DO R&D SUBSIDIES IMPROVE OPERATIONAL PERFORMANCE? NEW EVIDENCE FROM CHINA*

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Abstract

The sustainable development of the digital economy has attracted wide attention. To explore how to improve the operational performance of China's digital firms, this paper conducts an influence mechanism model to test the nonlinear effect, heterogeneity effects, and mediation effects using a panel data of China's digital firms from 2008 to 2017. The empirical results indicate that R&D subsidies have an inverted U-shaped effect on operational performance, and these results are still valid after a series of robustness tests. In addition, we find that R&D subsidies have a heterogeneous effect on operational performance in terms of region, company size, governance structure, and executive education background. Moreover, regarding the influence mechanism, R&D subsidies improve operational performance by improving innovation efficiency. This paper proposes some policy implications to improve the operational performance of China's digital firms.

Keywords: R&D subsidies, digital economy, operational performance
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1. Introduction

The digital economy has a huge impact on contemporary society and the overall economy (Arendt, 2015; Goldfarb and Tucker, 2019). New technologies and business models

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derived from global digitization have changed the global economic system, hence global digitization plays an essential role in driving economic growth (Myovella *et al*., 2020). Along with the prompt development of technology, the digital economy industry of China has ushered in a golden era, as published by the White Paper on the Development of China's Digital Economy in 2020[1]. The digital economy scale in China reached 31.3 trillion yuan in 2018, and the proportion of GDP rose from 34.8% in 2018 to 36.2% in 2019; thereby, we can see that the digital economy is becoming a new engine of economic growth. However, the core competitiveness of the digital economy is manifested in the sustainable development ability, which becomes a significant indicator of the survival of a digital firm. Due to the limited funds for development, a digital firm hardly achieves its best development on its own funds, so government research and development subsidies are necessary for it. Many provinces in China (*i.e.*, Guangdong, Hainan, Zhejiang and Jiangsu) have implemented subsidy policies for the digital economy industry. Notably, it is worth studying whether R&D subsidies can enhance the digital economy industry's operational performance.

Several studies have illustrated the relationship between R&D subsidy policies and firm performance (Nilsen *et al.,* 2018). However, the impact on the operational performance of digital economy companies has not been deeply analysed. First, we assume that there is a nonlinear relationship; that is, as R&D subsidies increase, the operational performance of a digital firm rises first and then falls. If this assumption is confirmed, policymakers should establish an optimal adjustment mechanism for R&D subsidies. In addition, as regions, company sizes, governance structures and executive education backgrounds differ in digital economy companies, the impact of R&D subsidies varies. Furthermore, the mechanisms have not been expounded. An in-depth analysis of these problems may help policymakers better understand the influence on the operational performance of digital economy companies.

This study aims to analyse the influence mechanism of R&D subsidies on the operational performance of the digital economy industry. By using panel data on the digital economy industry from 2008 to 2017, we establish a model to measure the influence mechanism of R&D subsidies on operational performance. Meanwhile, we test the nonlinear relationship, heterogeneity effects and the mediating effects with innovation efficiency as a mediating variable. The major contributions are presented as follows: firstly, this paper, for the first time, analyses the impact of R&D subsidies on the operational performance of the digital economy industry from a micro perspective, which enriches the research in the field of the digital economy. Secondly, through heterogeneous studies, we make an in-depth

1 The White Paper on the Development of China's Digital Economy (2020) is released by the China Academy of Information and Communications Technology.

analysis of the effects regarding region, company size, governance structure and executive education background. Thirdly, using the mediating effect model, we examine the influence channels of R&D subsidies and operational performance. This systematic empirical analysis is significant for the improvement of the digital economy.

This study is structured as follows. Section 2 reviews the related studies. Section 3 contains the methodology and model specifications. Section 4 describes the data sources and indicators. Section 5 discusses the estimation results. Section 6 is the conclusion.

2. Literature Review

2.1 Literature on digital economy

As a new economy, being a network economy and internet economy, the digital economy takes data resources as the key and modern information network as the carrier, and can effectively promote the optimization of economic structure and improve economic efficiency (Miao, 2021; Liu *et al*., 2022). The digital economy has received wide attention, and existing literature on the digital economy mainly revolves around its measurement, development trends, influencing factors, and challenges (Popkova and Sergi, 2020; Chen, 2020; Fogel and Kliment'yeva, 2021). Although relevant studies have shown that the digital economy brings difficulties, such as platform monopoly, digital divide, and regulatory difficulties (Aaronson and Leblond, 2018; Han, 2020), it can nonetheless improve the efficiency of production and circulation and promote high-end, intelligent and green traditional industries with the support of a new generation of information technology (Ren *et al*., 2022). The premise of the development of the digital economy is mainly the optimization and upgrading of digital enterprises and breakthroughs in core technologies, mainly in the software, information service industry, and information communication industry. The development of digital enterprises is inseparable from technological innovation, capital investment, and government subsidies. However, the literature lacks a microlevel assessment of the operational performance of digital enterprises. Therefore, it is very important to study the operational performance of digital enterprises and government subsidies.

2.2 Literature on R&D subsidies and operational performance

There are many previous studies on R&D subsidies and operational performance, and these mainly include three viewpoints: promotion, inhibition and neutrality. Some scholars believed that R&D subsidies can directly increase corporate cash flow, relieve corporate R&D pressure, and improve innovation efficiency (Minford and Meenagh, 2019;

Wang *et al*., 2021). In addition, Czarnitzki and Hottenrott (2017) found that R&D subsidies can promote the innovation output of subsidized enterprises from the perspective of innovation output. Luo *et al*. (2021) found that R&D subsidies can significantly improve the operational performance of high-tech firms. Interestingly, some scholars hold the opposing opinion that R&D subsidies have a crowding out effect on corporate R&D expenditure. To obtain more R&D subsidies, companies focus on rent-seeking activities rather than improving innovation and operational performance (Bianchini, 2019). Furthermore, some scholars hold a neutral view that the effect turns from positive to negative over time. R&D subsidies play a positive role in operational performance in the short term but may have an inhibiting effect in the long run, which hinders overall firm effectiveness (Yu *et al*., 2020; Qian and Yuan, 2022). Meanwhile, some scholars have found that the impact of R&D subsidies on operational performance is heterogeneous in terms of countries, industries, and enterprise scale (Vanino *et al*., 2019). Therefore, there are no absolute optimal, most correct or universal R&D subsidies.

In summary, previous literature has discussed the relationship between the digital economy, R&D subsidies and business performance. However, there is no consistent conclusion about the impact of R&D subsidies on corporate operating performance. Meanwhile, there are few studies on the operational performance of digital enterprises in China. In addition, as a high-tech and high-investment industry, the rapid development of digital enterprises has a positive driving effect on other industries. Therefore, to improve the operational performance of digital enterprises, it is very important to study the relationship between the government's differentiated R&D subsidies policy and the operational performance of digital enterprises. Furthermore, there is heterogeneity due to the large differences between enterprises in terms of geography, size, governance structure, and executive education background. Therefore, we construct models to examine the nonlinear, heterogeneous, and mediating effects of R&D subsidies on operational performance.

3. Methodology

3.1 Basic regressions

Considering that R&D subsidies may have a nonlinear and complex influence on operational performance, this paper constructs an econometric model using the squared terms of the explanatory variables as follows.

$$ROA_{it} = \delta_0 + \delta_1 SUB_{it} + \delta_2 SUB_{it}{}^2 + \sum_j \delta_j control_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{1}$$

where *ROA* is the return on corporate assets, which represents financial performance.

The core explanatory variable *SUB* represents R&D subsidies, and SUB^2 is introduced in Equation (1), and is used to test the inverted U-shaped relationship.μ_i represents firm fixed effects, and v_t represents time fixed effects. ε_{it} is the random error term. We use company age, company size, earnings per share, financing expenses, income tax expenses, and the ratio of managerial ownership as control variables.

3.2 Mediation model

According to previous studies, R&D subsidies can improve firms' operational performance by increasing their research investment, improving their innovation level, and promoting their productivity growth (Aerts and Schmidt, 2008; Castellani *et al*., 2019). However, research investments do not necessarily produce practical research outputs. The use of scientific research input or output alone is not enough to describe the influence mechanism. Therefore, this paper selects innovation efficiency as a mediating variable to test the channels of R&D subsidies on operational performance. Referring to Baron and Kenny (1986), we construct the mediation model as follows.

$$IE_{it} = \alpha_0 + \alpha_1 SUB_{it} + \alpha_2 SUB_{it}^{\ 2} + \sum_j \alpha_j control_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{2}$$

$$ROA_{it} = \beta_0 + \beta_1 IE_{it} + \beta_2 SUB_{it} + \beta_3 SUB_{it}^{\ 2} + \sum_j \beta_j control_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{3}$$

where IE_{it} is innovation efficiency, representing the mediating variable, μ_i and v_t represent the unobserved heterogeneitiesis ε_{it} the random error term. We focus on the significance of the coefficients δ_1, α_1, β_1, β_2. Specifically, δ_1 represents the coefficient of the overall impact of R&D subsidies on operational performance, which comes from Equation (1). α_1 is the coefficient of the impact of R&D subsidies on innovation efficiency, β_1 is the indirect effect of R&D subsidies on operational performance and β_2 represents the direct effect of R&D subsidies on operational performance.

When α_1 in Equation (2) and β_1 in Equation (3) are significant at the same time, it indicates that R&D subsidies will affect the operation performance of enterprises through innovation efficiency. Meanwhile, if β_2 is still significant, it indicates that innovation efficiency is a partial mediating variable. R&D subsidies directly affect operational performance and affect operational performance by affecting innovation efficiency. If β_2 is not significant, it indicates that innovation efficiency is a complete mediating variable. R&D subsidies have no direct impact on operational performance or other mechanisms, and they affect operational performance through innovation efficiency.

4. Data and Indicators

4.1 Definition of variables

This study focuses on China's digital firms. We choose companies belonging to the digital industry in China from 2008 to 2017 based on the 2017 China Digital Economy Development White Paper[2], which includes three specific industries: "telecommunications radio, television and satellite transmission services", "internet and related services", and "software and information technology services". Due to the data availability, 231 enterprises were finally included in this paper. This paper obtains data from the China Stock Market & Accounting Research Database, the Development Research Centre of the State Council Information Network Database, and the REESET database. The descriptions of the variables are as follows.

4.1.1 Dependent variables

The operational performance of digital companies includes profitability, asset operation level and subsequent development ability. We use return on assets, return on equity and operating margin as indicators to measure the profitability of the companies, the efficiency of the company's use of its capital and the company's ability to earn profits from operating income. Among them, return on equity (*ROE*) and operating margin (*OM*) are used in the robustness test.

4.1.2 Core explanatory variables

This paper uses the actual amount of government R&D subsidies (*SUB*)given to digital companies as the core explanatory variable (Chen *et al*., 2018). It expresses the government financial support for enterprise innovation.

4.1.3 Mediation variables

The innovation efficiency (*IE*) refers to the formula: $IE = \frac{patentf_{it}}{RD_{it}}$, where the numerator denotes the number of company patent inventions and the denominator is R&D expenditure. This paper uses innovation efficiency to measure the conversion efficiency between the company research input and the output of patented inventions.

2 The link to the 2017 China Digital Economy Development White Paper is: http://www.cac.gov.cn/2017-07/13/c_1121534346.htm

4.1.4 Control variables

Referring to the suggestions of the control variable selection (Angrist and Pischke, 2008), based on the exogeneity and data availability, this paper adds relevant variables to control the influence of other factors on operational performance, including company age, company size, earnings per share, financing expense, income tax expense, and the ratio of managerial ownership, while controlling for yearly and industry dummy variables. The specific variable characteristics are shown in Table 1.

Table 1: Variables and their definitions

Variable category	Variable name		Variable Symbol	Variable description
Dependent variable	Operational performance	Return on Assets	*ROA*	The rate of total profit to total assets of the company
		Return on Equity	*ROE*	Net profit / (Owner's equity at the beginning of the year + Owner's equity at the end of the year) / 2
		Operating Margin	*OM*	EBITDA (earnings before interest and tax) to operating income ratio
Core explanatory variables	Government R&D subsidies		*SUB*	Subsidies for research funds directly supported by governments
Mediation variables	Innovation efficiency		*IE*	The ratio of corporate patent inventions to corporate research expenditure
Control variables	Company age		*AGE*	The company has been operating from the date of registration to 2017
	Company size		*SIZE*	Total assets at the end of the year
	Earnings Per Share		*EPS*	The ratio of profit after tax to total equity
	Financing Expense		*FE*	Corporate finance costs
	Income Tax Expense		*ITE*	The expenses paid on the business income
	The ratio of Managerial Ownership		*MO*	The ratio of the number of shares held by executives to the total number of shares

Source: Own definition

4.2 Descriptive statistics of variables

Table 2 shows the descriptive statistics of all the variables. The mean value of the digital firm's return on assets (*ROA*) is 0.069 with a standard deviation of 0.336. Based on the mean value of return on assets, we find that operational performance is relatively low. Meanwhile, the standard deviation of R&D subsidies and innovation efficiency of different companies show a large gap, which may lead to differences in operational performance. To improve the stationarity of the data, we standardize the data in the empirical analysis below.

Table 2: Descriptive statistics of variables

Variables	Obs	Mean	Std. dev.	Min	Max	Unit
ROA	1,538	0.069	0.336	–1.100	12.825	–
ROE	1,043	0.095	0.753	–3.514	23.739	–
OM	1,538	0.193	2.579	–45.828	75.212	–
SUB	2,310	1.518	3.756	0.000	42.807	Ten million yuan
IE	1,055	1.288	4.654	0.000	93.471	–
AGE	2,310	13.500	5.530	0.000	32.000	Year
SIZE	2,310	0.411	3.381	0.000	61.591	Ten billion yuan
EPS	1,060	0.408	0.845	–4.558	16.539	–
FE	2,310	0.191	2.336	–1.681	64.934	Hundred million yuan
ITE	2,310	2.215	16.394	–14.295	386.861	Ten million yuan
MO	1,051	0.178	0.190	0.000	0.708	–

Source: Own calculation

5. Results and Discussion

5.1 Nonlinear relationship analysis of operational performance

In this part, we measure the impact of R&D subsidies on operational performance. Table 3 shows the consequence of the basic regressions of return on assets. Considering robustness and omitted variables, models I to V in Table 3 show the estimation results of gradually putting in control variables. As we can see from the results, before adding control variables, the effect of *SUB*, SUB^2 on operational performance is positive but not significant at the statistical level. However, with the gradual addition of the control variables, the effect of *SUB* on operational performance turns from negative to positive, and the statistical level gradually becomes significant. Model VI estimation results for all the control variables and the annual dummy variables show that the effect of *SUB* on the operational performance is observably positive at the 5% statistical level, showing that R&D subsidies have a promoting effect on operational performance and that increasing R&D subsidies help improve operational performance. In addition, according to the estimation results of SUB^2 in model VI, the effect of SUB^2 on operational performance is observably negative at the 5% statistical level after controlling for all variables. The effect of R&D subsidies on operational performance is positive at the beginning of the period, but the incentive effect turns from positive to negative when the subsidies exceed a certain point. Therefore, we can conclude that R&D subsidies have an inverted U-shaped effect on operational performance.

Table 3: Basic estimation results

Variables	*ROA*					
	I	II	III	IV	V	VI
SUB	0.0033 (0.71)	−0.0001 (−0.02)	0.0137* (1.66)	0.0318** (2.07)	0.0368** (2.42)	0.0422** (2.60)
SUB^2		0.0035 (0.48)	−0.0041 (−0.54)	−0.0598** (−2.21)	−0.0660** (−2.39)	−0.0734** (−2.59)
AGE			−0.0367*** (−5.82)	−0.0351*** (−2.71)	−0.0356*** (−2.68)	−0.0301*** (−2.79)
SIZE			−0.0007 (−0.10)	0.1090 (1.09)	0.1280 (1.28)	0.1150 (1.14)
EPS				0.0501** (2.29)	0.0502** (2.27)	0.0500** (2.27)
FE				−0.1150* (−1.95)	−0.1010** (−2.38)	−0.1030** (−2.48)
ITE					−0.0446 (−0.95)	−0.0463 (−0.98)
MO					−0.0049 (−0.62)	−0.0047 (−0.57)
Year	No	No	No	No	No	Yes
Individual	No	No	No	No	No	Yes
Constant	0.0619*** (332.23)	0.0620*** (280.71)	0.0740*** (34.59)	0.0705*** (7.93)	0.0699*** (7.86)	0.0703*** (8.15)
Observations	1,485	1,485	1,485	1,025	1,025	1,025
***R*-squared**	0.001	0.001	0.050	0.349	0.356	0.361

Notes: *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Own calculation

In addition, from the estimation results of the control variables in Table 3, the effect of companies' operating years (*AGE*) on operational performance is significantly negative at the 1% statistical level. According to the previous analysis, the longer the companies operate in years, the richer in knowledge, experience and funds accumulation the companies will become, which is also more beneficial for technological innovation. However, it is not certain that this will ultimately translate into improved levels of operational performance. The effect of earnings per share (*EPS*) on operational performance is statistically positive at the 5% level, so it shows that increasing earnings per share is beneficial to improve the operational performance of digital enterprises. The effect of corporate finance costs (*FE*) on operational performance is significantly negative at 5%.

5.2 Robustness test

Considering whether the basic estimation results are robust, we use four methods to test the robustness, including substituting dependent variables, substituting the explanatory variable, adding control variables, and endogenous tests. The robustness results are shown in Appendix Table A3.

Specifically, firstly, return on equity (*ROE*) and operating margin (*OM*) are used to replace dependent variables for robustness testing. Secondly, we use the government subsidy intensity to replace the explanatory variable, that is, the ratio of scientific research subsidies to corporate assets, to measure the government R&D subsidy intensity of enterprises. Thirdly, due to the omitted variables, we add the company's net profit, market share, and industry concentration to re-estimate. All the robustness estimation results show that R&D subsidies have an inverted U-shaped effect on operational performance. Finally, to solve the endogeneity problem, this paper selects the sales profit rate with a lag of one period as an instrumental variable and uses the instrumental variable method to estimate the two-stage least squares (2SLS). From the first-stage estimation results in Column V of Table A3, it can be seen that the instrumental variables are highly correlated with endogenous variables, and the first-stage F-value of 38.1 is greater than the critical value of 10, indicating that there is no weak instrumental variable problem. From the estimation results in Column VI, it can be seen that R&D subsidies have an inverted U-shaped effect on operational performance. Furthermore, the empirical results are still valid after a series of robustness tests.

5.3 Heterogeneity analysis

This section makes an in-depth examination of the effects using heterogeneous analysis in terms of different regions, company sizes, governance structures and executive education backgrounds.

Table 4: Regional heterogeneity test results

Variables	*ROA*		
	East	**Central**	**West**
SUB	0.0380** (2.20)	0.0225 (1.60)	0.0681 (0.42)
SUB²	−0.0703** (−2.21)	−0.0285 (−1.23)	−0.4640 (−0.34)
AGE	−0.0197** (−2.18)	0.0079 (0.68)	−0.0603 (−1.21)
SIZE	0.0966 (0.95)	−0.2010* (−1.84)	0.3550 (0.89)
EPS	0.0425** (2.37)	0.1730*** (30.22)	0.0191 (0.36)
FE	−0.1200*** (−3.45)	0.2370* (2.16)	−0.1560 (−1.50)
ITE	−0.0536 (−1.08)	0.0618 (0.77)	0.1010 (1.36)
MO	−0.0028 (−0.30)	−0.0032 (−0.25)	−0.0016 (−0.08)
Year	Yes	Yes	Yes
Individual	Yes	Yes	Yes
Constant	0.0650*** (7.35)	0.0880*** (8.12)	0.0511 (0.34)
Observations	856	81	88
***R*-squared**	0.368	0.964	0.325

Notes: *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Own calculation

First, to understand the current situation of the digital economy development in each of the various regions, we divided the sample into three districts – eastern, central and western – according to registered locations (as shown in Appendix Table A1). As we can see in Table 4, R&D subsidies have an inverted U-shaped effect on operational performance in the eastern region. However, for the central and western areas, R&D subsidies have a prominent but statistically insignificant influence on operational performance. This may be because the central and western regions are inland, with imperfect internet infrastructure and relatively backward economic development.

In addition, the results show that the R-squared is larger in the estimated results in the central region, indicating that the R&D behaviour of enterprises in the central region is theoretically in line with the inverted U-shaped model. This is mainly because companies in the central region are eager to use government R&D subsidies to improve operational performance. However, due to the limitations of regional talent and technology levels, the innovation effect is not satisfactory. Therefore, there is an inverted U-shaped trend, although it is not statistically significant. However, this does not have much impact on the conclusions of this paper.

Table 5: Heterogeneity analysis results

Variables	***ROA***		***ROA***		***ROA***	
	Small and medium	**Large**	**Imperfect**	**Perfect**	**Below graduate**	**Postgraduate and above**
SUB	0.0387** (2.42)	−0.0035 (−0.25)	0.0284 (1.37)	0.0351* (1.97)	0.0121 (0.97)	0.0442** (2.40)
SUB^2	−0.0409 (−0.47)	0.0020 (0.07)	−0.0299 (−0.95)	−0.0684** (−2.18)	−0.0275 (−1.32)	−0.0695** (−2.08)
AGE	−0.0346*** (−2.87)	−0.0036 (−0.29)	−0.0075 (−0.57)	−0.0446*** (−3.19)	−0.0110 (−1.53)	−0.0343** (−2.34)
SIZE	−0.0961 (−0.53)	−0.0690 (−1.22)	−0.2830*** (−3.32)	0.0323 (0.57)	−0.1970*** (−3.15)	0.1370 (1.38)
EPS	0.0387*** (2.68)	0.1420*** (6.71)	0.0480* (1.80)	0.0437*** (2.74)	0.0788*** (7.91)	0.0454** (2.29)
FE	0.0083 (0.14)	0.0454 (1.29)	0.1090*** (2.74)	0.0192 (0.62)	−0.0170 (−0.55)	−0.1000*** (−2.91)
ITE	0.2550*** (3.92)	−0.0496*** (−3.66)	0.2010*** (2.92)	0.0699* (1.79)	0.1330*** (4.64)	−0.0893*** (−2.85)
MO	−0.0045 (−0.47)	−0.0022 (−0.25)	0.0073 (0.98)	−0.0459 (−1.49)	−0.0034 (−0.61)	−0.0147 (−1.15)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0949*** (4.08)	0.0736*** (8.17)	0.0658*** (5.04)	0.0588*** (5.94)	0.0598*** (10.77)	0.0699*** (5.17)
Observations	773	252	447	578	403	622
***R*-squared**	0.271	0.862	0.441	0.330	0.586	0.378

Notes: *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Own calculation

We then divide the enterprises into small medium and large companies based on the number of employees at the end of the year (as shown in Appendix Table A2). Generally, the larger the scale of the companies is, the more likely enterprises are to increase their research resources in innovation and make more profits (Noori *et al*., 2017). As can be seen from the scale heterogeneity analysis results in Table 5, the impact of R&D subsidies on the *ROA* of small and medium-sized companies is prominently positive at the 5% level, and the coefficient of SUB^2 is not significant, which indicates that R&D subsidies have an important impact on operational performance and they do not exhibit an inverted U-shaped trend. A possible reason is that small companies are developing rapidly and pay more attention to *ROA*. However, from the estimation results of large digital companies, there is not an inverted U-shape of R&D subsidies on operational performance.

Afterwards, we test whether the corporate governance structure of the companies influences the effect of R&D subsidies on operational performance. We measure corporate governance structure by identifying whether the chairman and CEO positions are occupied by the same individual or two different individuals (Bhagat and Bolton, 2019). If they are occupied by the same person, we define it as a company with an imperfect governance structure, and if they are occupied by two different individuals, we define it as a company with a perfect governance structure. The estimation results are displayed in Table 5. R&D subsidies have an inverted U-shaped effect on operational performance for companies in which the chairman and CEO positions are held by two different individuals. In contrast, when the company's chairman and CEO positions are held by the same person, the effect of R&D subsidies on operational performance is not significant. This indicates that a perfect governance structure can help digital firms improve operational performance, consistent with Iqbal *et al*. (2019).

Finally, since digital economy companies are technology oriented, executives with different educational backgrounds have different orientation preferences, which will affect the business performance of the company. Therefore, this paper analyses the impact of R&D subsidies on companies with different executive education backgrounds by dividing the sample into high academic (postgraduate and above) and low academic (below postgraduate) groups. Notably, the data include directors and supervisory boards. From the results in Table 5, we can see that for the highly educated group, the impact of R&D subsidies on *ROA* is significantly positive under the 5% statistical standard. This means that R&D subsidies have a significant incentive effect on operational performance, and there is also an inverted U-shaped impact.

In summary, there is heterogeneity in the impact of R&D subsidies on operational performance in terms of company size, regional location, governance structure and executive education background. This analysis can help policy designers formulate effective policies.

5.4 Influence mechanism analysis

The above empirical results show that R&D subsidies can improve operational performance. Based on the analysis in this paper, R&D subsidies can affect a company's output via innovation efficiency and then affect operational performance. Therefore, this paper selects innovation efficiency as a mediation variable to analyse the influence mechanism in Equations (2)–(3). The analysis results are reported in Table 6.

Table 6: Influence mechanism analysis

Variables	*ROA*	*IE*	*ROA*
	I	II	III
SUB	0.0422** (2.60)	0.2110 (0.42)	0.0203* (1.94)
IE			0.0091** (2.20)
SUB^2	−0.0734** (−2.59)	−0.6020 (−0.58)	−0.0358* (−1.82)
AGE	−0.0301*** (−2.79)	−0.8830 (−1.23)	0.0029 (0.32)
SIZE	0.1150 (1.14)	43.2600*** (3.50)	−0.1200 (−1.52)
EPS	0.0500** (2.27)	0.2620 (0.86)	0.1210*** (7.15)
FE	−0.1030** (−2.48)	2.8490 (0.65)	−0.0402 (−1.26)
ITE	−0.0463 (−0.98)	−13.4700*** (−3.96)	−0.0167 (−0.97)
MO	−0.0047 (−0.57)	0.0866 (0.42)	−0.0144 (−1.31)
Year	Yes	Yes	Yes
Individual	Yes	Yes	Yes
Constant	0.0703*** (8.15)	3.4530*** (3.30)	0.0514*** (4.91)
Observations	1,025	747	747
***R*-squared**	0.361	0.612	0.612

Notes: *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Own calculation

We can see in model I of Table 6 that the total impact of R&D subsidies on operational performance is 0.0422 and is conspicuously positive at the 5% level. Regarding the effect of R&D subsidies on innovation efficiency (*IE*), the coefficient of *SUB* on *IE* is conspicuously positive, indicating that R&D subsidies help improve innovation efficiency but not at a statistically significant level (see model II in Table 6). Further analysis in model III shows that the coefficient of *IE* on operational performance is 0.0091, which is conspicuously positive at the 5% statistical level. The coefficient of the effect of R&D subsidies on operational performance is 0.0203, which is dramatically positive at the 10% level. There is evidence that innovation efficiency plays a mediating role in the impact of R&D subsidies on operational performance.

6. Conclusion

The operational performance of the digital economy industry is a significant component of the rapid development of the digital economy. Nevertheless, previous studies have neglected the effect of R&D subsidies on operational performance. This paper uses China's microlevel digital economy industry panel data from 2008–2017 and tests the nonlinear effects, heterogeneity effect, and mediation effects with innovation efficiency as a mediating variable. Based on the above analysis, this study draws the following main conclusions.

The overall effect of R&D subsidies on the operational performance of digital firms has a positive incentive impact, but the effect has an inverted U-shape, that is, as R&D subsidies increase, operational performance shows an upwards trend and then a downwards trend. In this paper, we find that the inverted U-shaped trend still exists by replacing the dependent variables, explanatory variables, estimation samples, and endogenous tests.

The heterogeneity analysis indicates that the influence of R&D subsidies on operational performance is more evident for geographic region, firm size, governance structure, and executive education background. Firstly, R&D subsidies have an apparent effect on operational performance in the eastern region, and there is an inverted U-shaped relationship. Secondly, there is an inverted U-shaped relationship on the operational performance of small and medium-sized companies. Thirdly, there is an inverted U-shaped relationship when the governance structure is perfect. Fourthly, among digital firms with executives who have high education, R&D subsidies have an observable positive incentive impact on operational performance.

The mechanism analysis indicates that R&D subsidies have a conspicuous effect on the operational performance of digital companies at a 5% statistical level. The improvement of innovation efficiency increases the output of enterprises and has a promoting effect on operational performance. The mediating effect test reveals that R&D subsidies can improve operational performance through innovation efficiency.

This study offers some ideas for improving operational performance. Policy designers should set the optimal R&D subsidy criterion for digital economy industries. Due to constraints on financial resources, local governments need to identify whether digital companies require R&D subsidies based on their development stage and build an effective subsidy mechanism to make full use of the subsidies. When formulating R&D subsidy policies, policy-makers need to formulate differentiated and targeted subsidies policies for companies in different regions, at different size levels, and with varying governance structures. In addition, enterprises should also pay attention to investment in technology research and development, introduce advanced technology, improve the intensity of innovation, and ultimately improve the level of operational performance.

This paper offers a new perspective on the digital economy, but we only consider the operational performance of China's digital firms due to data limitations. We hope to have more published data from different countries in the future for further comparative study.

Appendix

Table A1: Classification of three economic regions in China

Region	Provincial regions
Eastern	Liaoning, Hebei, Tianjin, Beijing, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan
Central	Heilongjiang, Jilin, Inner Mongolia, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan
Western	Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Chongqing, Sichuan, Yunnan, Guizhou, Tibet

Source: National Bureau of Statistics

Table A2: Statistical classification criteria for large, medium, small and micro companies

Industry name	Indicator name	Measurement unit	Large	Medium	Small	Micro
Information transmission industry *	Employees (X)	People	X ≥ 2,000	100 ≤ X < 2,000	10 ≤ X < 100	X < 10
	Operating income (Y)	Million (¥)	Y ≥ 1,000	10 ≤ Y < 1,000	1 ≤ Y < 10	Y < 1
Software and information technology services	Employees (X)	People	X ≥ 300	100 ≤ X < 300	10 ≤ X < 100	X < 10
	Operating income (Y)	Million (¥)	Y ≥ 100	10 ≤ Y < 100	0.5 ≤ Y < 10	Y < 0.5

Notes: The scope of each industry in the schedule is based on the National Economic Classification of Industries (GB/T4754-2017). Items with * are industry combination categories, among which the information transmission industry includes telecommunications, radio and television and satellite transmission services, Internet and related services.
Source: National Bureau of Statistics

Table A3: Robustness estimation results

Variables	Replace dependent variables		Replace explanatory variable	Add control variables	Endogeneity estimation	
	I	II	III	IV	V	VI
	ROE	***OM***	***ROA***	***ROA***	***sub***	***ROA***
SUB	0.0750** −2.09	0.1020** (2.32)	0.0279*** (2.71)	0.0260** (2.22)		3.7180*** (2.64)
SUB²	−0.0961* (−1.75)	−0.1840** (−2.51)	−0.0131** (−2.53)	−0.0425** (−2.11)	1.7860*** (15.34)	−6.6410*** (−2.68)
AGE	−0.1240 (−1.62)	−0.1230*** (−3.15)	0.0004 (0.07)	−0.0378*** (−4.03)	0.0040 (0.09)	−0.5100*** (−2.58)
SIZE	0.3850 (0.94)	1.0090*** (3.44)	−0.0167 (−0.54)	−0.2630*** (−2.64)	0.5250*** (3.02)	−1.7830* (−1.72)
EPS	0.1060** (2.05)	0.0857 (1.55)	0.1160*** (9.07)	0.0345*** (2.81)	0.0110 (0.67)	0.0067 (0.14)
FE	−0.0008 (−0.01)	−0.4160*** (−3.17)	−0.0284 (−1.29)	0.1670*** (3.27)	−0.0570 (−0.71)	0.0862 (0.28)
ITE	0.1490 (1.46)	−0.1010 (−0.90)	−0.0383** (−2.09)	0.1260** (2.60)	0.1580*** (3.07)	−0.6310** (−2.27)
MO	−0.0525 (−1.34)	−0.0163 (−0.66)	−0.0110 (−1.51)	−0.0052 (−0.76)	0.0150 (0.61)	−0.0612 (−0.72)
NP				0.0986*** (4.79)		
MS				−0.0108 (−0.97)		
HHI				−0.7410 (−1.37)		
I_OM					0.0010*** (2.68)	
Phase I *F*-value					38.10	
Year	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.1440*** (3.86)	0.2400*** (8.89)	0.0582*** (10.01)	0.0351 (1.19)	0.0730** (2.49)	−0.4430** (−1.97)
Observations	1,018	1,025	914	1,025	877	877
***R*-squared**	0.027	0.128	0.598	0.533	0.809	0.015

Notes: *t*-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Own calculation

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