal industrial economy. The conclusions reveal the positive effect of the degree of digitization empowering innovation efficiency and the phenomenon that the degree of digitization weakens the positive effect of value creation between provinces, providing empirical evidence of the degree of digitization empowering value creation at the provincial level and compensating for the lack of quantitative analysis in this area. Second, the inclusion of digitalization degree in the research framework of mediating effects explores the direct path, first half path, and second half path effects of R&D investment and value creation in large firms, enriching the research on the relationship between R&D investment and value creation in large firms. Finally, combined with the findings of the study, policy

insights on how to use the degree of digitalization to empower large enterprises are proposed to provide a basic reference for digital transformation and high-quality development of large enterprises.

1. Literature Review And Proposed Hypothesis

1.1 R&D investment and innovation efficiency

Xiao and Lin (2019) argue that the problem of corporate innovation is not just a short-term R&D investment, but also a long-term continuous investment process with continuity. There are certain efficiency differences among listed companies in different industries, which are affected by the "crowding out" effect of corporate financialization in different life cycle stages. Shen and Chen (2021) concluded that the R&D smoothing behavior of firms in different life cycles differed, with significant R&D smoothing in maturing firms and insignificant in growing and declining firms. Meanwhile, the level of industry competition can significantly moderate the R&D smoothing behavior of firms, and the smoothing effect of cash holdings on R&D investment becomes more significant as the level of industry competition increases. By decomposing the technical efficiency of enterprises, Yanping Zhang (2014) found that although SOEs experienced a long period of efficient innovation, they became inefficient in 2012 during the study period, and the causes of inefficiency were the decline in scale efficiency and diminishing returns to entry scale. From the perspective of provincial comparisons, Shuaiguan Song (2013) reveals that increased investment in innovative talents and enhanced cooperation between industry, academia, and research can moderately compensate for the inefficiency of technological innovation in large enterprises. Yuan, (2021) argued that the innovation efficiency brought by technological innovation investment in national high-tech zones showed a continuous growth and spatial imbalance during the sample period. Some scholars have also addressed this issue from a national policy perspective, alike Chen, Liu, Serrato, and Xu,(2021)found that the government gave significant tax breaks to firms that invested in R&D above a certain threshold or "grade", and that firms' R&D expenditures increased significantly, partly due to the relabeling of costs as R&D. Relabeling accounted for 24.2 percent of reported R&D while doubling R&D would increase productivity by 9 percent. This suggests that firm selection and relabeling determine the cost-effectiveness of stimulating R&D, i.e., modest spillover effects justify increased innovation from a welfare perspective. Xu, Wang and Liu (2021) concluded that government R&D subsidies stimulate firms' R&D investment but have no significant effect on innovation performance, while R&D investment has a significant effect on innovation performance. In addition, the study found a positive effect of R&D investment on the innovation performance of SOEs and firms with R&D staff.

A review of the above literature reveals that most studies conclude that R&D investment leads to an increase in firm innovation efficiency. Specifically, on the one hand, R&D investment can improve the added value of new products and enhance the level of consumer recognition of new products as well as the conversion rate of the technology market. On the other hand, digitization

reduces the transaction and contractual costs and innovation perception differences in the corporate innovation process, while the process of R&D investment in large companies has a cumulative scale, so that with continuous investment in the first period leads to a rapid increase in innovation efficiency in a later period.

Therefore, hypothesis 1 is proposed.

Hypothesis 1: R&D investment will improve innovation efficiency.

1.2 R&D investment and enterprise value creation

Donglian Wu (2016) argues that the current large retail enterprises in China have seen greater growth in both traditional and Internet trading models, but the growth rate of the Internet trading model is significantly higher than that of the traditional trading platform. In addition, while traditional trading methods still account for a large share of the total transaction volume of large retailers, the share of Internet-based trading models is also growing rapidly. In contrast, Li,Shen, (2009) concluded that there is no significant effect of R&D investment on the economic rate of return for either state-owned or non-state-owned enterprises. Research shows that the role of corporate R&D is only to promote technological progress, which is not reflected in changes in profitability, and therefore technological achievements are not successfully transformed into material productivity. The current research has different findings on the relationship between R&D investment and value creation depending on the heterogeneity of large firms.

Other scholars have explored the relationship between the two from both perspectives; for example, Ye (2010) argues that different approaches to China's economic transformation (gradual, decentralized, and experimental) have created different types of large enterprises. These large enterprises can be briefly categorized into five types: (1) enterprises made possible by business diversification; (2) large enterprises made possible by regional diversification; (3) large enterprises entrusted with the management of several single enterprises; (4) large enterprises transformed by governmental functions; and (5) large enterprises made possible by mergers and reorganizations. While different types of corporate headquarters need to create value from matching business portfolios and management models, there are differences due to the causes of large corporations and their types. This determines the differences in their business mix and management models and their matching, and thus their approaches to value creation. Similar studies include Solomon [11], where the impact of R&D on productivity is differentiated across different types of firms, showing a non-linear relationship, based on which hypothesis 2 is proposed in this paper.

Hypothesis 2a: R&D investment expands firm value creation.

Hypothesis 2b: R&D investment weakens firm value creation.

1.3 Corporate Innovation Efficiency and Corporate Value Creation

Yuan, Wu and Zhang (2017) concluded that environmental factors, scale efficiency, and random error significantly impact the innovation efficiency of large manufacturing firms in China and become the main factors limiting innovation efficiency. It is also noted that the average innovation efficiency of large manufacturing enterprises is highest in the eastern region, while it is relatively low in the central and western regions. In most provinces (cities) large manufacturing enterprises innovation efficiency there is room for four-dimensional improvement.Ding,Zhao and Hong, (2013) concluded that large local enterprises show large variability in technological innovation efficiency, and the reasons for the differences can be explored from three perspectives, including enterprise size, human resource status, and research activities. In formulating innovation policies, local governments should not simply take the scale of enterprises as the standard but should improve the quality of enterprise human resources as the core goal and improve the "government-enterprise-university" innovation network as the core means, to enhance the technological innovation capability of enterprises through collaborative innovation. And Meng Xu studied that innovation efficiency, in addition to showing spatial gradient differences, also pointed out that the overall relative differences in the level of innovation efficiency of high-tech industries in China showed a slight downward trend.

Synthesizing current research on firm innovation efficiency and firm value creation, the impact relations between the two are similarly undetermined. On the one hand, the improvement of enterprise innovation efficiency will lead to the increase of R&D expenditure of large enterprises, especially in the introduction of scientific and technological talents, the establishment and management of teams, etc., which will reduce the expansion of enterprise investment scale and affect their value creation. On the other hand, large enterprises, due to the existence of regional economic development differences, regional economic development has more preferential policies and support efforts. Therefore, the more efficient a firm's innovation is the more likely it is to receive government support, which in turn will lead to an increase in firm value creation. Based on this, hypothesis 3 is proposed.

Hypothesis 3a: Firm innovation efficiency expands firm value creation.

Hypothesis 3b: Firm innovation efficiency decreases firm value creation.

1.4 The mediating role of innovation efficiency

In summary, the above analysis shows that both corporate R&D investment and innovation efficiency have important effects on firm value creation, and corporate R&D investment leads to the improvement of corporate innovation efficiency. Specifically, the impact of corporate R&D investment on value creation is partly transmitted through corporate innovation efficiency as a mediating variable, i.e., corporate R&D investment leads to the improvement of innovation efficiency at the corporate level, and the improvement of corporate innovation efficiency leads to the increase of corporate value creation at the consumer market level. The organic combination of these two

processes forms a virtuous interaction between continuous corporate R&D investment and value creation. Therefore, hypothesis 4 is proposed.

Hypothesis 4: Innovation efficiency plays a partially mediating role between R&D inputs and value creation.

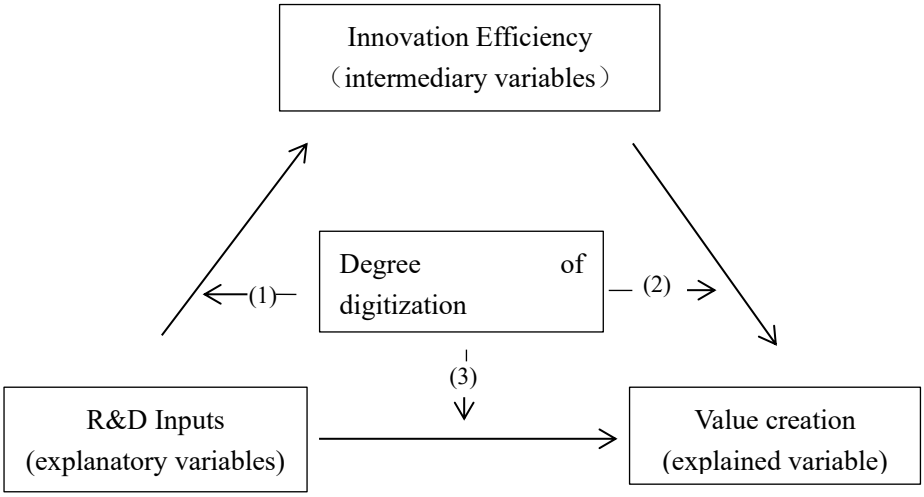
1.5 Moderating role of the level of digital trade development

Zhang,Shen,and Xue,(2021) argued that large enterprises assume an important role in entrepreneurial activities in the digital economy, and that various actors coexist and achieve value creation in a digital technology-driven, diversified enterprise ecology and platform-based environment. Yu, Liu,and Zhuang, (2021) concluded that Internet development significantly promotes technological innovation, both patent data and urban innovation index. At the same time, Internet development accelerates the depreciation rate of patents, conducive to improving the update rate of innovation knowledge; Internet development accelerates the dissemination of information, which enhances the domestic and foreign citations of patents and significantly increases the spillover of innovation knowledge.

It follows that the mechanistic relationship between R&D investment, innovation efficiency, and value creation in large firms in the context of the digital economy is different from that in the context of the traditional economy. In this paper, hypothesis 5 is formulated using the degree of digitalization as a moderating variable.

Hypothesis 5: The degree of digitization moderates the mediating effect between R&D investment and value creation.

In summary, it is argued that innovation efficiency plays a partially mediating role between R&D inputs and value creation, and this mediating role is moderated by the level of digitalization development. Accordingly, this theoretical model to be tested can be represented in Figure 3. In the figure, there are both mediating and moderating effects. Among them, the mediating effect is expressed in the fact that innovation efficiency plays a partial effect between R&D input and value creation; while the moderating effect is expressed in the direct moderating effect of R&D input on value creation and the indirect moderating effect of the first half of the path (from R&D input to innovation efficiency) and the second half of the path (from innovation efficiency to value creation).



Picture 3: Theoretical model to be tested

2. Study design

2.1 Source and processing of data

The sample of this paper is the panel data of 30 provincial-level administrative regions in China (excluding Hong Kong, Macao, Taiwan, and Jilin) from 2011 to 2020. The data are obtained from the National Bureau of Statistics website, the CSMAR database, and data from the Digital Finance Research Center of Peking University. The variables used in this paper are shown in Table 1.

2.1.1 Explanatory variable: value creation of large firms (valc)

According to Wang, (2015), the value creation of large enterprises usually indicates the innovation output of enterprises, which can be measured by the following three indicators: the number of patent applications per capita, the number of patent inventions per capita, and the ratio of new product sales revenue (new product sales revenue/enterprise main business input). According to Yu,Wang, (2021), economic development should not only focus on the improvement of "quantity", but also on the improvement of "quality", and the innovation output of enterprises is expressed by dividing the technology market turnover by the regional GDP. The value creation of large enterprises in this paper considers both the impact of new product sales revenue and the impact of regional GDP. Therefore, the value creation of enterprises is expressed by dividing the revenue of new product sales by the regional GDP.

2.1.2 Core explanatory variables, mediating variables, and moderating variables

R&D input is the core explanatory variable in this paper, which is represented using R&D expenditure/regional GDP. According to the hypothesis, innovation efficiency is the mediating variable between R&D input and firm value creation, and it is represented in this paper using technology market turnover/regional GDP. According to the hypothesis, the degree of digitalization

brings new models and business opportunities to enterprises, so the digital transformation is used to moderate the above mediating mechanism.

2.1.3 Control variables

For the selection of control variables, a reference was made to the selection of Wang ,(2015),Yu,Wang,(2021) In order to avoid obvious multicollinearity among the indicators, four indicators, namely fee profit rate, patent application cost rate, patent invention efficiency, and trade dependence, were screened as control variables to measure the economic and enterprise characteristics of different regions.

Table 1: Variable names and definitions

Variable abbreviations	Variable Name	Variable Definition
valc	Value Creation	New Product Sales Revenue / Gross Regional Product
r&di	R&D investment	R&D expenditure/regional GDP
inne	Innovation Efficiency	Technology Market Turnover/Regional GDP
dfi	Digital Financialization	Digitization degree/general digital finance index
exm	Expense Margin	Industrial Cost Margin
pacr	Patent Application Cost Ratio	R&D expenditure/number of patent applications
pie	Patent Invention Efficiency	Number of valid invention patents/number of patent inventions
trd	Trade Dependence	Total import and export/regional GDP

2.2 Regression Model Design

In the mediating effect model with multiple tests, one of the widely used methods is the sequential test method. Therefore, this method will also be used in this paper to test whether firm innovation efficiency is a mediating variable for R&D investment to affect firm value creation. Also, this method will be used to test the moderating effect of the degree of digitalization in this process. To this end, the model test in this paper can be carried out in two stages as follows.

In the first stage, the mediating effect of innovation efficiency between R&D input and firm value creation is tested. Where valc is firm value creation, r&di is firm R&D input, inne is firm innovation efficiency, and controls represent control variables. The model is set as ：

$$\ln valc = \alpha_1 + \beta_1 \cdot r\&di + \eta_1 \cdot controls + \varepsilon \quad (1)$$

$$\ln inne = \alpha_2 + \beta_2 \cdot r\&di + \eta_2 \cdot controls + \varepsilon \quad (2)$$

$$\ln valc = \alpha_3 + \beta_3 \cdot r\&di + \gamma_3 \cdot inne + \eta_3 \cdot controls + \varepsilon \quad (3)$$

Among them, model equation (1) tests whether the effect of corporate R&D investment on corporate value creation is significant; model equation (2) tests whether the effect of corporate R&D investment on corporate innovation efficiency mediating variables is significant; model equation (3) tests whether the effect of corporate innovation efficiency mediating variables on corporate value creation is significant after controlling for the effect of corporate R&D investment.

In the second stage, the moderating effect of the degree of digitization on the relationship between R&D investment and the value creation of the firm is tested. Specifically, the existence of three moderating effects between R&D inputs and innovation efficiency, between innovation efficiency and value creation, and between R&D inputs and value creation is tested. To better interpret the model coefficients, the data of R&D input, innovation efficiency, and value creation are centered on testing the existence of such moderating effects through the following three regression models. Where c_valc, c_ r&di, and c_inne denote the value creation, R&D input, and innovation efficiency of the firms after centralization, respectively.

$$\ln valc = \alpha_4 + \beta_4 \cdot c\_r\&di + \delta_4 \cdot c\_dfi + \varphi_4 \cdot c\_r\&di \cdot c\_dfi + \eta_4 \cdot controls + \varepsilon \quad (4)$$

$$\ln inne = \alpha_5 + \beta_5 \cdot c\_r\&di + \delta_5 \cdot c\_dfi + \varphi_5 \cdot c\_r\&di \cdot c\_dfi + \eta_5 \cdot controls + \varepsilon \quad (5)$$

$$\ln valc = \alpha_6 + \beta_6 \cdot c\_r\&di + \gamma_6 \cdot c\_inne + \delta_6 \cdot c\_dfi + \varphi_6 \cdot c\_r\&di \cdot c\_dfi + \lambda \cdot c\_inne \cdot c\_dfi + \eta_6 \cdot controls + \varepsilon \quad (6)$$

Regression model (4) tests the existence of the moderating effect of digitization on the direct path of the impact of R&D inputs on value creation; regression model (5) tests the existence of the moderating effect of digitization on the first half of the mediating process (i.e., the impact of R&D inputs on innovation efficiency); (6) tests the existence of the moderating effect of digitization on the second half of the mediating process (i.e., the impact of innovation efficiency on value creation) (6) test whether the moderating effect of digitalization on the second half of the intermediation process (i.e., the effect of innovation efficiency on value creation) exists.

3. Empirical Analysis

3.1 Descriptive description of the model and ADF test

Descriptive statistics were performed on the variables involved in the model, and the results are shown in the table.

Table 2: Descriptive statistics of variables

Variable	Mean	Std.Dev	Min	Max
valc	1730.653	1837.60	18.39	20225.25
r&di	107.033	62.719	2.362	324.157
inne	150.325	270.506	0.255	1749.516
dfi	1.407	0.432	0.095	5.097
exm	7.033	5.519	0.54	69.08
pacr	180.600	77.752	70.648	561.308
pie	2.456	1.160	0.615	8.000
trd	422.139	454.635	10.978	2266.336

The LLC test and Fisher-ADF test were applied to each of the above variables. It was found that these variables, except for the valc variable, satisfied the first-order single integer condition, as shown in Table 3. There was a long-term stable relationship among the variables, and a linear regression model could be constructed to analyze them. The cointegration test conducted by Kao method confirmed the existence of long-term stable relationships among the variables of the model at the 1% significance level, and a linear regression model could be constructed for their analysis.

Table 3: LLC, Fisher-ADF, KAO test results

Variables	LLC test		Fish-ADF test		Kao test(t-value)		
	(p，t)	adjust t	(p，t，d)	p-value	MDF	DF	ADF
valc	(1，1)	6.185	(1，1)	-1.545	-11.662***	-1.738**	-1.237*
r&di	(1，0)	-1.930**	(1，0，1)	4.308***			
inne	(1，1)	-5.232***	(1，0，1)	93.00***			
dfi	(0，0)	-34.062***	(1，0，1)	15.014***			
exm	(1，1)	-7.348***	(1，0，1)	6.497***			
pacr	(0，0)	-7.269***	(1，0，1)	8.594***			
pie	(0，0)	-2.050**	(1，0，1)	6.989***			
trd	(0，0)	-12.594***	(1，0，1)	7.753***			

Note: p indicates panel means; t indicates time trend; d indicates drift; 1 indicates included, 2 indicates noncluded; ***, **, and * indicate passing the test at 1%, 5%, and 10% significance levels, respectively.

3.2 Model regression analysis

Whether models 1-6 should be modeled as random effects or fixed effects is judged by a combination of Hausman and economic significance tests. As can be seen from the table below, the p-values of the Hausman test in models 1, 3, 4, and 6 are less than 0.01 and in line with the economic significance test. In contrast, models 2 and 5 Hausman test did not pass if the random effect was used. The degree and direction of the quantitative relationship between the variables are not in line with the actual economic significance, so the fixed effect model is used in line with the actual economic significance.

Models 1-3 test the mediating effect of firm innovation efficiency between R&D investment and value creation. Among them, model 1 tests the effect of R&D input on value creation. Its R&D input coefficient value is 0.339, which is also significant at the 1% level, which indicates that the theoretical hypothesis 2a holds. Model 2 tests the impact of large enterprises' R&D investment on enterprise innovation efficiency, and its regression coefficient is 0.5109, which is also significant at the 1% level, indicating that R&D investment will lead to the improvement of enterprise innovation efficiency, and the theoretical hypothesis 1 is valid: Model 3 tests the impact of large enterprises' innovation efficiency on enterprise value creation. Its regression coefficient is 0.332, while significant at the 1% level, implying that the innovation efficiency of large enterprises will lead to the increase of value creation. In addition, by comparing the regression coefficients of the core explanatory variables R&D input in models 1 and 3, it is found that 0.332 (model 3) is smaller than 0.339 (model 1) and significant at the 1% level, indicating that the theoretical hypothesis 4 holds, i.e., innovation efficiency plays a partial mediating effect between R&D input and value creation.

Models 4-6 test the moderating effect of the degree of digitization dfi on R&D input and value creation. Among them, the coefficient of regression model 4 digitization degree dfi is not significant, which indicates that there is no significant correlation between digitization degree and value creation. Then based on the coefficient of the interaction term between digitization degree and R&D input is also not significant, which means that the moderating effect of digitization degree on the relationship between R&D input and value creation of enterprises is not significant at this stage. The coefficient of regression model 5 is 0.345 and significant at the 5% level, indicating a positive correlation between the degree of digitalization and the efficiency of corporate innovation. The regression coefficient of the interaction term between R&D investment and digitalization is 0.287 and significant at the 10% level, which indicates that the increase in digitalization diminishes the role of the firm's technology level in reducing innovation efficiency, i.e., digitalization positively moderates the relationship between new technology and innovation efficiency of the firm. The coefficient of regression model 6 is not significant for the degree of digitization, and the interaction term with the R&D investment and innovation efficiency of firms is also not significant, implying that at this stage, since the digital economy has just emerged, the degree of digitization does not yet have the role of

directly regulating the value creation by the R&D investment of large firms, and also does not have the role of regulating the value creation by the innovation efficiency of firms.

In addition to this, it is clear from the table that the individual models containing interaction terms have higher intra-group R2 values than those without interaction terms. The above analysis of models 4, 5, and 6 indicates that the degree of digitalization does not have a moderating effect at this stage in the direct path of the impact of corporate R&D investment on value evaluation but has a positive moderating effect in the first half of the mediating process (from R&D investment to innovation efficiency), while the moderating effect is not significant in the second half of the path (from innovation efficiency to value creation).

Table 4: Model regression results

Dependent variable		Model 1 lnvalc	Model 2 lninne	Model 3 lnvalc	Model 4 lnvalc	Model 5 lninne	Model 6 lnvalc
Intermediate variables	inne	-	-	-0.1 (-0.52)	-	-	-
Core explanatory variables	r&di	0.339*** (4.08)	0.5109*** (2.72)	0.332*** (3.93)	-	-	-
Independent variable	c_inne	-	-	-	-	-	-0.01 (-0.35)
	c_ r&di	-	-	-	0.312*** (3.49)	-0.653*** (3.26)	0.320*** (3.52)
Control variables	lnexm	-0.285*** (-2.80)	-0.114 (-0.50)	-0.287*** (-2.81)	-0.282*** (-2.76)	-0.131 (-0.57)	-0.279*** (-2.72)
	lnpacr	-0.355** (-2.01)	-0.670* (-1.68)	-0.363** (-2.04)	-0.369** (-2.07)	-0.602 (-1.50)	-0.376** (-2.09)
	lnpie	-0.502*** (-4.80)	1.719*** (7.33)	-0.471*** (-3.90)	-0.465*** (-4.16)	1.530*** (6.13)	-0.440*** (-3.51)
	lntrd	-0.734*** (-5.88)	-0.187 (0.68)	-0.727*** (-5.80)	-0.727*** (-5.75)	-0.222 (-0.80)	-0.727*** (-5.72)
Adjustment variables	c_dfi	-	-	-	0.067 (0.94)	0.345** (-2.17)	-0.064 (0.87)
Interaction items	c_ r&di ·c_dfi	-	-	-	0.05 (0.73)	0.287* (-1.77)	-0.07 (0.84)
	c_inne·c_dfi	-	-	-	-	-	-0.02 (-0.86)

Table 4: Model regression results (cont.)

Dependent variable	Model 1 lnvalc	Model 2 lninne	Model 3 lnvalc	Model 4 lnvalc	Model 5 lninne	Model 6 lnvalc
Hausman Test	34.68***	5.74	32.98***	40.95***	15.18*	39.17***
F test	17.32***	19.39***	14.43***	12.44***	14.66***	9.73***
Within R^2	0.2477	0.2678	0.2484	0.2502	0.2807	0.2527
Between R^2	0.0040	0.1060	0.0007	0.0005	0.1447	0.0004
Total R^2	0.0285	0.1224	0.0189	0.0202	0.1542	0.0202

Note: Values in parentheses are coefficient t-statistics; ***, **, and * indicate passing the test at 1%, 5%, and 10% significance levels, respectively; semi-log t-values have been %-processed

3.3 Moderating effect analysis

In order to understand the moderating effect of the digitization degree dfi more intuitively, the panel data can be averaged for its digitization degree and divided into two groups: greater than dfi average and less than dfi average. Among them, the former includes the provinces of Gansu, Guangxi, Guizhou, Hebei, Henan, Heilongjiang, Inner Mongolia, Ningxia, Qinghai, Shanxi, Shaanxi, Tibet, Xinjiang and Yunnan; the latter includes the provinces of Anhui, Beijing, Fujian, Guangdong, Hainan, Hubei, Jiangxi, Shanghai, Tianjin, Hunan, Jiangsu, Liaoning, Shandong, Sichuan, Zhejiang and Chongqing.

The two-panel data are now regressed, and the results are shown in the table.

Table 5: Grouped regression results of digitization degree

Dependent variable			Provincial dfi mean above median		Provincial dfi means below median	
			lninne	lnvalc	lninne	lnvalc
Core explanatory variables	c_ r&di	fe	1.095*	0.314	0.426***	0.338***
			(1.70)	(1.27)	(2.88)	(3.98)
		re	1.453***	-	0.428***	0.350***
			(2.45)		(3.02)	(6.13)
Control variables	lnexm		-0.283	-0.289	-0.507**	-0.213
			(0.56)	(-1.49)	(-2.02)	(-1.49)
	lnpacr		-0.622	-0.417	-1.277***	-0.236
			(-0.92)	(-3.36)	(-2.86)	(-0.92)
	lnpie		1.664***	-0.564***	2.229***	-0.268
			(3.11)	(-2.72)	(7.54)	(-1.58)

Table 5: Grouped regression results of digitization degree (cont.)

Dependent variable	Provincial dfi mean above median		Provincial dfi means below median	
	lninne	lnvalc	lninne	lnvalc
Lntrd	-0.434	-0.781***	-0.672	-0.183
	(-1.15)	(-5.24)	(1.16)	(-0.55)
Hausman Test	6.15	31.79***	1.76	1.22
wald	32.2***	-	118.3***	56.61***
F test	6.15***	12.15***	22.63***	4.69***
Within R^2	0.2025	0.3360	0.4488	0.1453
Between R^2	0.0391	0.0393	0.1803	0.6794
Total R^2	0.0664	0.1208	0.2235	0.4328

Note: Values in parentheses are coefficient t and z statistics; ***, **, and * indicate passing the test at 1%, 5%, and 10% significance levels, respectively; semi-log t values have been % treated.

According to the results in the above table, the regression coefficient of enterprise innovation efficiency on R&D input is 1.453 and significant at a 1% level in provinces with provincial digitalization degrees higher than the median. While the regression coefficient of enterprise innovation efficiency on R&D input is 0.428 and significant at a 1% level in provinces with provincial digitalization degree less than the median, indicating that the digitalization degree has a positive moderating effect between enterprise R&D input and value. It can also be said that for regions with higher innovation capacity, the more obvious is the empowering effect of the digital economy on regional innovation capacity, which leads to the widening of the innovation capacity gap between regions, i.e., the empowering effect of the digital economy on enterprise innovation capacity is more obvious in regions with a higher degree of talent concentration or digital financial development. The overall increase in digitalization enhances the impact of R&D investment on innovation efficiency. This finding is highly consistent with the study by Han,Chen and Liang, (2021).

In addition, the regression coefficient of 0.314 was found to be insignificant in the regression of enterprise value creation on innovation efficiency in provinces where the degree of provincial digitization was higher than the median, while in provinces where the degree of digitization was less than the median, the regression coefficient of enterprise value creation on innovation efficiency was 0.35 and was significant at the 1% level. This indicates that the degree of provincial digitization does not have a moderating effect on the direct path between R&D investment and value creation, due to the difference in the perception of external environmental risks of firms (Xu,Yuan and Wang,2021), where more information in regions with better economic development makes it easier for firms to perceive external environmental risks, resulting in a decline in firm innovation efficiency eventually leading to a decline in firm value creation as well; on the contrary, in economically backward On the

contrary, in economically backward regions, the more companies perceive the external environmental risks, the higher the level of corporate innovation investment, the higher the innovation efficiency, and ultimately the higher the value creation. In other words, the increase of digitalization at this stage does not significantly improve the impact of R&D investment on value creation.

3.4 Model Robustness Test

In order to test the robustness of the model, the enterprise innovation efficiency is now replaced by the original economic output indicators with the indicators in terms of prior inputs, and the new product development expenditure and the number of projects developed are used to represent the enterprise innovation efficiency level. The regression models 1-6 are re-estimated, and the results are shown in the following table.

Table 6: Robustness test results

Dependent variable		Model 1 lnvalc	Model 2 lnnppe	Model 3 lnvalc	Model 4 lnvalc	Model 5 lnnppe	Model 6 lnvalc
Intermediate variables	lnnppe	-	-	0.039	-	-	-
				(0.19)			
Core explanatory variables	ln r&di	0.760***	-0.121*	0.764***	-	-	-
		(3.39)	(-1.78)	(3.39)			
Independent variable	c_nppe	-	-	-	-	-	0.007
							(0.30)
	c_ r&di	-	-	-	0.342***	-0.083***	0.349***
					(4.09)	(-3.35)	(4.04)
Control variables	lnexm	-0.260**	-0.047	-0.258**	-0.293***	-0.044	-0.274**
		(-2.50)	(-1.17)	(-2.47)	(-2.80)	(-1.41)	(-2.55)
	lnpacr	-0.425**	-0.012	-0.425**	-0.371**	-0.006	-0.369**
		(-2.29)	(-0.21)	(-2.29)	(-2.03)	(-0.11)	(-2.00)
	lnpie	-0.529***	-0.148***	-0.523***	-0.502***	-0.149***	-0.487***
		(-4.99)	(-4.63)	(-4.69)	(-4.78)	(-4.84)	(-4.39)
	lntrd	-0.792***	-0.071*	-0.788***	-0.773***	-0.116***	-0.780***
		(-6.25)	(-1.88)	(-6.13)	(-5.66)	(-2.93)	(-5.55)
Adjustment variables	c_dfi	-	-	-	-0.039	-0.078***	-0.333
					(-0.44)	(-2.96)	(-0.37)
Interaction items	c_ r&di·c_dfi	-	-	-	-0.060	-0.079***	-0.060
					(-0.67)	(-3.00)	(-0.66)
	c_nppe·c_dfi	-	-	-	-	-	2.56
							(0.74)

Table 6: Robustness test results (cont.)

Dependent variable	Model 1 lnvalc	Model 2 lnnppe	Model 3 lnvalc	Model 4 lnvalc	Model 5 lnnppe	Model 6 lnvalc
Hausman Test	45.52***	11.10	44.61***	45.37***	16.46**	47.30***
F test	16.03***	5.94***	13.31***	12.37***	7.24***	9.64***
Within R^2	0.2335	0.1007	0.2336	0.2491	0.1616	0.2510
Between R^2	0.0410	0.0002	0.0441	0.0008	0.0093	0.0006
Total R^2	0.0576	0.0052	0.0606	0.0196	0.0000	0.0914

Note: Values in parentheses are coefficient t-statistics; ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively; semi-log valuation has been done as a % treatment.

Comparing the results in Tables 4 and 6, it can be observed that the coefficients and the degree of significance changes of the core explanatory variables in the models remain largely consistent. In addition, the control variable pie has opposite signs in the second and fourth models, which indicates the heterogeneity of the economic output and economic input aspects of the degree of digitization regulating innovation efficiency, i.e., the degree of digitization shows positive regulation of innovation efficiency of economic output, while it shows negative regulation of innovation efficiency of product input. In addition to this, the signs of the coefficients of the control variables are largely consistent, indicating that the regression model constructed in this paper has good robustness.

4. Model conclusions and policy recommendations

The text uses a provincial panel data model for 2011-2020 to empirically analyze the relationship between R&D investment, innovation efficiency and value creation of large enterprises in provincial administrative regions of China. The results of the study indicate that.

First, the process of improving R&D investment in large enterprises is conducive to promoting the creation of enterprise economic value. On the one hand, in the process of upgrading the technology level, the investment of human, material, and financial resources of enterprises will enhance the development space of large and medium-sized enterprises to expand the market. On the other hand, the application of new technologies in large enterprises will not only help to grasp the market share but also prompt the upgrading of technology in enterprises in the same industry, which will lead to the introduction of new products. The study by Wang,Ji, (2006) shows that there is a multiplier effect between technological innovation investment and value creation, and reveals that the incentives and constraints of key employees are the factors affecting the multiplier effect, which is the core of technological innovation-based value management in enterprises. The empirical study in this paper mirrors this view that the development of a firm's technology level will lead to an increase in its value creation.

Second, the R&D investment of large firms is positively associated with the innovation efficiency of firms. This finding is in line with He,Qin, (2019) study the quality that digital transformation, driven by the innovation-driven model in the new era, significantly improves the economic efficiency of firms.

Third, a firm's innovation efficiency partially mediates the relationship between R&D investment and innovation efficiency. Firms with higher innovation efficiency tend to have more patent applications and contribute to the increase of commercial conversion rate, which leads to firm value creation. The results of the empirical study in this paper indicate that R&D investment drives innovation efficiency, and firms with high innovation efficiency tend to have more value creation. Therefore, the increase in value creation due to R&D investment in large and medium-sized firms is partly brought about by the mediating variable of firm innovation efficiency.

Fourth, the degree of digitization positively moderates the relationship between R&D investment and innovation efficiency. This empirical study shows that the positive relationship between R&D investment and innovation efficiency is stronger in regions with a higher degree of digitalization. Conversely, the influence of R&D investment on innovation efficiency is weaker in regions with a lower degree of digitalization.Tang,liu and ding,(2020) concluded that the overall degree of "Internet+" in China is low and unevenly distributed, and the technological innovation efficiency of both technology development and technology transformation in the high-tech manufacturing industry shows spatial dependence. This conclusion is also consistent with the empirical study in this paper, such that the impact of R&D investment on innovation efficiency is significantly greater in regions with a high degree of digitalization than in regions with a low degree of digitalization.

Fifth, large firm R&D investment in value creation does not show regional heterogeneity in the degree of digitization, and also, the degree of digitization does not have a significant moderating effect of innovation efficiency on value innovation. The research in this paper shows that the role played by large firm R&D investment in improving firm value creation is not significant in regions with high and low provincial dfi. The reason is that, firstly, firms in regions with relatively slow economic development have more flexible applicability of technology than firms in regions with a high degree of digital transformation. Secondly,He,Qin,(2019) concluded that the contribution of digital transformation to firm performance is more significant in private firms, which are more clustered in economically underdeveloped regions. Also, this paper found that the degree of digitalization does not have a significant moderating effect of innovation efficiency on value innovation. This finding is consistent with Tang,liu and ding,(2020),Li,Yang,Chen, (2021) that "Internet+" has a significant positive impact on technological innovation efficiency in the R&D stage, but not in the transformation stage. Although this digital transformation in the form of "Internet+" can significantly improve the efficiency of enterprise innovation, it also has cumulative effects and lags.

According to the above conclusions, the following policy recommendations are proposed:

First, the overall advantage of technological progress of large enterprises should be vigorously exploited. The conclusion of this paper shows that the technological progress of enterprises can effectively improve the value creation of enterprises. Therefore, the acceleration of the process of technological innovation and upgrading of large enterprises is conducive to the enhancement of value creation. The current technological advancement paths of large enterprises in China mainly include internal R&D, the introduction of foreign technology, and purchasing domestic technology according to the different sources of technological knowledge. Internal R&D is a large enterprise based on its own technical level to break through technical difficulties to generate new technology and effective technology innovation for external absorption of technology. The introduction of foreign technology enterprises should have their own development rhythm, plan, and focus on introducing external technology that the enterprise has not fully mastered but has a pressing need. At the same time, to strengthen the domestic institutions of higher education, industry, academia, and research projects to promote the transformation of scientific research results.

Second, further restructuring the industrial structure, especially the industrial layout of economic regions. The analysis in this paper shows that the impact of large enterprises' R&D investment on innovation efficiency is partly achieved by the increase of digitalization. The vigorous development of the "Internet+" development model has effectively contributed to improving technological innovation efficiency. However, the regional economy of China is regionally heterogeneous in terms of both the level of technological innovation and the efficiency of technological innovation. In the "pro" "clear" government-enterprise relationship, the government should focus on the development of policies to consider the shackles of regional technological innovation capacity, but also to consider the promotion of large and medium-sized enterprises to invest in R&D mobility, especially to strengthen the innovation of human and financial resources upfront investment. For regions with high technological innovation efficiency and low enterprise value creation, the focus should be on accumulating and guiding technological innovation efficiency, improving the ability of technology transformation to create value through government support or talent introduction, and thus improving the ability of large enterprises to create value.

Thirdly, the traditional enterprise development model should be changed, and innovation efficiency should be improved by relying on the "Internet+" economic background and green environment. This study shows that the degree of digitalization does not show significant moderation in the relationship between innovation efficiency and enterprise value creation. The reasons for this are twofold. One is that innovation efficiency is still in a state of technology accumulation at this stage of "Internet+", and has not yet reached the process of quantitative to qualitative change, so we cannot see the improvement of innovation efficiency transformation in large enterprises in the era of the digital economy. On the other hand, the change of economic development mode from focusing on economic efficiency to green environmental protection needs to improve environmental protection. It also needs to invest the necessary human and material resources.

Fourth, deepen the reform of the science and technology system to improve the efficiency of large enterprises' science and technology resource allocation. The research in this paper shows that the level of new technology R&D in large enterprises does not show the heterogeneity of regional digitalization degree on value creation. The reason is that the large enterprises with a high degree of digitization are still in the traditional processing stage, especially in the manufacturing industry, facing the contradictory problems of low product market demand structure and unreasonable matching of R&D resources, resulting in the low-value creation ability of enterprises, which shows similarity with the value creation ability of large enterprises with a low degree of digitization. Therefore, it is necessary to deepen the scientific and technological reform of large enterprises, integrate the existing R&D resources, build a platform to encourage technical cooperation and exchange, transform the traditional conservative model into a new intensive model, and then enhance the innovative value of high technology.

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