

Li, Junjun

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R&D Subsidies and Technological Progress in the Chinese ICT Manufacturing Industry

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R&D Subsidies and Technological Progress in the Chinese ICT Manufacturing Industry

ABSTRACT

In the past decades, the Chinese ICT industry has received fiscal, taxation, and financial policy support in technology R&D. This research adopts causal inference methods for mediation analysis with interaction to empirically examine the direct and indirect effects of R&D subsidies in the Chinese ICT manufacturing industry. We found that the impact of R&D subsidies on private R&D expenditure and innovation outputs is positive and statistically significant. However, higher subsidy intensity crowds out private R&D expenditures. Second, in the Eastern region, firms invest more in R&D but more in incremental rather than radical innovation. And, the enterprise average private R&D expenditure is insufficient in the ECE sector. Finally, openness and information levels positively contribute to innovation outputs. Based on the findings, we propose several policy suggestions.

Keywords: R&D subsidies, innovation output, private R&D investment, Chinese ICT manufacturing, causal mediation analysis

I. Background

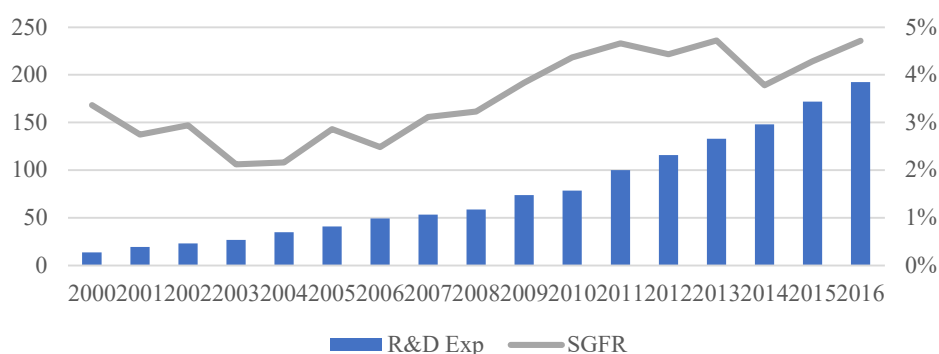
The Chinese government views the ICT industry as a vital force to lead the future social and economic development and the frontier industry for China's transition from a manufacturing to a knowledge-based economy. At the same time, the global communication network is booming, and smart consumer devices are widely popularized. The Chinese ICT industry has achieved enormous growth when facing tremendous development opportunities at home and abroad, and its industrial-scale ranks among the top in the world. In 2018, the Chinese ICT market grew 8.2%, reaching a value of 2.86 trillion CNY, and the total output of the ICT sector exceeded 18 trillion CNY in 2017 (Atradius, 2018; 2019).

China's ICT manufacturing industry started from a fragile foundation. In the early days of reform and opening up, it was almost entirely composed of state-owned enterprises (SOEs), and foreign firms almost monopolized the whole market. Meanwhile, the research and development (R&D) was mainly performed by state-owned research institutes until the 1990s. With the deepening of reform and opening up, the types of enterprises have shifted to diversification. Many local private and foreign-funded firms have joined and played a significant role in the growth of ICT manufacturing. In 1997, the state officially recognized the non-public sector as an essential part of the socialist market economy. The government extended R&D support to the non-public sector, and private firms became beneficiaries of China's innovation policies.

In 2006, the *Medium to Long-term Plan for Science and Technology Development* was implemented. Furthermore, the State Council issued the *Decision on Accelerating the Cultivation and Development of Strategic Emerging Industries* in 2010. These policies brought

a vast impetus to ICT technology innovation. Technology R&D investment is increasing year by year (Figure 1). In 2019, ICT manufacturing attracted the most R&D funding— totaling \$35.4 billion (ChinaPower). The innovative output in ICT has also achieved remarkable results. The number of patents representing technological competitiveness has increased annually, and its proportion in the total global ICT patents has increased (Figure 2). In the 5G era, China's 5G patent applications account for 36.4% of the worldwide total, ranking at the top. China has transformed from a mere ICT sales market to a strategic focus of R&D cooperation and an essential source of creativity.

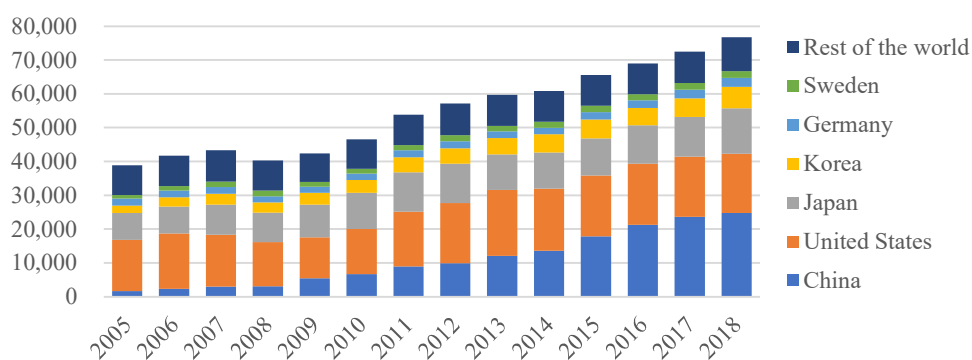
Figure 1 R&D investment & subsidy intensity in Chinese ICT manufacturing (2015 constant prices, billion CNY)



Notes: subsidy intensity = R&D subsidies / total R&D expenditure

Source: Author's calculation and graphing base on the data from *China Statistics Yearbook on High Technology Industry*

Figure 2 ICT patent applications filed under the PCT by country (Priority date)



Source: Author's graphing base on the data from OECD.Stat

It aims to correct market failures in producing knowledge (Arrow, 1962) that governments introduce policies to encourage private R&D investment. The Chinese government expects to achieve high-quality economic growth by stimulating innovation. As one of the High-tech and strategic emerging industries in China, ICT manufacturing has received fiscal, taxation, and financial policy support for R&D. Figure 1 shows the R&D subsidy intensity, R&D subsidies over total R&D expenditure, in the Chinese ICT manufacturing during the period 2000-2016. Since implementing the "Medium and Long-Term

Science and Technology Development Plan" in 2006, the subsidy intensity increased significantly and remained at around 4 to 5 percent in the 2010s.

In most countries that implement R&D support, governments at different levels develop and enforce their subsidy programs. For example, a firm in Flanders, Belgium, may apply and get R&D support from the EU, Belgian government (national), and Flemish Government (regional) (Czarnitzki & Lopes-Bento, 2013). In China, it is similar but has more levels and support programs and funds. Support programs and funding can come from national (ministerial), provincial, municipal, district, and high-tech industrial park government agencies.

After the 1980s, several Chinese central government agencies had established around 100 science and technology programs and funds, such as Key Technologies R&D Program, National High Technology Program (863 Program), and Industrial Technology R&D Program. To integrate resources and improve efficiency, in 2015, they were integrated into five categories: National Natural Science Foundation of China (NSFC), National Science and Technology Major Project (STMP), National Key R&D Program (KRP), Technology Innovation Guidance Special fund (TIGS), Base and Talent Special (BTS).

Local governments have also launched various subsidy programs and funding to attract investment and high-tech firms on one side and to complete the tasks assigned by the central government on the other side. Taking Shenzhen as an example, the local subsidies include such as High-tech Enterprise R&D Expense Subsidies, R&D Expense Grants, Programs for Science and Technology Development, and Awards for Innovation and Entrepreneurship Competition. Meanwhile, national subsidies, such as the TIGS, are allocated from central finance to local and planned and managed by provinces and municipalities.

Different opinions have been on whether the government should grant R&D subsidies to firms. The scandal of government-funded microchip development in the 2000s has raised questions from academia, and the incident exposed the problems of poor oversight, wasted resources and corruption in government-funded projects. Afterwards, the government have strengthened the supervision and public oversight, introduced peer review, and gradually delegated power to local governments to enhance the efficiency of government R&D support. However, there are still many doubts about the effect of Chinese R&D subsidies.

This research empirically explores whether R&D subsidies promote private R&D investment and technological progress in the Chinese ICT manufacturing industry. The research questions are:

in the Chinese ICT manufacturing sectors,

1. do R&D subsidies encourage firms to invest more in R&D?
2. do R&D subsidies improve innovation output, such as the number of patents and the output of new products?
3. do regional and sectoral characteristics, such as information level, human capital level, and export dependence impact private R&D investment and innovation efficiency?

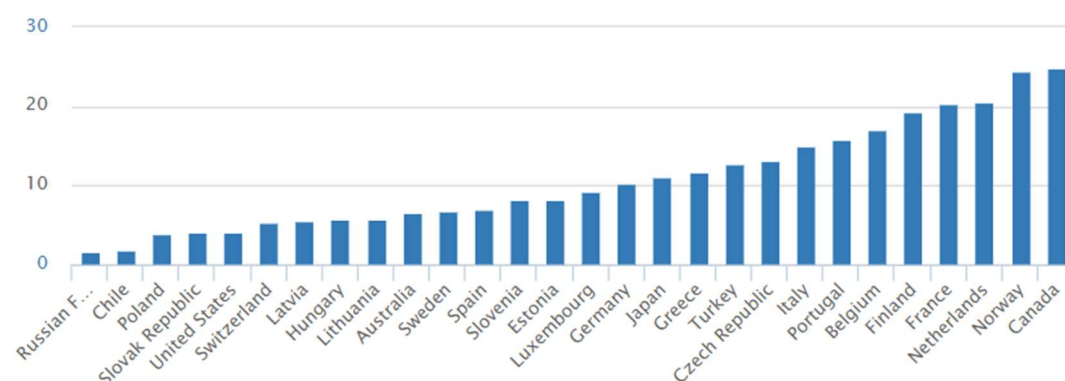
II. Literature review

In classical economic research (Schumpeter, 1939) and neoclassical growth theory (Solow, 1956), innovation and technological progress is the causative factor of economic

growth. However, due to market failures in the production of scientific and technological knowledge (Arrow, 1962), firms tend to underinvest in R&D. The cost of R&D is high because of its long periodicity and uncertainty in returns. In addition, the capital market induces firms to ignore innovations with social values and pay more attention to those with commercial values (Griliches, 1987).

To achieve higher economic growth and improve economic welfare, governments in industrialized countries attempt to encourage the private sector to invest more in R&D by introducing policies, such as direct subsidies, tax incentives, and low-interest loans. These incentives are designed to reduce the cost and/or raise the marginal rate of return on investment in R&D activities. R&D subsidies constitute a direct support measure in contrast to indirect fiscal support (e.g. tax credits) and are widely implemented (Figure 3).

Figure 3 Percentage of innovative firms receiving public subsidies for innovation, 2016



Source: OECD, The STI.Scoreboard

2.1 Direct contribution to economic output

Some economic studies investigate the effects of government R&D support on economic growth. However, they do not find empirical evidence that R&D subsidies directly contribute to economic output. Some find private R&D has a substantial and statistically significant direct effect on economic output. In contrast, the impact of government R&D support is close to zero or negative or statistically insignificant.¹

Levy (1990) argues that in equilibrium, the marginal product of government R&D support could be equal to zero, as a firm can employ it at no private cost. Therefore, its non-significant impact on output growth does not mean the inefficiency of R&D subsidies. Van Pottelsberghe (1997) argues that firms must spend much money on project preparation, lobbying, and competition to attract government support. Although the private cost of R&D subsidies is not zero, it is lower than the total private cost of the project, and it should be one of the reasons that the direct effect of government R&D on output growth is weaker.

However, the study of Nilsen et al. (2020) shows that R&D support is significantly positive for output and employment. They analyzed all direct and indirect R&D support sources

¹ See David et al. (2000). The findings are from Griliches (1980), Griliches & Lichtenberg (1984), Bartelsman (1990), and Lichtenberg & Siegel (1991).

for the private sector in Norway from 2002 to 2013. The study of Korean manufacturing SMEs suggests that the effects of R&D subsidies on the value-added productivity are also positive and statistically significant (Cin et al., 2017).

2.2 Direct effect on private R&D activities

R&D subsidies are used as policy instruments to encourage private R&D activities directly. Accordingly, many empirical studies assess the direct effect of R&D subsidies on private R&D investment. Are government R&D support and private R&D substitutes or complements? Most researchers believe R&D subsidies can stimulate private R&D investment, and they estimate the effect of R&D subsidies on private R&D based on the complementarity assumption. Zúñiga-Vicente et al. (2012) surveyed 77 empirical studies since the middle of the 1960s, and 60 percent of the studies report overall complementarity while 19.5 percent report a crowding-out effect.

In the recent decade, studies still show both complementary and substitutive effects. Huergo and Moreno (2017) find that all types of direct subsidies enhance the probability of private R&D activities through the analysis of three types of public support to Spanish firms: the national low-interest loans for R&D projects, the national scheme of R&D subsidies, and the European system of R&D grants. Cin et al. (2017) find significant evidence for the positive effects of R&D subsidies on private R&D expenditure of Korean manufacturing SMEs. Marino et al. (2016) examined French firms from 1993 to 2009 and find no evidence of either complementarity or substitution effects between public and private R&D expenditure. However, medium-high levels of public subsidies and under the 2004 new regime of R&D tax credit show a crowding-out effect. Szücs (2020) evaluates the EC's three most recent Framework Programmes, and the results suggest that, on average, subsidies do not increase private research budgets. However, they increase the private R&D investment of small firms and more R&D-intensive firms.

2.3 Empirical studies with China data

Until the 1990s, most of the studies were conducted with US data. In the late 1990s, empirical research on EU countries increased rapidly. In the surveys of Zúñiga-Vicente et al. (2012), more than 80 percent of these studies are based on US and EU data. Since the late 2000s, the rise of China as an innovation-driven economy and the promotion of government economic policies have attracted attention, and related research is increasing. The studies mainly focus on assessing the effect of public support on private R&D investment at the firm level.

Boeing (2016) examined data from listed firms in China between 2001 and 2006. He finds that "R&D subsidies instantaneously crowd-out own R&D investment of firms but are neutral in later periods". He argues that the influence of government innovation policies on increases in private R&D investment is most likely not significant and questions the efficiency of government support measures employed in China. Petti et al. (2017) find a positive effect in their study on the 2009 data of Chinese high-tech SMEs. Their results suggest that innovation support policies positively moderate the relationship between R&D investment and performance, but this effect diminishes when embedded innovation capability is higher.

Some literature conducts comparative analysis on subsidy types, subsidy sources and subsidy objects. The research of Xin et al. (2016) examines the impact of the Innovation Fund for Small and Medium Technology-based Firms (Innofund) from 2001 to 2007 and finds that a loan interest subsidy is more effective than a grant. Meanwhile, the crowding-in effect is mainly for private-owned enterprises (POEs), not for state-owned enterprises (SOEs). Gao et al. (2021) find that R&D subsidies generally promote firms' innovation activity in Jiangsu province, and the effects of local R&D subsidies are more significant than those of central support.

2.4 Contributions and limitations

As David et al. (2000) criticized, all research performed until the end of the 1990s ignored endogeneity problems. They assume that subsidy distribution is random; however, most of the subsidy distribution is not accidental. Governments may choose recipients based on political, economic and technological priorities. To circumvent sample selection bias, a variety of approaches have been used in recent studies, such as the combination of non-parametric propensity-score matching (PSM) with difference-in-differences (DID) estimation (Boeing, 2016; Huergo & Moreno, 2017; Xin et al., 2016; Szücs, 2020), Heckman's treatment effect model (Huergo & Moreno, 2017), and dose-response matching approach (Nilsen et al., 2020).

Kauko (1996) argues that, at the firm level, the exogeneity assumption of R&D subsidies is almost certainly unacceptable. There is a statistical correlation between private R&D and R&D subsidies regardless of the effectiveness of the subsidies. It suggests that private R&D intentions may be one of the main determinants of R&D subsidies (Van Pottelsberghe, 1997). Governments are more inclined to support firms which conduct R&D activities and have innovative performance. Otherwise, it could be the case that government support those firms which do not spend money on R&D.

This research investigates the macro-level effects of R&D subsidies on business R&D investment and innovation output in the Chinese ICT manufacturing industry. Taking R&D subsidies as an exogenous determinant at the macro level is more acceptable. Although it masks heterogeneity between firms, macro-level research can avoid sample selection bias and obtain a more credible and robust result.

Account for their poor direct performance, some scholars hypothesize that the impact of R&D subsidies on economic output is indirect via stimulating private investment in R&D. The mediation analyses are employed to explore the process that one variable influences another variable through a mediator variable. Causal inference methods for mediation analysis (Robins & Greenland, 1992; Pearl, 2001; Vanderweele, 2009) are an extension of the traditional approach (Baron & Kenny, 1986).

This research adopts the causal inference methods for mediation analysis with independent variable and mediator variable (X-M) interaction to estimate the direct, indirect and total effects of R&D subsidies. This method can avoid masking the actual effect of R&D subsidies due to the mediator effects. Meanwhile, it can avoid the substantial simultaneity bias, and the estimated results are more reliable by involving the interaction between R&D subsidies and private R&D investment. This study discusses policy suggestions related to the design of R&D subsidies based on the estimated results, and contributes to R&D subsidy literature with macro study on China data.

There are some limitations to this study. First, similar to other macro studies, errors caused by individual differences are ignored. Second, this study does not distinguish between ex-ante and ex-post subsidies due to data availability. In practice, some subsidies are issued before the project starts, and some are granted after the cost is incurred.

III. Methods

3.1 Model

This research adopts causal inference methods for mediation analysis (causal mediation analysis) with interaction and bootstrap methods to empirically examine the direct and indirect effects of R&D subsidies on private R&D activity and R&D outputs in the Chinese ICT manufacturing industry from 2002 to 2019. Causal mediation analysis conducts mediation analysis within a counterfactual framework, considering what would happen to an observation instead of observing one feature (e.g., granted) but observing together with another (e.g., not granted). Meanwhile, it allows for direct and indirect effect decomposition in the presence of independent variable (R&D subsidies) and mediator variable (private R&D expenditure) interaction. In addition, the bootstrap procedure is performed to correct bias and ensure a robust result.

The study hypothesis is that the impact of R&D subsidies on R&D outputs is indirect, via stimulating private investment in R&D. Meanwhile, the interaction between R&D subsidies and private R&D investment influences the output (Figure 4). Based on this hypothesis, a three-step estimation of the direct and indirect effects of R&D subsidies is designed as:

Step one, evaluate the direct effect of R&D subsidies on private R&D expenditure as

$$pfr_t = \gamma_0 \cdot gfr_t^{\gamma_1} \cdot e^{\sum \gamma_{2n} x_{n,t}} \quad (1)$$

where the subscript t refers to the year; gfr is R&D subsidies; pfr is private R&D expenditures; x_n are control variables, including variables at the sector level: export dependence and importance in the local economy, variables at the regional level: economic level, human capital level, proportion of state-owned enterprise (SOE), information level, population, and degree of openness; and sector, region; γ_1 is private R&D elasticity of R&D subsidies.

Step two, evaluate the direct effect of R&D subsidies on R&D outputs as

$$out_{t+l} = \beta_0 \cdot gfr_t^{\beta_1} \cdot pfr_t^{\beta_2} \cdot (gfr \times pfr)_t^{\beta_3} \cdot e^{\sum \beta_{4n} x_{n,t}} \quad (2)$$

where out is innovation outputs, including patent grant numbers, patent application numbers, and revenue of new products; the subscript l refers to the lag years, which differ by output types; $gfr \times pfr$ is the interaction between gfr and pfr .

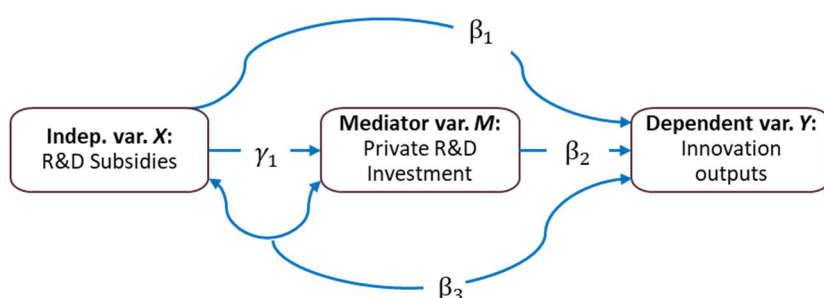
Step three, estimate the direct, indirect, and total effects of R&D subsidies on innovation output based on equation (1) and equation (2) (the estimation method refers to Appendix i).

Besides, this study examines whether higher subsidy intensity encourages more business R&D expenditure. Replacing R&D subsidy amount with subsidy intensity in equation (1), we get

$$pfr_t = \gamma_{s0} \cdot e^{\gamma_{s1} s} gfr_t \cdot e^{\sum \gamma_{s2n} x_{n,t}} \quad (3)$$

where $sgfr$ is subsidy intensity, the proportion of R&D subsidies over total R&D expenditures.

Figure 4 The relationship between innovation output, R&D subsidies, and private R&D



Source: Author's graphing

3.2 Data

OECD defines ICT manufacturing as "the products of a candidate manufacturing industry must be intended to primarily fulfill the function of electronic information processing and communication (including transmission, recording, storage and display)". It also includes the production of electronic components. The scope of ICT manufacturing includes 2610 Manufacture of electronic components, 2620 Manufacture of computers and peripheral equipment, 2630 Manufacture of communication equipment, 2640 Manufacture of consumer electronics, and 2680 Manufacture of magnetic and optical media of the International Standard Industrial Classification for all Economic Activities (ISIC Rev. 4).

Accordingly, China's ICT manufacturing scope, 39 computers, communications and other electronic equipment, has been adjusted (GB/T 4754-2017 of China). However, it is still classified into two major sectors according to ISIC Rev. 2 in the statistic books. They are Manufacture of Electronic Equipment and Communication Equipment (ECE) and Manufacture of Computers and Office Equipment (COE).

We matched the sector data from *China Statistics Yearbook on High Technology Industry*, the human capital level data from *China labour statistical yearbook*, and other provincial data from *China Statistical Yearbook*. The cross-provincial panel data are from 2002 to 2019, including 31 main-land provincials (province, autonomous region, and municipality), excluding two special administrative regions, Hong Kong and Macau. Since the distribution of ICT manufacturing sectors differs by province, the sample size varies. Table 1 shows the definition and value set of variables. All price value data are at constant prices to eliminate the impact of inflation.

The independent variable is R&D subsidies, the government-funded R&D expenditures. The proportion of R&D subsidies is calculated by dividing R&D subsidies by total R&D expenditures. The dependent variable is innovation outputs, such as the number of granted patents, number of patent applications, and new product revenue. Time lags are set according to the output cycle. We set one year lag for patent application numbers and new product revenue. According to the China National Intellectual Property Administration (CNIPA, 2011; 2018) data, the invention patent examination cycle was 22 to 26 months during the 2000s and stable

at 22 months in 2018. The time lag for the patent grant numbers is set for three years. The mediator variable is private R&D expenditures, calculated by total R&D expenditures minus government-funded R&D expenditures. We adopt firm average data to eliminate the scale impact caused by the number of enterprises.

The control variables include degree of export dependence and importance in the local economy of ICT sectors, provincial human capital level, provincial SOE proportion, provincial economic level, provincial informatization level, degree of openness, population, and sector, region. The degree of export dependence is calculated by dividing sector exports by sector revenue. Export data for the ICT sector in 2009 are missing, and the average of 2008 and 2010 exports are used. The sector's importance in the local economy is calculated by dividing sector revenue by provincial GDP.

The provincial human capital level adopts the proportion of employment with a college degree or above as a proxy. The provincial SOE proportion is proxied by the revenue proportion of SOE over the total revenue for industrial enterprises above designated size. The provincial informatization level adopts the proportion of internet users in the population as a proxy. The provincial economic level is proxied by the GDP per capita population. The degree of openness is proxied by the proportion of total imports and exports in GDP.

Table 1 The definition and value set of variables

<i>Variables</i>	<i>Definition</i>	<i>Value Set</i>	
Dependent variables	ppe	Number of granted patents	Number of granted patents per ent., year t+3
	pape	Number of patent applications	Number of patent applications per ent., t+1
	npdpe	New product revenue	New product revenue per ent., t+1
Independent variable	gfrpe	R&D subsidies	Government-funded R&D exp. per ent.
	sgfr	gfr intensity	GFR/total R&D expenditure
Mediator variable	pfrpe	Private R&D exp.	Private R&D exp. per ent.
Control variables	sexpo	Export dependence, sector	Exports / Revenue
	prop	Importance in local economy, sector	Sector Revenue / Provincial GDP
	hc	Human capital level, province	Prop. of employment with a college degree or above
	ssoe	Proportion of SOE, province	Revenue of SOE / Total revenue (industrial enterprise above designated size)
	infor	Level of informatization, province	Proportion of internet users
	lngdppc	GDP per capita, province	ln(GDP per capita)
	openn	Degree of openness, province	(Imports + exports) / GDP
	lnpop	Population, province	ln(Population)
	sector	Sector	Dummy, ETE sector = 1, COE sector = 0
	region	Region	Dummy, Eastern region = 1, inner region = 0

Source: made by the author

The sector is a dummy variable, the ETE sector is 1, and the COE sector is 0. The four regions are divided into two groups, the Eastern region with a relatively developed economy (dummy value 1) and the inner region with a relatively backward economy (dummy value 0),

including the Middle Region, the Northeastern Region, and the Western Region.

The variance inflation factor (VIF) of $\ln \text{gdppc}$ is above 10 in all regression equations (refer to Appendix ii for VIF results). Therefore, we removed $\ln \text{gdppc}$ from the control variables. Then, all VIFs are less than seven; the highest VIF for the independent variable (R&D subsidies) and the mediator variable (private R&D expenditure) is 2.2. Multicollinearity for all estimations in this study is not high. In addition, Table 2 shows the correlation test results.

Table 2 The correlation test of variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) ppe,t+3	1.000												
(2) pape,t+1	0.587 (0.000)	1.000											
(3) npdpe,t+1	0.315 (0.000)	0.569 (0.000)	1.000										
(4) pfrpe	0.453 (0.000)	0.632 (0.000)	0.499 (0.000)	1.000									
(5) gfrpe	0.076 (0.036)	0.290 (0.000)	0.098 (0.007)	0.188 (0.000)	1.000								
(6) sgfr	-0.065 (0.102)	-0.068 (0.177)	-0.098 (0.013)	-0.152 (0.000)	0.610 (0.000)	1.000							
(7) sexpo	0.082 (0.025)	0.017 (0.724)	0.317 (0.000)	0.160 (0.000)	-0.065 (0.062)	-0.257 (0.000)	1.000						
(8) prop	0.098 (0.007)	0.080 (0.094)	0.292 (0.000)	0.113 (0.001)	-0.059 (0.093)	-0.242 (0.000)	0.466 (0.000)	1.000					
(9) hc	0.556 (0.000)	0.441 (0.000)	0.334 (0.000)	0.377 (0.000)	0.055 (0.119)	-0.143 (0.000)	0.289 (0.000)	0.332 (0.000)	1.000				
(10) ssoe	-0.126 (0.000)	-0.064 (0.186)	-0.288 (0.000)	-0.225 (0.000)	0.066 (0.060)	0.348 (0.000)	-0.527 (0.000)	-0.482 (0.000)	-0.239 (0.000)	1.000			
(11) infor	0.452 (0.000)	0.336 (0.000)	0.273 (0.000)	0.364 (0.000)	0.027 (0.441)	-0.201 (0.000)	0.406 (0.000)	0.279 (0.000)	0.757 (0.000)	-0.486 (0.000)	1.000		
(12) openn	0.223 (0.000)	0.338 (0.000)	0.365 (0.000)	0.234 (0.000)	-0.050 (0.158)	-0.256 (0.000)	0.480 (0.000)	0.738 (0.000)	0.535 (0.000)	-0.455 (0.000)	0.317 (0.000)	1.000	
(13) pop	-0.027 (0.463)	0.037 (0.437)	0.043 (0.241)	0.068 (0.053)	-0.060 (0.085)	-0.158 (0.000)	0.144 (0.000)	0.193 (0.000)	-0.215 (0.000)	-0.470 (0.000)	-0.006 (0.854)	0.041 (0.217)	1.000

Source: made by the author

3.3 The regression settings

Taking the natural logarithm of the equation (1), a standard linear regression form for estimating the direct effect of R&D subsidies on private R&D expenditure is

$$\ln pfrpe_{ijt} = \gamma'_0 + \gamma_1 \ln gfrpe_{ijt} + \sum \gamma_{2n} x_{n,ijt} + \mu_{1t} + \sigma_{1i} + \varphi_{1j} + \varepsilon_{1ijt} \quad (4)$$

Where the subscripts i and j respectively refer to the sector and province; $gfrpe$ is R&D subsidies per enterprise; $pfrpe$ is private R&D expenditures per enterprise; μ_t measures the time-specific effects, σ_i measures the sector-specific effects, φ_j measures the provincial specific effects, and ω_{jit} is the serially uncorrelated random errors.

And, the standard liner regression form for estimating the direct effect of R&D subsidies on new product revenue is

$$\ln npdpe_{ij,t+1} = \beta_0^{npd} + \beta_1^{npd} \ln gfrpe_{ijt} + \beta_2^{npd} \ln pfrpe_{ijt} + \beta_3^{npd} (\ln gfrpe_{ijt} \cdot \ln pfrpe_{ijt}) + \sum \beta_{4n}^{npd} x_{n,ijt} + \mu_{2t} + \sigma_{2i} + \varphi_{2j} + \varepsilon_{2ijt} \quad (5)$$

where $npdpe$ is new product revenue per enterprise.

Patent numbers are count variables with many zeros. We checked their means and variances, and found that both the number of patent grants and patent applications are over-dispersed, the variance is quite large relative to the means. Accordingly, the negative binomial regression method is used as

$$ppe_{ij,t+3} = e^{(\beta_0^p + \beta_1^p \ln gfrpe_{ijt} + \beta_2^p \ln pfrpe_{ijt} + \beta_3^p (\ln gfrpe_{ijt} \cdot \ln pfrpe_{ijt}) + \sum \beta_{4n}^p x_{n,ijt})} + \mu_{3t} + \sigma_{3i} + \varphi_{3j} + \varepsilon_{3ijt} \quad (6)$$

$$pape_{ij,t+1} = e^{(\beta_0^{pa} + \beta_1^{pa} \ln gfrpe_{ijt} + \beta_2^{pa} \ln pfrpe_{ijt} + \beta_3^{pa} (\ln gfrpe_{ijt} \cdot \ln pfrpe_{ijt}) + \sum \beta_{4n}^{pa} x_{n,ijt})} + \mu_{3t} + \sigma_{3i} + \varphi_{3j} + \varepsilon_{3ijt} \quad (7)$$

where ppe is patent grant number per enterprise, and $pape$ is patent application number per enterprise.

Finally, the standard linear regression form for estimating whether subsidy intensity impacts private R&D expenditure is

$$\ln pfrpe_{ijt} = \gamma'_{s0} + \gamma_{s1} sgfr_{ijt} + \sum \gamma_{s2n} x_{n,ijt} + \mu_{1t} + \sigma_{1i} + \varphi_{1j} + \varepsilon_{1ijt} \quad (8)$$

IV. Descriptive statistics of variables

Table 3 is the descriptive statistics of variables, and Tables 4 and 5 are the descriptive statistics of variables by region and sector. The Mann-Whitney test result shows the significance that the distributions of the two populations are not equal.

Table 3 Descriptive statistics of variables

		N	Mean	SD	Min	Median	Max
gfrpe	R&D subsidies	815	439.31	1401.595	0	91.073	19824.49
sgfr	GFR intensity	693	.085	0.129	0	.037	1
pfrpe	Private R&D exp.	815	5324.107	8436.279	0	2637.942	85864.93
ppe,t+3	Number of granted patents	761	4.41	12.239	0	1	210.022
pape,t+1	Number of patent applications	436	2.879	6.504	0	1.063	66.49
npdpe,t+1	New product revenue	759	127.721	232.401	0	42.609	2116.773
sexpo	Export dependence	815	.266	0.250	0	.202	1.931
prop	Importance in local economy	930	.039	0.069	0	.008	.548
hc	Human capital level	930	.121	0.088	.003	.094	.559
ssoe	Proportion of SOE	930	.516	0.223	.114	.518	.96
infor	Level of informatization	930	.281	0.196	.011	.269	.77
gdppc	GDP per capita	930	33653.122	21459.948	5448.327	28799.837	123194.42
openn	Degree of openness	930	.326	0.390	.032	.138	1.712
pop	Population	930	42.832	27.355	2.68	37.84	119.08
noe	Number of enterprises	930	197.761	547.042	0	25	4866

Source: made by the author

4.1 The difference between regions

The distributions of all variables in the two regions are unequal (Table 4). First, in the Eastern region, the number of ICT manufacturing firms (noe) and the importance of ICT sectors in the local economy (prop) are much higher. The mean of noe is ten times that in the inner

regions, and the mean of prop is 7.2 times that in the inner regions. Second, the Eastern region's private R&D investment per enterprise (pfrpe) is 2.9 times that in the inner regions. Compared to its importance in local economy (prop), in other words, its contribution to local economy, the R&D intensity (the rate of R&D expenditure over revenue) in the Eastern region is lower than that in the inner regions.

Third, in the Eastern region, all R&D outputs are higher than those in the inner regions. The mean of patent grants per enterprise is 3.7 times higher, the mean of patent applications per enterprise is 4.5 times higher, and the mean of new product revenue per enterprise is 3.9 times higher. Meanwhile, ICT sector export dependence (2.2 times), provincial human capital level (1.8 times), provincial informatization level (1.6 times), provincial GDP per capita (2.1 times), provincial openness degree (5.8 times), and provincial population (1.3 times) in the Eastern region are higher.

Finally, there are more SOEs in the inner regions, and the R&D subsidies per enterprise and the subsidy intensity are higher than those in the Eastern region. The mean inner regions' SOE proportion is 1.9 times that in the Eastern region, and the mean of R&D subsidies per enterprise is 1.4 times that in the Eastern region. Furthermore, the mean subsidy intensity is 3.5 times that in the Eastern region. The annual country average private R&D expenditures (per enterprise) and intensity of R&D subsidies between the Eastern and inner regions show similar differences (Figure 5).

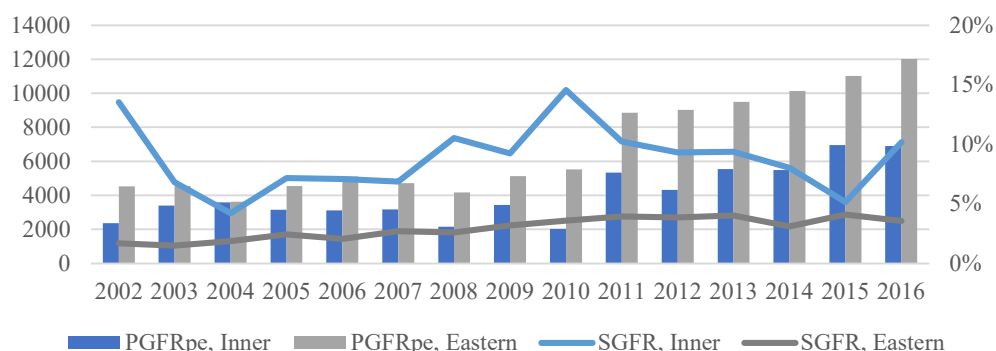
Table 4 Descriptive statistics of variables by region

	Inner regions				Eastern region				Mann–Whitney test
	N	Mean	SD	Median	N	Mean	SD	Median	
gfrpe	528	487.513	1654.256	76.884	287	350.631	732.430	111.697	**
sgfr	420	.118	0.153	.068	273	.034	0.049	.022	***
pfrpe	528	3199.604	5429.040	1435.026	287	9232.601	11161.958	5909.14	***
ppe,t+3	495	2.267	3.855	.583	266	8.397	19.426	2.363	***
pape,t+1	284	1.299	2.014	.577	152	5.829	10.041	2.507	***
npdpe,t+1	492	63.107	139.407	23.536	267	246.784	309.975	123.487	***
sexpo	528	.187	0.233	.097	287	.413	0.212	.412	***
prop	630	.013	0.022	.003	300	.094	0.097	.066	***
hc	630	.097	0.050	.087	300	.172	0.123	.14	***
ssoe	630	.609	0.189	.635	300	.32	0.148	.31	***
infor	630	.237	0.169	.234	300	.374	0.214	.403	***
gdppc	630	24792.434	11163.364	23405.96	300	52260.567	25610.396	48292.683	***
openn	630	.128	0.080	.107	300	.739	0.454	.649	***
pop	630	39.467	23.028	37.27	300	49.899	33.697	43.96	***
noe	630	50.384	94.909	13	300	507.253	876.910	181	***

Notes: *** $p < .01$, ** $p < .05$, * $p < .1$

Source: made by the author

Figure 5 Private R&D expenditures per enterprise & subsidy intensity by region
(Country average, thousand CNY)



Source: Author's calculation and graphing base on the data from *China Statistics Yearbook on High Technology Industry*

4.2 The difference between sector

From Table 3, we can observe the difference between sectors. First, the number of firms and the output scale of the ECE sector are much higher than that of the COE sector, as both the mean and the median of enterprise number (noe) and proportion in the regional economy (prop) are higher in the ECE sector. The average number of firms in the ECE sector is 350, 7.8 times the average of 45 firms in the COE sector. Meanwhile, the average contribution of the ECE sector to provincial GDP is 2.4 times the average contribution of the COE sector.

Second, R&D investment per enterprise in the ECE sector is relatively weak, although the total amount of subsidies and private investment in the ETE sector is much higher. The mean of R&D subsidies per enterprise (gfrpe) and the mean of private R&D investment per enterprise (pfrpe) in the COE sector are 1.4 and 1.5 times that in the ECE sector, respectively. Correspondingly, all R&D outputs in the COE sector are higher than those in the ECE sector. Among them, the mean of patent grants per enterprise is 1.4 times higher, the mean of patent applications per enterprise is 1.6 times higher, and the mean of new product revenue per enterprise is 2.1 times higher.

Table 5 Descriptive statistics of variables by sector

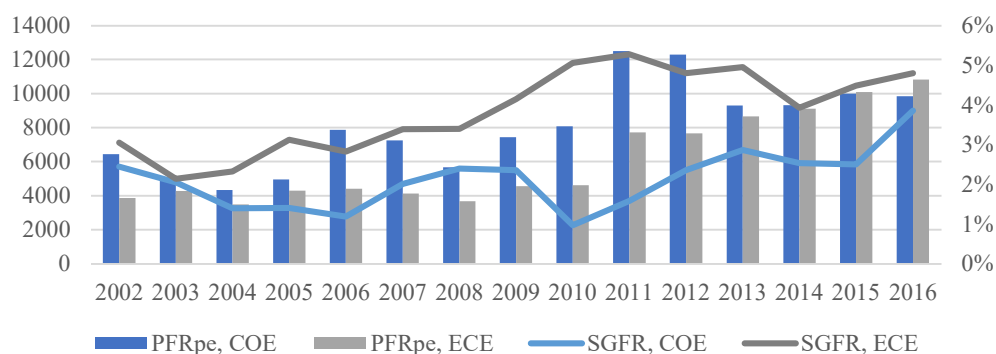
	COE Sector				ECE Sector				Mann–Whitney test
	N	Mean	SD	Median	N	Mean	SD	Median	
gfrpe	373	514.06	1928.675	24.701	442	376.229	692.484	146.96	***
sgfr	287	.085	0.164	.016	406	.084	0.098	.05	***
pfrpe	373	6511.457	10743.340	2361.422	442	4322.113	5639.875	2879.989	
ppe,t+3	348	5.27	16.796	.711	413	3.685	6.129	1.166	***
pape,t+1	198	3.614	9.101	.688	238	2.267	2.823	1.243	***
npdpe,t+1	347	179.263	315.108	33.998	412	84.31	109.035	47.342	
sexpo	373	.297	0.300	.227	442	.24	0.196	.202	
prop	465	.023	0.047	.002	465	.055	0.083	.017	***
noe	465	45.486	110.872	8	465	350.037	735.110	87	***

Notes: *** $p < .01$, ** $p < .05$, * $p < .1$

Source: made by the author

Third, the mean subsidy intensity (sgfr) for the two sectors is similar. However, the annual country average subsidy intensity in the ECE sector is much higher (Figure 6), and varies significantly between provinces (table 5). In addition, the R&D subsidies per enterprise, the patent grants per enterprise, and the patent applications per enterprise in the COE sector vary greatly among provinces. Finally, the distribution of private R&D investment per enterprise (pfrpe) and export dependence (sexpo) for the two sectors is similar.

Figure 6 Private R&D expenditures per enterprise & subsidy intensity by sector
(Country average, thousand CNY)



Source: Author's calculation and graphing base on the data from *China Statistics Yearbook on High Technology Industry*

V. Results

4.1 The direct effect of R&D subsidies on private R&D expenditure and innovation outputs

In Table 6, column (1) reports the results of step one, the estimation of the direct effect of R&D subsidies on private R&D expenditure. The results shows that the impact of R&D subsidies on private R&D expenditures is positive and statistically significant. It suggests that government R&D support does stimulate firms to invest more in R&D. A one percent increase in R&D subsidies leads 0.324 percent increase in private R&D expenditures. Compared to other studies, such as 0.54~0.60 in Korea (Lee & Cin, 2010), 0.102 in Ireland (Görg & Strobl, 2006), and 0.23 in Israel (Lach, 2002), it is higher than in most countries but lower than in South Korea.

Column (5) is the estimated results of the direct effect of R&D subsidy intensity on private R&D expenditures. It shows that the relationship between the subsidy intensity and private R&D expenditures is negative at a 10% significant level. It means higher subsidy intensity crowds out private R&D expenditures.

Columns (2), (3), and (4) report the results of step two, the estimation of the direct effects of R&D subsidies on R&D outputs, the number of patent grants (column (2)), the number of patent applications (column (3)), and the new product revenue (column (4)). The results shows that the private R&D expenditure has significant (statistical) positive effects on innovation outputs, while the direct effects of R&D subsidies are either weak or negative and statistically insignificant. The impact of the interaction of government support and private R&D investment is weak and statistically insignificant as well.

Table 6 Estimate results of the direct effect of R&D subsidies on private R&D expenditure and innovation outputs

	(1)	(2)	(3)	(4)	(5)
	pfrpe	ppe,t+3	pape,t+1	npdpe,t+1	pfrpe
gfrpe	.324*** (.037)	.06 (.227)	-.178 (.262)	-.264 (.239)	
pfrpe		.414** (.174)	.642*** (.181)	.32** (.151)	
gfrpe#pfrpe		0 (.026)	.029 (.031)	.039 (.029)	
sgfr					-.812* (.48)
sexpo	.248 (.168)	-.261 (.25)	-.379 (.294)	.398 (.351)	-.084 (.251)
prop	1.846*** (.623)	-1.987** (.872)	-2.007** (1.009)	3.239*** (.813)	1.934*** (.721)
hc	1.258* (.73)	-.136 (.904)	.13 (.751)	-.003 (.932)	1.006 (.737)
ssoe	-.114 (.244)	.65** (.328)	.68 (.46)	-.212 (.438)	.798* (.448)
infor	.74** (.373)	4.977*** (.38)	.215 (.611)	.206 (.514)	2.177*** (.445)
openn	-.113 (.173)	.666*** (.176)	.769*** (.214)	-.166 (.21)	-.179 (.187)
lnpop	.121 (.085)	.365*** (.118)	.092 (.232)	-.327*** (.121)	.132 (.099)
region	.763*** (.131)	-.326** (.156)	.199 (.195)	.57*** (.139)	.75*** (.201)
sector	-.338*** (.11)	-.046 (.112)	.154 (.123)	-.292* (.156)	-.216** (.103)
_cons	5.459*** (.362)	-5.822*** (1.742)	-6.028*** (1.818)	2.254* (1.352)	6.242*** (.54)
/lnalpha		-.921*** (.148)	-1.457*** (.381)		
Observations	612	564	348	546	691
R-squared	.461	.z	.z	.435	.251

Notes: Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Source: made by the author

The effects of R&D subsidies vary significantly across regions and sectors. In the Eastern region, firms spend more on R&D and produce more new products, while more patents are granted to firms in the inner regions. At the same level of government R&D support, the private R&D expenditure in the Eastern region is 2.14² times that in the Inner regions, while the patent grant number in the Eastern region is 27.8³ percent lower than that in the inner regions. It suggests that firms may invest more in incremental innovation than a radical innovation in the Eastern region, although they spend more on R&D than firms in the inner regions.

At the same level of government R&D support, firms in the COE sector invest more in R&D and produce more new products. The private R&D expenditure and the new product

² $\gamma_{2,region} = 0.763$, then $exp(0.763) = 2.14$ (Eastern region = 1)

³ $\beta_{4,region}^p = -0.326$, then $1 - exp(-0.326) = 0.278$ (Eastern region = 1)

revenue in the COE sector are 1.40⁴ times and 1.34⁵ times those in the ECE sector. The results show that the incentive effect of R&D subsidies on firms in the ECE sector is relatively weak compared with that in the COE sector, and the private R&D investment per enterprise in the ECE sector is insufficient.

The sector export dependence (*sexpo*) impact on patent numbers is negative; however, it is statistically insignificant. The sector's importance in local economy (*prop*) negatively and significantly (statistical) correlated with patent numbers, while it positively and significantly (statistical) encourages private R&D expenditures and new product revenue. It means sectors with a higher level of importance in the local economy spend more on R&D and produce more new products, but their efficiency of patent outputs is low. It is the same as in the Eastern region.

The proportion of SOE (*ssoe*) significantly (statistical) positively correlated with patent grant numbers. SOEs are larger than other types of firms in general. The literature suggests that innovation needs to be carried out by larger firms since they have more resources than smaller firms. The problem is that larger firms do not have the incentives to carry out innovation. Since the 2000s, the Chinese government has adopted R&D investment as an essential indicator to evaluate the performance of state-owned enterprises. Meanwhile, SOEs receive more government support for R&D. Technical achievements such as patents are essential to continue receiving subsidies. Consequently, SOEs receive more patent grants.

The provincial human capital level (*hc*) positively affects R&D expenditure at a 10% significant level. It suggests that R&D subsidies encourage more private R&D investment in provinces with a higher human capital level. The information level (*infor*) positively contributes to patent grant numbers and private R&D expenditure. The higher the provincial openness degree (*openn*), the greater the number of patent grants and patent application. Firms pay more attention to intellectual property protection in the provinces with higher information level and openness.

4.2 The total effects of R&D subsidies on innovation outputs

Table 7 reports the results of step three, the controlled direct effect (CDE), the natural direct effect (NDE), the natural indirect effect (NIE), and the total effect (TE) of R&D subsidies on innovation outputs. The CDE shows the average effect of R&D subsidies on innovation output by “setting” private R&D expenditures at a constant value to prevent the mediator effect. The NDE reports the average effect of R&D subsidies on innovation output without the mediator effect by keeping whatever value that private R&D expenditures attain naturally in the population. The NIE reports the average effect of R&D subsidies on innovation output without the direct effect by holding the R&D subsidies constant, and changing private R&D expenditures to whatever value it would have attained naturally had R&D subsidies changed. In other words, the NIE is the average causal mediated effect (ACME) of private R&D expenditures. And, the TE shows the total effect of R&D subsidies on innovation output.

The results suggest that the effects of R&D subsidies on patent outputs are positive and statistically significant. Totally, a one percent increase in the amount of R&D subsidies leads

⁴ $\gamma_{2,sector} = -0.338$, then $1/exp(-0.338) = 1.40$ (COE sector = 0)

⁵ $\beta_{4,sector}^{npd} = -0.292$, then $1/exp(-0.292) = 1.34$ (COE sector = 0)

to a 0.196 percent increase in the number of granted patents increasing and a 0.241 percent increase in the number of patent applications. Meanwhile, the indirect effect of GFR on the revenue of new products is positive and statistically significant, but the direct effects (negative) and total effect (positive) are not statistically significant.

Table 6 shows that the impact of the interaction between R&D subsidies and private R&D expenditures is weak (0 on patent grant numbers, 0.029 on patent application numbers, and 0.039 on new product revenue) and statistically insignificant. We reperform the step two and step three estimation for the effect of R&D subsidies on innovation output without the interaction. Table 8 shows the results of step three (the outcomes of step two refer to Appendix iii). The effect of R&D subsidies on patent grant numbers is almost the same; however, the effects on patent application numbers and new product revenue are more remarkable. Especially, the total effect of R&D subsidies on new product revenue shifts from 0.105 to 0.213 and is statistically significant. Because the interaction between government support and private R&D investment exists, if we ignore the interactions between the two, the effects of R&D subsidies on patent applications and new product revenue may be biased and be overestimated.

Table 7 The direct, indirect, and total effects of R&D subsidies

	(1) ppe,t+3	(2) pape,t+1	(3) npdpe,t+1
CDE	0.06*** (0.166)	-0.15*** (0.156)	-0.224 (0.194)
NDE	0.061*** (0.076)	0.024*** (0.084)	-0.011 (0.062)
NIE	0.134*** (0.057)	0.218*** (0.076)	0.116*** (0.041)
TE	0.196*** (0.131)	0.241*** (0.153)	0.105 (0.083)

Notes: Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

CDE: controlled direct effect, NDE: natural direct effect, NIE: natural indirect effect, TE: total effect

Source: made by the author

Table 8 The direct, indirect, and total effects of R&D subsidies without interaction

	(1) ppe,t+3	(2) pape,t+1	(3) npdpe,t+1
CDE	0.061*** (0.040)	0.081*** (0.052)	0.053 (0.043)
NIE	0.134*** (0.031)	0.259*** (0.069)	0.16*** (0.029)
TE	0.195*** (0.043)	0.34*** (0.079)	0.213*** (0.039)

Notes: Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

CDE: controlled direct effect, NIE: natural indirect effect, TE: total effect

Source: made by the author

VI. Discussion and conclusion

The Chinese government expects to achieve high-quality economic growth by stimulating innovation, and views the ICT industry as a vital force to lead the future social and economic development and the frontier industry for China's transition from a manufacturing to a knowledge-based economy. In the past decades, the ICT industry has received fiscal, taxation, and financial policy support in technology R&D as one of China's high-tech and strategic emerging industries. This research adopts causal inference methods for mediation analysis with interaction and bootstrap methods to empirically examine the direct and indirect effects of R&D subsidies in the Chinese ICT manufacturing industry at the macro level.

First, the estimated results show that the impact of R&D subsidies on private R&D expenditures is positive and statistically significant. It means that government R&D support encourages firms to invest more in R&D. Meanwhile, the results also suggest that higher subsidy intensity crowds out private R&D expenditures. The answer to research question one is that R&D subsidies promote firms to invest more in R&D; a one percent increase in the amount of R&D subsidies leads to a 0.324 percent increase in private R&D investment in Chinese ICT manufacturing. However, subsidies should be moderate in intensity, or they will backfire and decrease private R&D investment.

Second, via stimulating private investment in R&D, R&D subsidies promote R&D outputs, such as patent grants and application numbers. Totally, a one percent increase in the amount of government R&D subsidies leads to a 0.196 percent increase in number of granted patents and a 0.241 increase in number of patent applications. However, the contribution (total effect) of R&D subsidies to new product revenue is statistically insignificant. We can not go with the zero-cost argument from Levy (1990), as every dollar has its value. The value of R&D subsidies is that they can encourage firms to invest more in R&D and thus improve innovation output, although R&D subsidies are much smaller than private R&D expenditure.

Third, the effect of R&D subsidies varies significantly across regions and sectors. R&D subsidies encourage firms in the Eastern region to spend more on R&D activities, but only bring in more new product revenue. They invest 2.14 times as much in R&D as inner region firms, and receive 27.8 percent fewer patents than inner region firms. On the one hand, the economic benefits in the eastern region are better, and the willingness of firms to invest in R&D is more vital. They are more market-oriented and invest more in incremental than radical innovation. On the other hand, the inner regions are relatively backward, and firms depend more on government funding (the government also intends to favour backward regions). To continue to obtain subsidies, they pay more attention to acquiring patents and other R&D achievements. Policymakers should consider incentivizing firms in the Eastern region to give full play to their advantages and carry out more cutting-edge technological innovations. Meanwhile, encouraging firms in the inner regions to transform R&D results into productivity is equally important.

Firms in the COE sector invest more in R&D and produce more new products. It suggests that the incentive effect of R&D subsidies on firms in the ECE sector is relatively weak. The national average subsidy intensity is much higher in the ECE sector, while the private R&D investment per enterprise is lower than in the COE sector. Compared with the COE sector, the total private R&D expenditure of the ECE sector is very high, but the enterprise average private

R&D expenditure is insufficient. In the ECE sector, firms with little or no R&D investment should actively use the policies and increase investment in R&D to boost their innovation capacity and output. It is the way to ensure long-term survival and development.

Finally, provincial openness degree and information level positively contribute to innovation outputs. The openness degree positively promotes the number of patent grants and applications, and the information level positively encourages patent grant numbers. It suggests that an open and transparent environment is more conducive to innovation. Although the sector export dependence has no statistically significant impact on innovation outputs, policymakers should also steer export-dependent firms from investing more in incremental product innovation to radical innovation. Another point is that SOEs remain the biggest beneficiaries of the policy. The growth of outstanding private firms in China's ICT industry also tells us that equal support to all types of firms will significantly improve the incentive efficiency of subsidies.

Appendix:

i. The calculation of direct effect and indirect effect (Pearl, 2012):

The controlled direct effect (CDE) expresses how much the outcome (*out*) would change on average if the independent variable (*gfr*) were changed from *gfr* to *gfr'*. At the same time, the mediator (*pfr*) was set to a fixed value *pfr* to prevent the independent variable (*gfr*) from transmitting its change along the mediating path.

$$CDE(pfr) = E(Out|gfr', pfr) - E(Out|gfr, pfr)$$

where $E(out|gfr', pfr)$ is the expected value of *out* when *gfr* equals *gfr'* and *pfr* equals *pfr*.

The natural direct effect (nde) is the weighted average of the controlled direct effect. It expresses the expected change in outcome (*out*) if the independent variable (*gfr*) were changed from *gfr* to *gfr'* while keeping the mediator (*pfr*) constant at whatever value they would have obtained naturally in the population when the independent variable (*GFR*) had been *gfr*.

$$NDE_{gfr, gfr'}(out) = \sum_{pfr} [E(out|gfr', pfr) - E(out|gfr, pfr)] P(pfr|gfr)$$

where $P(pfr|gfr)$ is the pre-transition distribution used as a weighting function.

The natural indirect effect (NIE) is the expected change in the outcome (*out*) affected by holding the independent variable (*gfr*) constant at *gfr*, and changing the mediator (*pfr*) (for each individual) to whatever value it would have attained naturally had *gfr* been set to *gfr'*.

$$NIE_{gfr, gfr'}(out) = \sum_{pfr} E(out|gfr, pfr) [P(pfr|gfr') - p(pfr|gfr)]$$

The total effect (TE) is the difference between the direct and indirect effects of the reverse transition.

$$TE_{gfr, gfr'}(out) = NDE_{gfr, gfr'}(out) - NIE_{gfr', gfr}(out)$$

where $NIE_{gfr',gfr}(out)$ is the indirect effect of the transition from $gfr = gfr'$ to $gfr = gfr$.

ii. The results of variance inflation factor (VIF)

VIF result for equation (4)

variable	VIF	1/VIF
lngdppc	12.41	0.080606
infor	6.91	0.144657
hc	5.82	0.171802
openn	5.36	0.186467
ssoe	4.04	0.247409
region	3.17	0.315736
prop	2.66	0.375795
sexpo	1.80	0.554978
lnpop	1.58	0.631233
sector	1.33	0.751744
lngfrpe	1.24	0.803535
Mean VIF	4.21	

VIF result for equation (5)

variable	VIF	1/VIF
lngdppc	12.45	0.080310
infor	6.87	0.145546
hc	5.87	0.170266
openn	5.43	0.184086
ssoe	4.20	0.238120
region	3.38	0.295676
prop	2.71	0.368519
sexpo	1.85	0.540428
lnpfrpe	1.85	0.541689
lnpop	1.64	0.609793
lngfrpe	1.63	0.613205
sector	1.36	0.736786
Mean VIF	4.10	

VIF result for equation (6)

variable	VIF	1/VIF
lngdppc	12.83	0.077971
hc	6.90	0.144893
infor	6.08	0.164475
openn	5.15	0.194362
region	3.68	0.271894
ssoe	3.25	0.308030
prop	2.67	0.375106
lnpfrpe	2.20	0.453540
lnpop	1.78	0.561621
lngfrpe	1.75	0.570612
sexpo	1.74	0.576188
sector	1.50	0.666090
Mean VIF	4.13	

VIF result for equation (7)

variable	VIF	1/VIF
lngdppc	12.19	0.082040
infor	6.61	0.151279
hc	5.81	0.172055
openn	5.78	0.172938
ssoe	4.12	0.242814
region	3.39	0.294940
prop	2.76	0.362794
sexpo	1.87	0.534187
lnpfrpe	1.82	0.548472
lngfrpe	1.67	0.598458
lnpop	1.60	0.624950
sector	1.34	0.747772
Mean VIF	4.08	

VIF result for equation (8)

variable	VIF	1/VIF
lngdppc	11.69	0.085553
infor	6.43	0.155488
hc	5.67	0.176368
openn	5.42	0.184559
ssoe	3.89	0.257244
region	2.94	0.339843
prop	2.72	0.367590
sexpo	1.74	0.573264
lnpop	1.52	0.656598
sector	1.28	0.779862
sgfr	1.19	0.842175
Mean VIF	4.05	

iii. The estimate results of the direct effect of R&D subsidies on innovation outputs without the interaction between R&D subsidies and private R&D expenditures

	(2)	(3)	(4)
	ppe,t+3	pape,t+1	npdpe,t+1
gfrpe	.061 (.041)	.081 (.052)	.053 (.039)
pfrpe	.415*** (.078)	.799*** (.076)	.495*** (.079)
sgfr			
sexpo	-.261 (.2)	-.413 (.251)	.395 (.278)
prop	-1.987* (1.015)	-1.994** (.799)	3.179*** (.823)
hc	-.135 (1.049)	.311 (.861)	.346 (.98)
ssoe	.65** (.293)	.647 (.471)	-.189 (.337)
infor	4.977*** (.439)	.159 (.616)	.164 (.476)
openn	.666*** (.219)	.727*** (.246)	-.223 (.194)
lnpop	.365*** (.128)	.11 (.211)	-.314*** (.118)
region	-.326** (.165)	.227 (.187)	.61*** (.137)
sector	-.047 (.109)	.141 (.11)	-.299** (.14)
_cons	-5.828*** (.841)	-7.45*** (1.205)	.803 (.719)
/lnalpha	-.921*** (.149)	-1.451*** (.362)	
Observations	564	348	546
R-squared	.z	.z	.431

Notes: Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Source: made by the author

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