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Additionality of public R&D funding in business R&D within the life science industry¹

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Background and purpose

Research grants awarded to universities and university hospitals that promote new research activities are expected to create new knowledge, discoveries and recognition that enhance the skills of researchers and the qualifications of researchers and their research environments. R&D is widely recognized as one of the most important engines of economic growth (Romer, 1990). The increased return from knowledge and knowledge collaboration is expected to increase the research expenditure of companies as research activities in public-sector institutions will grow. Studies in the United Kingdom *Health Economics Research Group, Brunei University, Office of Health Economics, RAND Europe* (2008) show that £1 of additional investment in research produces an increase of £2.20 to £5.10 in private investment in research, which in turn results in an increase in GDP of £1.10 to £2.50 per year.

The public funding of research in collaboration with companies can induce companies to increase their investment in planned or new R&D projects: that is, new activities to which companies would otherwise not have started. However, public funding can also potentially displace privately funded research if, for example, public money funds research activities the private sector would otherwise have undertaken anyway. Public research may also occupy resources and researchers, creating a barrier for private investment in R&D.

The extent to which publicly funded research substitutes for or complements private investment in research must be elucidated empirically. The purpose of this study was to analyse how investments in the public sector influence private sector investment in R&D in these fields. The specific hypothesis research question is to analyse to what extent do public and private research complement each other?

This study examined the extent to which public research complements or substitutes for private research within biomedicine and biotechnology in Denmark. Denmark has substantial publicly and privately funded medical research and has unique registry data for companies, over an extended time period.

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Methods and empirical strategy

To assess how public research funds affect a company's propensity to make private investment in R&D in the relevant sectors, a model of five estimates has been proposed: 1) Heckman's two-step model¹; 2) simple ordinary least squares (OLS); 3) OLS with correction for selection bias and bootstrapped standard deviation; 4) OLS with the forecast values of public funding and correction for selection bias; and 5) instrumental variables (IV) regression.

Heckman's Two-Step Model

Heckman's two-step model is useful because the companies receiving publicly funded R&D are not randomly selected. The expectation is precisely that the decision to award public funds for R&D to company A, rather than company B, depends on the extent to which the company can expect to use the funds for R&D activities that add value for society, including whether a company has the necessary framework in place to use the funds appropriately. The public funding of R&D is therefore determined endogenously. The Heckman model has two steps and estimates the following:

1. the probability of receiving public funding; and
2. the predicted quantity of public funds for companies based on key variables.

Simple OLS

In simple OLS regression, the value of privately funded R&D in year t is predicted based on:

- a company's private funding of R&D in the previous period ($t-1$);
- a company's current publicly funded R&D (t);
- whether a company has applied for any patents (t);
- the number of employees in full-time equivalents (t);
- a company's current collaboration on R&D with private actors (t);
- a company's current collaboration on R&D with public actors (t);
- whether a company is large or small, measured by the number of employees in full-time equivalents; and
- a company's growth relative to the previous period, measured by changes in the number of employees in full-time equivalents.

This OLS regression thus provides results with no correction for selection bias.

OLS corrected for selection bias and with bootstrapped standard deviations

OLS regression includes Mills ratio, which is calculated through the Heckman model to correct for selection bias resulting from public funding being determined endogenously. In addition, the observed values of public funding are replaced by the predicted values of public funding that are estimated through the second step in the Heckman model (see above).

OLS with the predicted values of public funding and correcting for selection bias

This uses OLS regression similar to the simple OLS (number 2) but with the Mills ratio to correct for selection bias.

Instrumental variables (IV) regression

This part of the model comprises IV regression to predict the private funding (t), using the variation in public funding of R&D activities (t) that can be explained by:

- a company's collaboration on R&D with the private sector in the previous period ($t - 1$);
- a company's collaboration on R&D with public actors in the previous period ($t - 1$);
- a company's total expenditure (publicly and privately funded) on R&D in the previous period ($t - 1$);
- whether a company has applied for patents in the previous period ($t - 1$);
- the number of employees in full-time equivalents (t);
- whether a company is large or small, measured by the number of employees in full-time equivalents; and
- a company's growth relative to the previous period, measured by changes in the number of employees in full-time equivalents.

The theoretical baseline model is formulated by determining the probability of a company receiving public funding for R&D activities and determining the amount of public fundingⁱⁱ. The model assumes that decisions on funding are made at the start of the period based on the information companies have provided. Companies then decide themselves the exact funding of R&D with the full information on the funding decision and the amount of money involved.

$$(1) R_t = \rho R_{t-1} + \beta G_t + \alpha' X_t + e_t$$

$$(2) G_t^* = \lambda R_{t-1} + \gamma' Z_{t-1}^1 + u_t^1$$

$$(3) f_t^* = \lambda^2 R_{t-1} + \delta' Z_{t-1}^2 + u_t^2$$

where $G_t = G_t^*$ if $f_t^* > 0$; $G_t = 0$, which means that the public sector will invest in company i if $f_t^* > 0$.

This model determines (1) private R&D, where R is private funding of R&D and G_t is public funding of R&D. Lag is expected, with R&D funding in the current period depending on previous fundingⁱⁱⁱ. To account for this, the previous period's funding R_{t-1} is incorporated as an explanatory variable. In addition, X_t is a vector of the explanatory variables which, for example, include a company's size, patent applications, collaboration with industry and public research institutions and the like. Collaboration between industry and public research institutions is often an important policy instrument and a requirement for receiving funding or investment.

Equations (2) and (3) determine the funding decisions and how large the investment should be. Equation (2) is the latent (predicted) variable for public funding of R&D, where G_t is the observed amount of publicly funded R&D. f_t^* is the predicted variable for the value of public funding. The public sector will invest ($G = G^*$) in a company if $f_t^* > 0$. Z^1 and Z^2 are vectors of the explanatory variables. Thus, the decisions about funding and about the actual amount invested both depend on the characteristics of a company based on the information that the public funding body has available.

Data and descriptive statistics

The analysis used research, development and innovation statistics for companies from Statistics Denmark for 2000–2013, compiled every other year^{iv}. Only companies that have

R&D were analysed. A unique company ID is linked to the data that enables the data to be linked with the statistics for all Danish companies.

Table 1. Descriptive statistics

	Companies that had R&D activities more than once in 2000–2013			
	Average for companies that received public funding in 2000–2013	Average for companies that did not receive public funding in 2000–2013	Average for companies in the relevant sectors that had R&D activities more than once in 2000–2013	Average for companies in the relevant sectors that had R&D activities once in 2000–2013
Number of observations	143	1185	1328	384
Total company private funding (DKK 1000)	101,996	25,075	33,358	981
Total company public funding (DKK 1000)	11,665		1,256	111
Total company funding (DKK 1000)	113,661	25,075	34,614	1,092
Public budget within the sector (DKK 1000)	205,435	71,803	88,351	34,817
Percentage with <50 employees	61%	66%	65%	365
Percentage with >50 employees	39%	34%	35%	19
Employees, full-time equivalents	3.37	3.36	165	15
Number of private collaboration partners	3.60	1.03	1.30	0.15
Number of public collaboration partners	1.36	0.34	0.45	0.43

The data are time-series that contain observations from the same entities over time, thereby enabling a company's R&D activities in year 2 to be compared with the activities in year 1. This also enables controlling for dependence, which is highly likely for company decisions on funding R&D. Companies register their R&D activities every 2 years. This means that a lagged value of a variable ($t-1$) is equivalent to the value of the variable 2 years earlier. About half of the 75 companies that received public funds for R&D activities in 2000–2013 received funding once; about 30% received public funds twice; and about 20% received public funds three or more times (maximum six times) in 2000–2013. Thus, public funds were distributed or earmarked for R&D activities within selected sectors 143 times in 2000–2013. The companies in the sectors included received about DKK 1.7 billion in public funding for R&D activities in 2000–2013. About 14% of this came from public actors outside Denmark.

Results

Results from the Heckman model are shown in Table 2. Column 2 (the selection part) presents the factors affecting the probability of receiving public funding for R&D. Previous total stock of R&D positively influences this probability significantly. In addition, both public

and private collaboration positively affect the probability of receiving public funding for R&D. Finally, a company's growth measured in terms of the number of employees in full-time equivalents (in the previous period) also positively affects the probability. The first column in Table 2 shows the results for the factors influencing the amount of public funding (assuming the company receives public funding for R&D). The total budget for public funding within the respective sector and company size measured by the number of employees positively affects the amount of public funding. The amount of funding is reduced if a company collaborates with other companies, which may indicate that public funding is primarily allocated to basic research, but the results are not statistically significant.

Table 2. Estimated results for the Heckman public funding model

	Heckman estimation model	
	Ln(public funding)	$P(\text{public funding} > 0)$
$\text{Ln}(\text{private R\&D})_{t-1}$	-0.081 (1.43)	
$\text{Ln}(\text{public funding})_{t-1}$	0.074 (1.74)	
$\text{Ln}(\text{public budget})_t$	0.70 (14.66)**	
$\text{Ln}(\text{patent applications})_t$	0.113 (0.40)	
$\text{Ln}(\text{number of full-time employees})_t$	0.271 (1.92)	-0.06 (1.09)
$\text{Ln}(\text{R\&D total})_{t-1}$		0.06 (3.49)**
$\text{Ln}(\text{collaboration with public sector})_{t-1}$		0.47 (2.88)**
$\text{Ln}(\text{collaboration with private sector})_{t-1}$		0.28 (2.82)**
$\text{Ln}(\text{patent applications})_{t-1}$		0.27 (1.72)
$\text{Ln}(\text{collaboration with public sector})_t$	0.159 (0.39)	
$\text{Ln}(\text{collaboration with private sector})_t$	-0.161 (0.70)	
$\text{Ln}(>49 \text{ employees})$	1.763 (3.50)**	-0.20 (1.10)
$\text{Ln}(\text{trend in employees})$	-0.863 (1.84)	0.53 (3.47)**
<i>n</i>	1324	1324
<i>P</i> , likelihood ratio test	<0.0001	<0.0001

* $P < 0.05$; ** $P < 0.01$. All the models include a constant. The lag $t-1$ corresponds to 2 years to account for cadence in data collection. All variables are expressed by the natural logarithm (ln), except for >49 employees and patent applications, which are dummy variables.

Table 3. Estimated results for determining the private funding of R&D

	LN(private R&D) _t			
	OLS (naive)	Boot	OLS (incl. Mills ratio)	IV
Ln(private R&D) _{t-1}	0.489 (19.86)**	0.44 (11.36)**	0.605 (16.55)**	0.603 (15.56)**
Ln(patent applications) _t	3.517 (15.00)**	2.96 (13.18)**	3.606 (15.33)**	2.936 (10.68)**
Ln(number of full-time employees) _t	0.084 (0.96)	0.354 (14.47)**	0.063 (0.72)	0.237 (3.29)**
Ln(public funding) _t	0.157 (4.61)**		0.186 (5.39)**	0.358 (4.13)**
Ln(public funding predicted) _t		0.397 (14.47)**		
Ln(collaboration with public sector) _t	-0.630 (2.33)*	-0.447 (1.82)	-0.461 (1.69)	-0.887 (2.50)*
Ln(collaboration with private sector) _t	1.259 (7.96)**	1.329 (9.35)**	1.339 (8.54)**	1.44 (6.13)**
(>49 employees)	0.398 (1.35)	0.611 (2.08)**	0.101 (0.33)	
Ln(trend in number of employees)	0.840 (2.93)**	1.620 (5.07)**	1.524 (4.59)**	1.487 (4.35)**
Mills ratio		1.167 (3.01)**	1.557 (3.88)**	1.696 (3.54)**
<i>n</i>	1324	1324	1324	916
<i>R</i> ²	0.58	0.65	0.58	0.58

*P < 0.05; **P < 0.01. All the models include a constant. The lag t-1 corresponds to 2 years to account for cadence in data collection. All variables are expressed by the natural logarithm (ln), except for >49 employees and patent applications, which are dummy variables.

Table 3 shows the main results for the estimates of how public funding affects privately funded R&D. As described previously, the model estimates through various means: OLS – naive, boot, OLS including the Mills ratio and IV. For each of these methods, the model is estimated through the companies' observed values of publicly funded R&D, and one model uses predicted values (Boot). The regression includes the Mills ratio to account for selection bias (except for simple OLS). The Mills ratio should be considered as a proxy for the probability of receiving public funding of R&D. The Mills ratio is positive and statistically significant in all models in which it is included, which indicates that selection bias is present and neglect controlling for this would have produced (positive) biased estimates.

The results are generally similar for the three methods of estimation. The coefficient for (observed) public funding is positive and statistically significant at 0.15–0.39, which indicates that public funding complements private funding of R&D. In addition, the results show that a 1% increase in publicly funded R&D generates a positive increase of 0.15–0.39% in privately funded R&D. These results are in accordance with the literature, such as González et al. (2005). Bloch & Graversen (2012) found varying results of 0.08–0.14% across all sectors. The elasticity for the spillover is thus above average across sectors, which is somewhat expected because public and private R&D within biomedicine and biotechnology should be closely linked.

As expected, the results for lagged private funding of R&D are positive and statistically significant for all estimates. Lagged private funding of R&D can be regarded as a proxy for the persistence of research and can indirectly express a company's potential in R&D.

Patent applications have a statistically significant positive effect on the private funding of R&D, which is not surprising because patent applications tend to send a powerful signal indicating persistent and robust R&D. However, the variable for patent applications is a dummy variable, which does not provide much information to the model but eliminating the information about patents application may not improve the model.

The results for collaboration between companies are statistically significantly correlated with the private funding of R&D for all estimates; collaboration with public institutions is negatively correlated, but this is not statistically significant, which could be explained by differences in funding schemes. Fx. most likely the 14% of public funding from outside of Denmark are EC funds, which often require public-private collaboration. The rest of public funding from within Denmark could be 'simple' tax credits or subsidies not requiring any collaboration, which may impact private R&D differently.

The analysis shows robust results for complementarity between the public and private funding of R&D. This means that research policy that increases funds for public R&D positively influences the spillover effects to private funding of R&D, which can strengthen the overall economy in the long run.

Discussion and conclusion

In what way public research funds affect a company's propensity to make private investment in R&D a structural selection model have been estimated, using R&D data from Danish firms from 2000 to 2013, within the life science sector. This is an important contribution on whether publicly funded R&D is a substitute or a complement to privately funded R&D. The results finds robust evidence of significant complementary effects, with a 1% increase in public funding yielding between 0.15% and 0.39% increase in privately funded R&D across the different models.

The main result is that public funding of R&D positively affects privately funded R&D, which indirectly increases the overall national R&D within biotechnology and biomedicine. Crowding out was not detected, but selection bias cannot be ruled out. Thus, one result of the analysis was demonstrating complementarity through econometric analysis of the correlation between public research expenditure and private research expenditure within biomedicine and biotechnology.

This high elasticity within life science industry may be a result of companies that depend more on research and collaboration with the public research institutions. This analysis did not explore the reasons for this greater elasticity.

Despite the robust results, the analysis could be strengthened by more data on companies' propensity to obtain public funding that could be related to unobserved characteristics such as dedicated leadership, reputation, credit opportunities and market status.

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ⁱ Heckman, J. (1979).

ⁱⁱ The funding decision is taken at the start of the period based on the information available at the time.

ⁱⁱⁱ The funding decision depends on the characteristics from the previous period in terms of a company's previous share of public and private funding of R&D, collaboration, size of the company, etc.

^{iv} Innovation data such as product or process are not collected from 2000 – 2007.