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Are R&D subsidies effective? The effect of industry competition

Xiang Xin

Abstract
This study explores the effect of industry competition on public R&D subsidies' effectiveness. The author finds the non-linear threshold effect of industry competition on R&D subsidies' effectiveness. Specifically, R&D subsidies' effectiveness reaches its peak when industry competition lies between the two estimated thresholds.

JEL H25, L11, G31, G38

Keywords Social status; redistribution; externalities; optimal taxation

Authors
Xiang Xin, Macau University of Science and Technology,
xiangxinmacau@163.com

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1. Introduction

Private R&D investment is crucial to ensure a country's economic growth, and the country typically encourages private R&D investment through R&D subsidies. For instance, some tax preferential policies in China allow additional deductions for R&D expenditure. However, arguments about the R&D subsidies effectiveness are controversial. On the one hand, R&D subsidies provide firms with public financing and induce firms to increase their private R&D spending (Bronzini & Piselli, 2016). On the other, cheap public funds may crowd out private funds, since firms tend to apply for subsidies rather than raise funds in imperfect capital market(Carboni, 2011). Thus, to what extent subsidies benefit R&D activities is still a question. In this paper, I expand existing literatures by examining the extent to which R&D subsidies encourage private R&D spending and how R&D subsidies effectiveness is determined by industry competition.

Up to date, little attention has been paid to competition's effect on R&D subsides effectiveness, while the link between competition and R&D expenditure has been fully discussed. First, traditional arguments dating back to Schumpeter (1934) note that low competition increases the probability that monopoly rent benefits R&D activities, so firms in less competitive industries, which are rewarded by monopoly profit, tend to invest more in R&D activities (Schumpeter, 1934; Aghion et al., 2005). Thus, it is reasonable for me to expect that firms facing less industry competition would have strong innovation incentive and then take fully advantage of public R&D grants.

Second, the arguments based on "escape competition" theory predict the positive effect of industry competition on private R&D spending. The arguments note that firms in competitive industries face more similar production costs. R&D activities aimed at decreasing production costs reward firms with post-innovation rent and then help firms to escape from competition (Aghion et al., 2005, 2009), so firms in competitive industries would invest more in R&D. Escape competition effect spurs firms' innovation incentive, and then I could expect that public subsidies could be efficient at increasing private R&D spending when firms faced intense industry competition. However, neither predictions has been examined.

In this study, I first investigate the extent to which R&D subsidies encourage private R&D spending, and find that subsidies can strongly complement private R&D spending. As to the effect of competition on subsidies effectiveness, the relationship between them points to a presence of non-linear threshold effect. That is, escape-competition leads the complement between public and private funds to increase when competition intensifies to reach a threshold level; whereas Schumpeterian effect induces the complement to increase when competition lessens to reach another threshold level.

2. Data and variable construction

My data set comes from China Stock Market & Accounting Research Database. I exclude financial firms because of their special financial leverage. Firms that have missing values for financial data and those with at least two years deficits are also excluded from my sample. After these cleaning, I employ a balanced panel for 901 publicly traded firms in China among 135 industries based on the classification of China's Securities Regulation Commission over the period 2000-2016, which includes 15317 firm-year observations.

2.1 Dependent variables

I use two proxies to measure private R&D expenditure. The first one is firms' internal expenditure on R&D, which subtracts government subsidies from firms' total R&D expenditure (Clausen, 2009). As mentioned by González & Pazó (2008), an efficient public program would complement private R&D spending and induce private spending even beyond subsidies. I use internal R&D expenditure, which subtracts government subsidies from total R&D expenditure, to measure the amount of private R&D spending. The subsidy program would be efficient if subsidies induced firms to obtain R&D financing through private means, and firms' internal R&D expenditure would be high in this case. The other proxy is simply firms' total R&D expenditure, which measures both public and private funds. Table 1 shows that the mean level of internal R&D spending to sales ratio is 0.199, and the sample mean of total R&D spending to sales ratio is 0.366.

2.2 Independent variables

The primary focus of this paper is competition's effect on R&D subsidies efficiency, so I include public subsidies obtained to support private R&D programs in my regressions (Lee, 2011). Public subsidies are typically operated through the channels of both fiscal and tax incentive. Fiscal incentive is the most common form of public subsidies, but fiscal grants benefit firms only if the R&D projects are expected to be valuable. So, the allocation of public funds is likely to be subject to "pick the winner" criteria. Tax incentive, by contrast, exhibits a more random process, since tax burden, which is influenced by the amount of R&D expenditure, is reduced automatically (Bronzini & Piselli, 2016). Thus, a small number of literatures address selection bias problem by including tax incentive programs only (Czarnitzki et al., 2011; Cappelen et al., 2012). In my study, public subsidies include both fiscal and tax grants, since fiscal benefits are also crucial parts of public subsidies (Bérubé & Mohnen, 2009). I correct potential selection bias problem by employing industry mean of individual firms' R&D subsidies as instrumental variable (Clausen, 2009). Table 1 shows that the sample mean of subsidies' industry mean is 11.026.

As to industry competition, I employ two competition proxies in my regressions. The first one is simply Herfindal index of firms' sales for each industry. Herfindal index measures the distribution of industry firms' sales, and the high Herfindal index of firms' sales usually indicates the low competition environment. For robustness, I repeat my analysis by using industry median of firms' profit margin as competition proxy. Firms facing less competition typically earn a higher profit margin than the firms facing intense competition do. In this case, high profit margin also indicates low industry competition. Table 1 shows that the sample mean of Herfindal index is 0.136, and the mean of industry profit margin is 0.064.

2.3 Control variables

I first include natural logarithm of total assets as control variable. Total assets are often used to control for firm size, which is considered to has possible influences on firms' R&D incentive (Hyytinen & Toivanen, 2005; Meuleman & De Maeseneire, 2012). I also use natural logarithm of sales to control for firms' sales scale, and use the change in sales over fiscal year to capture firms' sales growth. Sales are considered to influence firms' willingness to develop new products (Ernst et al., 2010). Besides, I also control for firms' financial leverage, and use debt to asset ratio as the proxy of financial leverage. Financial leverage changes firms' financing ability and then influences firms' R&D incentive. (Cai & Zhang, 2011; Sasidharan et al., 2015). In table 1, the sample mean of total assets' natural logarithm is 21.683. The mean of sales scale and sales growth are 20.901 and 0.204, respectively. As to financial leverage, the mean level of financial leverage is 0.534.

2.4 The model

In order to estimate the effect of industry competition on R&D subsidies efficiency, I modify the empirical model suggested by Clausen (2009). The empirical model is defined as:

$$R\&D_{i,t} = \beta_1 + \beta_2 Subsidy_{i,t} + \beta_3 Com_{i,t} + \sum \beta_i Control_{i,t} + \varepsilon_{i,t} \tag{1}$$

in which R&D denotes internal R&D spending to sales ratio, and I also employ total R&D spending to sales ratio as my innovation proxy. All R&D ratios are calculated by multiplying the original ratios by 100. Subsidy denotes instrument variable, which is defined as the industry mean of the natural logarithm of individual firms' R&D subsidies. For robustness, natural logarithm for the total subsidies allocated to industries is also employed as instrument variable. Com denotes two competition variables that I have mentioned above. Control refers to the control variables in part 2.3.

I use threshold regression approach developed by Hansen (1999) to estimate the equations. Hansen (1999)'s methodology allows an examination for the existence of competition' threshold levels in explaining R&D subsidies effectiveness. This method first gives the potential competition thresholds beyond which R&D subsidies effectiveness changes drastically, and then estimates the subsidies effectiveness separately for each competition threshold level. Besides, Hansen (1999)'s methodology addresses the potential firms' fixed effect by employing a data transformation. This transformation, which avoids the estimations of so many dummy variable parameters, involves subtracting the time-mean of each firm entity away from the variable's values.

(insert table 1)

3. Empirical Results

3.1 Determination of threshold number

Table 3 shows results of the determination of threshold number. I determine the number of threshold by estimating the baseline model allowing for one, two or more competition thresholds. According to Aghion et al. (2005)'s study, the relationship between competition and firms' innovation incentive is an inversed-U shape. Since the efficiency of public R&D grants depends on firms' innovation incentive, the relationship between competition and R&D subsidies efficiency is also non-linear and exhibits at least two cut-points.

In table 3, both the threshold parameters and their confidence intervals have been estimated. The competition variables in column (1) and (2) are Herfindal index of industry firms' sales. In Column (1), all the threshold parameters ($\widehat{\alpha}_1 = 0.0396$ and $\widehat{\alpha}_2 = 0.0706$) lie within their 95% confidence intervals, suggesting that both $\widehat{\alpha}_1$ and $\widehat{\alpha}_2$ in column (1) are statistically significant. These results also indicate that the relationship between R&D subsidies and private R&D investment can be estimated in three stages, and R&D subsidies' effect on private R&D spending will change drastically when competition reaches the two thresholds. The two threshold parameters in column (2) (0.0459 and 0.0706) also lie in their 95% confidence intervals, indicating that competition exhibits two statistically significant cut-points when explaining subsidies' effect on firms' total R&D spending. I also find that the first cut-point in column (2) (0.0459) is larger than that in column (1) (0.0396), suggesting that subsidies' effect on private R&D also changes drastically for firms that are operated in industries in which the Herfindal index ranges between 0.0396 and 0.0459. The competition proxies in column (3) and (4) are industry median of individual firms' profit margin. Results in column (3) and (4) also exhibit two statistically significant thresholds, which are in line with our expectation.

I sequentially carry out the LM tests and the bootstrapped P-values are reported in table 2. In column (1) to (4), all the P-values in single threshold tests are smaller than 10%, and P-values in column (3) and column(4) are even smaller than 1%. These results indicate that the competition has at least one cut-point when describing the relationship between R&D subsidies and private R&D spending. Then I extend the LM tests to double threshold tests and find that the P-values in double threshold tests are also smaller than 10%, suggesting that two competition thresholds are also acceptable. However, when the LM tests extend to third level's tests, the results are no longer statistically significant, indicating that two cut-points are more proper.

(insert table 2 and table 3)

3.2 Competition's effect on R&D subsidies effectiveness

Table 4 shows regression results for competition's effect on R&D subsidies effectiveness. For internal R&D measure, all the coefficients of R&D subsidies (Subsidy) in column (1) and (3) are positive and significant at 1%, indicating that subsidies increase the amount of private internal R&D spending. These results are in line with González & Pazó (2008) and Carboni (2011) who demonstrate that perfect crowding-out between public and private financing of R&D should be rejected, and public grants enhance innovation firms' access to market financing to some degree.

Consistent with my prediction, the relationship between competition and R&D subsidies efficiency points to an existence of non-linear threshold effect. Specifically, Subsidy's coefficients for the second level's regressions in column (1) and (3) are the largest (0.046 and 0.044), indicating that firms that lie between the two critical values of industry competition ($\widehat{\alpha}_1$ and $\widehat{\alpha}_2$) are more likely to use public funds to complement their internal R&D spending. Economically, one unit increases in R&D subsidies induce firms to increase their internal R&D ratio 0.046 % in column (1) and 0.044 % in column (3). In contrast, the coefficients for the first level's regressions are 0.015 in column(1) and 0.026 in column(3), and the coefficients for the third level's regressions are 0.017 and 0.012, which are all much lower than those in first level's regressions. In column (1), one unit increases in subsidies lead to merely 0.015% increases in internal R&D ratio in the first level's regression, and this result is 0.031% lower than that in second level's regression. In addition, one unit increases in subsidies result in 0.017% increases in internal R&D ratio in the third level's regression, and this effect is also 0.029% lower than that in second level's regression. The similar effect could also be found in the regressions in column (3).

The results in table 4 also indicate that complement between subsidies and internal R&D spending increases when industry competition intensifies to reach the threshold $\widehat{\alpha}_2$, even if the initial level of competition is low. This finding coincides with the escape competition theory suggested by Aghion et al. (2005). In addition, the degree to which R&D subsidies complement internal R&D spending increases when competition lessens to reach another threshold level ($\widehat{\alpha}_1$), while the initial competition is high in this case. This result could be explained by the increased monopoly profit.

The innovation proxies in column (2) and (4) are firms' total amount of funds devoted to R&D projects. The coefficients of Subsidy in column (2) and (4) are also positive and significant at 1%, indicating subsidies' positive effect on total R&D expenditure. The largest coefficients of Subsidy in column (2) and (4) all lie in the second level's regressions (0.103 and 0.074), suggesting that the complement effect of public funds tends to reach its peak when subsidized firms lie between the two competition thresholds. Besides, the Subsidy's coefficients in second level's regressions in column (2) and (4) (0.103 and 0.074) are higher than those in column (1) and (3) (0.046 and 0.044). This may be because firms use public funds as the critical channel of R&D financing, and R&D subsidies in turn could lead to higher increases in total R&D spending than those in private spending.

3.3 Robustness tests

For robustness, I also use the total subsidies allocated to industries as instrument. In column (5) to (8) of table 3, each column reports two possible competition thresholds ($\widehat{\alpha}_1$ and $\widehat{\alpha}_2$), and the competition thresholds are quantitatively similar to those in column (1) to (4). Column (5) to (8) of table 2 exhibit the results of LM tests. In column (5), (7) and (8), all the P-values of single and double threshold tests are smaller than 5%, indicating that competition exhibits two cut-points. However, the Herfidahl index doesn't show any cut-point when considering the relationship between subsidies and firms' total R&D spending in column (6) of table 2. Table 5 employs the original subsidies allocated to individual firms as the explanation variable Subsidy, that is to say no instrument variables are used in this table. Although the potential selection problems are not taken into consideration, our main findings are also strongly held.

(insert table 4 and table 5)

4. Conclusion

This study estimates the impacts of industry competition on R&D subsidies effectiveness. I provide solid evidences for the complement effect of public R&D support, while the impacts of this effect differ among the levels of industry competition. Specifically, the extend to which public subsidies complement private financing increases when competition intensifies to reach a threshold level, and the complement effect increases again when competition lessens to reach another threshold after which the competition becomes less pronounced.

This study contributes to existing literatures by shedding light on the relationship between industry competition and effectiveness of public R&D support. Most studies focus on R&D subsidies efficiency, but few researches show that subsidies efficiency differs among industries. In addition, this paper adds to the literatures about market competition. Market competition impacts firms' financial plans (Xu, 2012; Chang et al., 2015), but its impacts on R&D subsidies effectiveness have seldom been discussed. Findings in this paper indicate that industry competition appears as an important determinant of R&D subsidies effectiveness.

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Table 1 Summary statistics

Variables	Obs.	Mean	Std. Dev.	Min	Max
Internal R&D expenditure to sales ratio	15317	0.199	1.201	-5.594	20.326
Total R&D expenditure to sales ratio	15317	0.366	1.386	0	25.725
Natural log of individual firms' subsidies	15317	7.436	8.034	0	20.160
Industry mean of individual firms' subsidies	15317	11.026	7.408	0	19.002
Natural log of total industry firms' subsidies	15317	13.654	9.076	0	22.945
Hhi	15317	0.136	0.152	0.02	1
Industry median of individual firms' profit margin	15317	0.064	0.063	-0.105	0.345
Assets	15317	21.683	1.315	18.977	25.528
Sales	15317	20.901	1.932	17.072	25.095
Sales growth	15317	0.204	0.637	-0.659	4.08
Debt ratio	15317	0.534	0.26	0.078	1.94

Table 2 Tests for threshold effect : P-values from LM tests

Threshold	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Single	0.017**	0.053*	0.000***	0.000***	0.040**	0.133	0.000***	0.000***
Double	0.040**	0.063*	0.003***	0.000***	0.027**		0.000***	0.000***
Triple	0.470	1.000	0.773	0.7133	0.980		0.727	0.733

Notes: * Significant at 10%; ** significant at 5%; *** significant at 1%

Table 3 Threshold estimates [95% confidence intervals]

Threshold	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
First($\widehat{\alpha}_1$)	0.0396	0.0459	0.0434	0.0456	0.0396	0.0399	0.0434	0.0456
	(0.0383-0.0402)	(0.0396-0.0480)	(0.0420-0.0445)	(0.0451-0.0462)	(0.0383-0.0402)	(0.0396-0.0411)	(0.0420-0.0445)	(0.0451-0.0561)
Second($\widehat{\alpha}_2$)	0.0706	0.0706	0.0491	0.0491	0.0706	0.0703	0.0491	0.0491
	(0.0679-0.0709)	(0.0686-0.0709)	(0.0487-0.0497)	(0.0487-0.0497)	(0.0679-0.0709)	(0.0684-0.0710)	(0.0487-0.0497)	(0.0487-0.0497)

Notes:(i) The threshold estimates refer to the level of competition variables

(ii) Confidence intervals are reported in parentheses

Table 4 The impacts of industry competition on R&D subsidies effectiveness

Variable	(1) Hhi-internal R&D	(2) Hhi-total R&D	(3) Margin-internal R&D	(4) Margin-total R&D	(5) Hhi-internal R&D	(6) Hhi-total R&D	(7) Margin-internal R&D	(8) Margin-total R&D
Subsidy								
I(Com<$\widehat{\alpha}_1$)	0.015***	0.036***	0.026***	0.048***	0.012***	0.023***	0.021***	0.039***
	(5.43)	(13.42)	(15.15)	(25.86)	(5.63)	(9.78)	(15.13)	(25.74)
I($\widehat{\alpha}_1$<Com<$\widehat{\alpha}_2$)	0.046***	0.103***	0.044***	0.074***	0.037***	0.060***	0.036***	0.059***
	(16.88)	(24.67)	(16.46)	(20.30)	(16.97)	(23.97)	(16.62)	(20.39)
I(Com>$\widehat{\alpha}_2$)	0.017***	0.035***	0.012***	0.023***	0.014***	0.028***	0.010***	0.019***
	(12.71)	(22.45)	(7.35)	(12.91)	(12.75)	(22.00)	(7.54)	(13.09)
Constant	-2.302***	-4.266***	-2.472***	-4.733***	-2.335***	-4.480***	-2.508***	-4.810***
	(-9.68)	(-16.01)	(-10.31)	(-17.64)	(-9.84)	(-16.84)	(-10.49)	(-17.97)
Firm fixed effect and control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$\widehat{\alpha}_1$	0.040	0.046	0.043	0.046	0.040	0.040	0.043	0.046
$\widehat{\alpha}_2$	0.071	0.071	0.049	0.049	0.071	0.070	0.049	0.049
Obs.	15317	15317	15317	15317	15317	15317	15317	15317
R2	0.041	0.104	0.042	0.102	0.041	0.099	0.042	0.102

Notes: This table presents the results of industry competition's effect on R&D subsidies effectiveness. Internal R&D spending to sales ratio is employed in column (1), (3), (5) and (7), while total R&D spending to sales ratio is used in column (2), (4), (6) and (8). Subsidy denotes industry mean of individual firms' R&D subsidies in column (1) to (4). And natural log for the total subsidies allocated to industries is employed in column (5) to (8). Com denotes Herfidahl index of firms' sales for each industry in column (1), (2), (5) and (6). And industry median of firms' profit margin is used in column (3), (4), (7), and (8). Firms' fixed effect has been already addressed by using Hansen (1999)' methodology. $\widehat{\alpha}$ denotes two thresholds. The T-statistics are given in parentheses. *, ** and *** denote significant at 10%, 5% and 1% level, respectively.

Table 5 Original subsidies' estimations

Variable	(1) Hhi-internal R&D	(2) Hhi-total R&D	(3) Margin-internal R&D	(4) Margin-total R&D
Tests for threshold effect				
Single	0.000***	0.000***	0.000***	0.000***
Double	0.000***	0.000***	0.000***	0.000***
Triple	0.940	1.000	0.637	0.567
Threshold estimate				
First ($\widehat{\alpha}_1$)	0.0706	0.0706	0.0516	0.0491
Confidence interval	(0.0686-0.0709)	(0.0686-0.0709)	(0.0511-0.0524)	(0.0487-0.0497)
Second ($\widehat{\alpha}_2$)	0.0396	0.0396	0.0434	0.0434
Confidence interval	(0.0383-0.0402)	(0.0383-0.0402)	(0.0303-0.0445)	(0.0303-0.0445)
Estimated variables				
Subsidy				
I(Com$<\widehat{\alpha}_1$)	0.010***	0.031***	0.026***	0.056***
	(3.19)	(9.29)	(15.45)	(29.85)
I($\widehat{\alpha}_1<$Com$<\widehat{\alpha}_2$)	0.045***	0.077***	0.057***	0.089***
	(20.24)	(31.03)	(18.30)	(25.93)
I(Com$>\widehat{\alpha}_2$)	0.014***	0.036***	0.009***	0.024***
	(9.56)	(21.25)	(5.17)	(12.74)
Constant	-1.493***	-2.575***	-1.630***	-2.718***
	(-5.94)	(-9.23)	(-6.44)	(-9.70)
Firm fixed effect and control variables	Yes	Yes	Yes	Yes
Obs.	15317	15317	15317	15317
R2	0.046	0.120	0.049	0.128

This table also reports the regressions of public subsidies on private R&D expenditure, which are influenced by industry competition. The subsidies' proxy (Subsidy) in this table is original public funds allocated to individual firms, that is no instrument variables are used in this table. R&D spending ratios, Competition variables (Com) and control variables are the same to those in table 4. Firms' fixed effect has already been addressed by using Hansen (1999)' methodology. $\widehat{\alpha}$ denotes two thresholds. The T-statistics are given in parentheses. *, ** and *** denote significant at 10%, 5% and 1% level, respectively.