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Additionality of public R&D funding in business R&D*

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Abstract

An important issue in R&D policy is whether publicly funded R&D is a substitute or a complement to privately funded R&D. However, measuring the impact of R&D policies has proven a difficult task, complicated by simultaneity and selection bias. We utilize an approach to examine the effect of public funding that takes account of both these potential biases, using R&D data for Danish firms from 1998 to 2005. This data allows more complete quantitative estimates of funding impacts than earlier studies. We find robust evidence of significant complementary effects, with a 1% increase in public funding yielding 0.08-0.11% increase in private R&D.

Keywords: Additionality, Public R&D funding, crowding out, selection bias

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1. Introduction

While innovation policy discussions take on a broader and broader focus, public support of business R&D remains the core element of innovation policy. For example, estimates of innovation policy expenditures in the EU indicate that around 95 percent of funding is directly towards the support of business R&D (Arundel, 2007).

Public R&D support policies have a long history and are based on strong arguments that, due to market failures, levels of business R&D activity fall short of what would be socially optimal. From a societal perspective, firms are assumed to under invest in R&D. Public funding is intended to increase firms' R&D activities. This can be either by allowing firms to increase investment in planned projects or to start activities that the firm otherwise would not have undertaken. These investments can also increase expected returns of other projects, inducing further R&D investment. However, public funding can potentially crowd out privately funded R&D, in effect financing investments that the firm would have undertaken regardless.

Hence, an important issue is whether publicly funded R&D is a substitute or a complement to privately funded R&D. However, measuring the impact of R&D policies has proven to be a difficult task, with empirical studies arriving at differing results.

A number of studies have examined this issue at firm, industry and aggregate levels[1]. These analyses generally use an investment equation for privately funded R&D that, in addition to publicly funded R&D, can include variables for firms' size, output and financial conditions.

The results of these studies are mixed. While the majority of studies find that public funding is a complement for privately funded R&D, a number of papers find the opposite. David et al (2000) also note that the neglect of certain estimation issues may bring some results into question. Here they stress the importance of controlling for the endogeneity of public funding amounts, which has been addressed in only a few studies. An additional related issue is selectivity. Firms that receive public funding are not chosen randomly and failure to control for this can introduce serious bias in the results.

R&D policies themselves have changed character over time, with potentially large implications for the impact on private R&D investment. Earlier government support was often in the form of government contracts, implying that the government was not only a funder of private R&D but also a buyer of the final product or research results. As Lichtenberg (1984, 1987) points out in a series of analyses, this impacts firm incentives to conduct R&D, along with the risk involved in R&D activities. In addition, government contracted R&D projects could potentially be quite different from R&D activities for commercial projects, implying that government and privately funded R&D might not be directly related.

[1] E.g. Leyden and Link (1991), Guellec and van Pottelsberghe (2003), Wallsten (2000), Hussinger (2003), Busom (2000), and Ali-Yrkko (2005). See also the review in David et al. (2000).

In contrast, current measures generally are in the form of subsidies to businesses' commercial activities. R&D subsidies in the form of grants or tax credits are more directly focused on reducing market failures, but they may also exacerbate potential measurement problems. For example, to the extent that funding agencies award grants to the most promising research projects, publicly funded businesses may be expected to perform better even in the absence of funding.

Only a few papers have explicitly dealt with simultaneity or selection bias. Among these few, Wallsten (2000) controls for endogeneity of the amount of public funding by assuming that it is a function of overall funding budgets and Hussinger (2003) as well as Busom (2000) controls for selectivity, but not for the endogeneity of the amount of funding.

To our knowledge none of these analyses attempts to control for both simultaneity and selection bias. However, in order to obtain accurate estimates of the effects of public funding, it may be important to control for both types of bias. For example, only under very restrictive conditions will standard instrument variable methods be suitable for dealing with potential bias from censored explanatory variables. Likewise, controlling for selection bias will generally not eliminate bias due to simultaneity.

The objective of this paper is to do precisely this. We utilize an approach to examine the effect of public funding on private R&D that models both the simultaneity of public funding and private R&D, and the fact that public funding is a censored variable. The measurement issues encountered here are very similar to those in many labor market analyses. We draw on models proposed for labor market analysis, such as Vella (1993) and others.

We examine the impact of public funding on private R&D investments for Danish businesses using the Danish R&D statistics over the period from 1998 to 2005. These statistics contain data on size of public funding by source and total R&D expenditures, along with a number of auxiliary variables that are useful in characterizing businesses' R&D activities. This data thus allows us to provide more complete quantitative estimates of the effect of public than earlier studies.

The empirical analysis finds evidence of significant complementary effects of public funding. Even though there is a high persistence in the propensity to receive public funding, we do find robust evidence on an increase in private funded R&D, i.e. business R&D, on 0.08-0.11% when public funding increases 1 %. The effect of domestic public funding solely on business R&D is of similar size, while the effect of foreign public funding is found to be marginally higher. The latter result may be caused by a more consistent demand of self finance in most EU RTD programs.

Section 2 in the paper reviews the recent literature on effects of public funding of business R&D and makes the basis for the modeling of R&D and funding in Section 3. Section 3 also sketches the econometric methods to be used. Section 4 describes the Danish public funding system and gives descriptive statistics on the empirical data. Finally Section 5 reports and comments the results from the econometric modeling while Section 6 concludes the paper.

2. Literature

A large literature has examined the impact of public funding, from the level of commercial labs to aggregate country level studies. David et al (2000) provides an overview of the empirical literature on public R&D funding. Overall results are quite mixed. While the majority of analyses find that public funding is a complement to private R&D – i.e. it leads to increases in private R&D investments – there are also a large number of studies that find the opposite, that public funding crowds out private R&D investment.

David et al (2000) emphasize the importance using a structural framework to examine these issues. They also discuss in detail the econometric problems involved in examining the impact of funding and the general neglect of these issues in many empirical studies. First, there may be both simultaneity and selection bias in the funding process. Private R&D investment decisions and public funding are very likely to affect each other and depend on a number of the same factors. And, given that the selection of funding recipients is far from random, there are likely significant differences in the characteristics of businesses with and without funding and these businesses may also respond differently to public funding. A second problem is bias due to omitted latent variables that may affect both public and business R&D investment decisions.

A fairly early example of work that dealt with some of these issues is Lichtenberg (1984, 1987, 1988), which focuses on government R&D contracts and how their design affects firm incentives to conduct R&D. Lichtenberg utilized IV methods to address potential bias due to omitted variables. In all three analyses he finds that significant, positive effects of public funding using OLS either disappear or become negative when accounting for potential endogeneity of public funding.

Leyden and Link (1991) and Leyden, Link and Bozeman (1989) explicitly model the relationship between public funding and private R&D. As with Lichtenberg, there focus is on government contracts which, given that they are intended for government use, may not be directly related to businesses' commercial activities. They argue that firms' ability to utilize government contract R&D in other R&D activities depends on their ability to exchange or share knowledge. They estimate a three equation system that models private R&D investment, firms' sharing efforts, and government R&D expenditures. They find that government R&D contracts have a positive impact on private R&D both directly and through firms' knowledge sharing.

In a more recent analysis, Wallsten (2000) explicitly models the public funding process. In addition to firm specific variables, he assumes that the amount of public funding depends on the size of overall funding budgets within the firms' industry grouping. He analyses the effects of R&D subsidies from the Small Business Innovation Research Program in the US. While estimates with OLS give positive significant impacts of funding on employment, when the endogeneity of funding is taken into account (using 3SLS), the coefficient is insignificant. A drawback to Wallsten's analysis is that he only has R&D data for firms that are publicly listed, leading him to use employment as a proxy. For the (much smaller) subsample of publicly listed firms, estimations using 3SLS indicate full crowding out of public funding. In addition, while Wallsten models the simultaneity of public funding and private R&D, he does not address potential bias due to selectivity.

Lach (2002) examines the effect of public subsidies for Israel over 1991-1995. He addresses the endogeneity problem in two ways. First, he restricts his analysis only to firms (or observations) that did not receive funding in the previous period, and may or may not have received a subsidy in the current period. He then assumes that any differences in firms' response to public funding are firm specific and time invariant, and estimates the model in differences (thereby eliminating fixed effects). Though, he notes that his model does not control for unexpected developments that affect both funding and private R&D investments. This can be considered a drawback to his analysis, which focuses on firms that have received a subsidy but did not receive one in the past. He finds a very large negative impact on private R&D in the same period, suggesting more than full crowding out. However, when looking instead at firms that did not receive funding in period t-2 (but may or may not have received funding in period t and t-1), he again finds both a large negative impact for funding in the same period but an even larger positive impact from lagged funding.

Kaiser (2006) examines the effect of public funding for Denmark in 1999 and 2001. His analysis, however, does not use actual amounts of funding only a binary 'treatment' indicator of whether firms received funding. He estimates the impact of the binary subsidy indicator using three different sets of assumptions: 1) random selection among firms with and without subsidies; 2) treatment effects for the two groups are dependent on a set of observable factors only; and 3) firm specific, time invariant effects using a 'difference in difference' estimator along the same lines as Lach (2002). However, only a very small share of firms (less than 4 percent) actually changed subsidy status in the two periods, weakening the validity of the latter method. He finds some weak evidence of a positive effect of receiving subsidies, but the results are mixed and inconclusive.

Busom (2000) and Hussinger (2003) both contain careful detailed treatments of the selection problem for public funding. Busom (2000) examines the impact of public funding for Spanish firms. She models R&D effort both for firms with and without funding, and finds the impact of a number of factors to be statistically different for the two groups. However, she does not find evidence of selection bias. She does not have data on actual R&D funding amounts nor on privately funded R&D (only total R&D), and thus is not able to obtain to model the funding process or to obtain quantitative estimates of the impact of public funding.

Hussinger analyses public funding for German firms. In addition, Hussinger (2003) examines the use of a variety of parametric and semi-parametric estimation methods. As in Busom (2000), Hussinger (2003) does not have data on public funding amounts, but she does have data on private R&D investments, allowing the estimation of treatment effects. In contrast to Busom, Hussinger finds evidence of selection bias and also of a positive treatment effect, indicating that public funding has a positive effect on private R&D investments.

A number of recent papers (Almus and Czarnitzki, 2003; Ebersberger, 2005) have examined an alternative method to examine the impact of funding, the propensity score matching approach. The approach has become a popular approach to estimate treatment effects and it seeks to match subsidized and non-subsidized firms based on characteristics that may influence the likelihood of conducting R&D but not the likelihood of receiving public funding. Thereby, the effect of receiving public funding on the amount of R&D can be estimated as the difference in differences. However, as shown in Caliendo and Kopeinig (2008), the method involves a lot of questionable decisions, which includes the trade off between bias and efficiency. Hence, the method used in this paper is – in our opinion – a more straight forward and coherent approach to measure additionality of public funding. The present approach, although also complicated, gives an immediate quantitative measure of the impact and is doable even though the share of public funded firms is low.

3. Model and methodology

The basic model used in this paper models the determination of privately financed R&D and both the decision to provide public funding and determination of the amount of funding.

The basic model is the following:

$$p_i = \beta g_i + \alpha' X_i + e_i \qquad (1)$$

$$g_i^* = \gamma' Z_i^1 + u_i^1 \qquad (2)$$

$$f_i^* = \delta' Z_i^2 + u_i^2 \qquad (3)$$

$$g_i = g_i^* \quad if \quad f_i > 0; \quad g_i = 0 \quad otherwise$$

Equation (1) is the determination of private R&D. p_i is privately funded R&D for firm 1, while g_i is public funding. X_i is a vector of exogenous variables that includes industry and size dummies, and whether the firm has applied for patents among others. We are also interested in examining whether cooperation with public research institutions has an impact on private R&D. Promoting industry-science interaction is often an important policy objective in order to increase knowledge exchange and utilization. Furthermore, public funding may also be linked to cooperation with public research. Hence, in the analysis in Section 5 we will also include public cooperation.

Equations (2) and (3) model the decision to fund and determination of the amount of public funding. g^* gives the latent amount of publicly funded R&D, while g_i gives the actual observed amount. f^* is the latent value of public funding. The government will thus provide public funding (and g_i=g^*) to firm i if f^*>0. Z^1 and Z^2 are vectors of exogenous variables. Both the decision to provide funding and the actual amount are assumed to depend on a number of firm factors, and these decisions are made based on information available to funding agencies. We assume that this information is limited to data for the end of the previous period. Z^2_i is assumed to contain the lagged values of total (privately and publicly funded) R&D for firm i, whether the firm has applied patents, whether it has engaged in cooperation with a public research institution, and industry and size dummies. And, following Wallsten (2000), we assume that the actual amount of funding will be influenced by government funding budget pools within firm i's research area. Equations (2) and (3) thus comprise a standard Heckman's two step model (Heckman, 1976).

Focusing again on the main equation (1), X_i is assumed to be exogenous and thus uncorrelated with the error term, e_i, while public funding may be endogenous. Taking expectations conditional on g_i gives:

$$E(p_i \mid g_i) = \beta g_i + \alpha' X_i + E(e_i \mid g_i)$$
$$E(g_i^* \mid g_i) = \gamma' E(Z_i^1 \mid g_i) + E(u_i^1 \mid g_i)$$

On the assumption that the error terms, e_i, u^1_i and u^2_i are joint normally distributed, (1) can be rewritten as (see Vella, 1993):

$$p_i = \beta g_i + \alpha' X_i + \lambda E(\nu_i \mid g_i) + \eta_i \qquad (4)$$

where $\nu_i = E(u_i \mid g_i)$ and η_i is a zero mean error term uncorrelated with the regressors.

If instead p_i depends on the latent variable, g^*, then (4) becomes:

$$p_i = \beta E(g_i^* \mid g_i) + \alpha' X_i + \lambda E(\nu_i \mid g_i) + \eta_i \qquad (4')$$

Estimates of ν_i can be obtained from the generalized residuals using the results of Gourieroux et al. (1987), i.e.

$$\tilde{\nu}_i = E(u_i \mid g_i) = -\tilde{\sigma}_\nu (1 - I_i)\tilde{\phi}_i (1 - \Phi_i)^{-1} + I_i \tilde{u}_i$$

where $\tilde{u}_i = g_i - \tilde{\gamma} Z_i$, I_i is an indicator function that equals one if g_i is greater than zero, and $\tilde{\gamma}$, $\tilde{\sigma}_\nu$ are measured using Heckman's two step model.

Hence, the model can be estimated in two stages: Heckman's two step model to estimate (2) and (3) and thereafter OLS for (4) where $\tilde{\nu}$ is included in the regression. If instead (4') is estimated, then both $\tilde{\nu}$ and $\tilde{g}_i = \tilde{\gamma} Z_i$ are included in the regression.

4. The data on public R&D funding in Denmark

This section describes briefly the main funding sources for private sector R&D firms in Denmark and presents summary statistics concerning public funding of business R&D over the period 1997 – 2005.

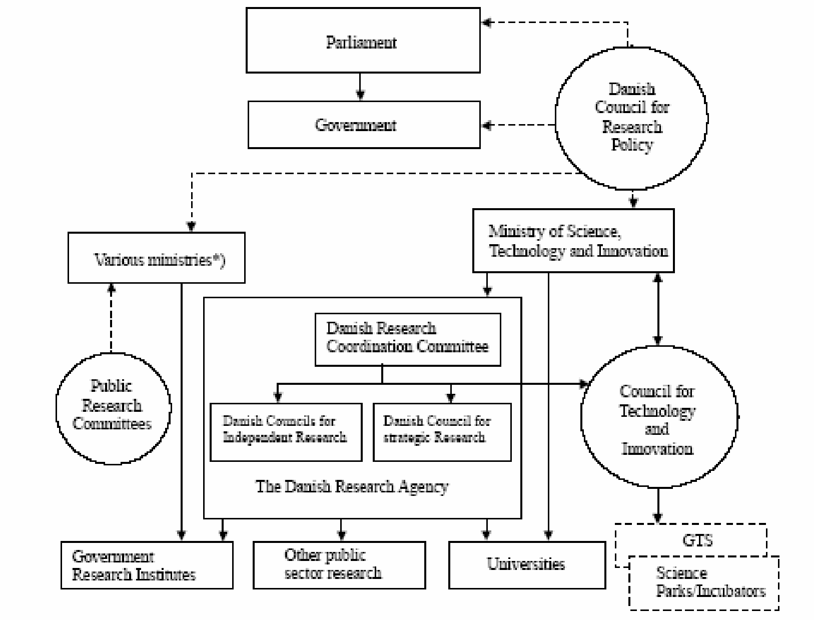
4.1 Public funding sources among private sector R&D firms

The Danish innovation system has been restructured considerably in recent years. In July 2000, a Danish Research Commission was established to review the relevant legislation with a view to enhancing the efficiency of the entire research system. Based on the Commission's recommendations the Parliament and the government embarked on a reform of the entire public research and innovation system in 2002. To strengthen the coordination and the overall function of the research and innovation system, responsibility for both research and innovation were given to a single ministry, the Ministry of Science, Technology and Innovation.

The research funding and advisory system has also been reformed in order to ensure an optimal use of research resources. The reform is an attempt to simplify the organizational structure of the system and to strengthen the management. The intention was to open up competition for research resources that are not allocated as basic appropriations to institutions, and to ensure that a larger part of appropriations are channeled through the advisory and funding system.

The Ministry of Science, Technology and Innovation allocates research funding both directly and through a number of research councils of research funding councils, cf. figure 1. In the latest reform, the funding aspects of the research advisory system have been divided into two subsystems. The **Council for Independent Research** is the umbrella for five research councils and will support research projects based on the researchers' own research initiatives. It will also encourage Danish research to be as broad and of as high a quality as possible by carrying out open competitions based on independent assessments.

Figure 1. Schematic presentation of the Danish innovation policy system



Source: INNO-Policy TrendChart – Policy Trends and Appraisal Report. DENMARK 2007. European Commission, Enterprise Directorate-General.

The other subsystem of the funding structure is made up of the **Council for Strategic** Research, which will support research based on politically defined programs. It will also give advice on research and technical subjects to applicants and others within its scope of activities. The Council has an obligation to contribute to an increased co-operation between public and private research.

While the Ministry of Science, Technology and Innovation has the main responsibility for R&D and innovation policy, the Ministry of Economics and Business Affairs is also active in the funding of business sector R&D activities.

The main unit within this ministry concerning innovation policy is the **Danish Enterprise and Construction Authority**. Among the areas they are concerned with are entrepreneurship, public-private cooperation, user-driven innovation, regional innovation, design, standards and trade regulations. The **Vaekst Fonden (VF)** supports Danish companies by helping to finance R&D, internationalization and skills development projects. This support is organized through an institution operating under the legal form of a private venture capital company. With a capital base of 300 million VF is one of the largest Danish venture capital players. The VF is a state backed investment company, which provide funding to fast-growing Danish companies and act as a fund-of-funds investor in the private equity sector in the Nordic region. The fund invests in early stage ventures mainly focusing on Life Science/Med Tech and High Tech, and provide mezzanine financing to a broad range of industries. It is part of the strategic objectives to work actively to facilitate access to international venture capital and drive the development of an internationally competitive private equity environment in Denmark.

The **Danish National Research Foundation** has the status of an independent fund, and funds larger research activities based on researchers' own ideas, and contributes to the development of Centers of Excellence. The Foundation has a capital of approximately EUR 270 million. At present, 33 centers are funded. In addition a **Foundation for High-Tech Development** was established recently to give the Foundation a cash injection of EUR 269 million on average per year over the next 12 years. The proceeds from the Foundation will be allocated to strategic high-tech projects in which Danish research and industry have strong qualifications. To be eligible, projects must have an element of interaction between public knowledge institutions and companies.

In addition to these national funding agencies, there is also some funding of business R&D at the local and regional levels.

The firms have the following funding sources of their R&D activities (c.f. the questionnaire behind the Danish private sector R&D Statistics for 2005):

Danish Sources:

Private sector

- Own internal finance
- Other Danish firms in the same concern
- Other Danish firms inclusive venture capital firms
- Private Danish organizations and funds

Public sector

- Ministry of Science, Technology and Innovation
- The Research Councils
- Other governmental institutions
- Regions and municipalities
- The Danish National Research Foundation
- The Business Development Finance
- Other Danish public organizations and funds

Foreign Sources

Private sector

- Foreign firms in the same concern
- Other foreign firms
- Private foreign organizations and funds

Public sector

- EU-funding
- Other public foreign funding

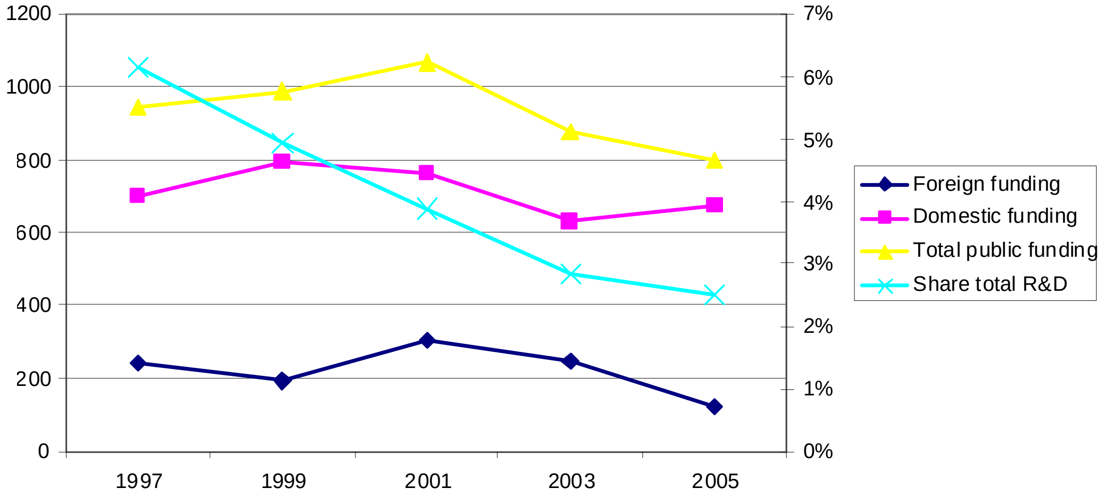
In year 2005 the Danish private sector contributed with 14 % of the total external funding to firms' R&D activities. The foreign private sector contributed with the far largest share, 68 %. The Danish public funding amounted to 15 % while the foreign public funding amounted to 3 % of total external funding of business R&D activities in 2005.

Overall R&D expenditures in Denmark as share of GDP amounted to 2.45% in 2005, 1.67% in the business sector and 0.78 in the public sector. This puts Denmark as the ninth highest among OECD countries, slightly higher than the OECD average.

Over the period 1997-2005, aggregate R&D expenditures in Denmark have increased substantially, by just under 50%. However, public financing of these expenditures have actually fallen slightly over this period. In 2005, total public R&D funding to both businesses and public research institutions was 0.73% of GDP. The largest share of public R&D funding in Denmark goes to public research, with about 7% of public funding going to private businesses in 2005.

Figure 2 shows developments in the public funding of business R&D over the period from 1997 to 2005. Funding from domestic sources decreased from 1999 to 2003, but rose in 2005. In contrast, foreign funding has declined significantly since 2001. The figure also shows that only a small share of business R&D in Denmark is publicly financed, and this share has fallen substantially from 1997 to 2005.

Figure 2. Public funding of business R&D in Denmark, 1997-2005. MN DKK (left) and % of total R&D (right)



Source: The Danish Private Sector R&D Statistics 1997-2005.

4.2 The empirical data

The data used in this analysis are taken from the Danish R&D statistics, collected by the Danish Centre for Studies in Research and Research Policy. The R&D survey is conducted every other year from 1997 to 2005. In order to used lagged values as instruments firms were only kept in the sample if they were included in the survey for two consecutive periods. The sample used in the analysis consists of 1369 observations total with R&D for 1999, 2001, 2003 and 2005, of which 290 had received public funding. Measured in terms of ratios such as the share of R&D to sales or the share of public funding in total R&D, there are some extreme values on both ends. In an analysis of the effect of R&D on productivity, it would seem reasonable to exclude firms with little sales, on the argument that these firms have not yet commercialized their R&D activities. However, this same argument is less applicable in analyzing the impact of funding on R&D expenditures. These firms may very well be subject to credit constraints which could impact the effect of public funding on private R&D.

However, we cannot identify such potential constraints and do not see any compelling reason to exclude these firms from the analysis. Hence, no cleaning of the data was undertaken whatsoever. Instead, in order to check the robustness of the results to outliers, all analyses were also conducted after having removed the highest and lowest 5% of observations in terms of R&D to employees and public funding to total R&D. In discussing the results we will mention how much the coefficient estimates are affected by these subsamples, see also the Appendix. In general, however, results are similar for the ‘full’ sample and for estimations where extreme values are removed. This indicates that the results are robust and general to all firms receiving public funding, and not a select subgroup.

Table 1 shows descriptive statistics for the sample across industries. The highest shares of firms receiving funding are actually in services - R&D services and (technical) business services. Also in terms of shares of R&D expenditures that are publicly funded, these two sectors are the highest. Surprisingly, among the lowest shares receiving funding is Chemicals and Pharmaceuticals. Though, with the exception of R&D and tech business services, shares of firms receiving funding are fairly similar across sectors in the sample. The table also shows shares of firms in the sample that have received funding from different sources. Domestic funding sources are divided in to those that mainly finance basic and applied research and those that focus more on development activities. In terms of firm size, a higher share of large firms has received funding, but the share of funding in terms of expenditures is substantially higher for small firms.

Table 1. Descriptive statistics across sectors and size groups

Sectors	R&D firms	G-funded firms	G-funded firms	Domestic G-funded	Foreign G-funded	G-fund share of R&D expenses given G-funding>0	Share of firms cooperating with public sector R&D institutions	
	Number		----- Share of all -----			G-funded	All	G-funded
Food and Beverages	76	15	0.20	0.12	0.13	0.09	0.57	0.87
Chemicals	72	11	0.15	0.13	0.08	0.05	0.69	1.00
Materials	208	32	0.15	0.11	0.08	0.13	0.50	0.77
Machinery	228	35	0.15	0.11	0.08	0.11	0.39	0.74
Electronics	60	13	0.22	0.15	0.12	0.07	0.60	0.91
Instruments	151	18	0.12	0.06	0.09	0.20	0.50	0.82
Manufactures	92	17	0.19	0.16	0.09	0.13	0.47	0.88
Wholesale	78	16	0.21	0.15	0.10	0.10	0.58	0.50
ICT services	141	18	0.13	0.09	0.10	0.15	0.23	0.44
R&D services	90	47	0.52	0.43	0.34	0.27	0.66	0.74
Business services	172	73	0.42	0.36	0.31	0.46	0.61	0.82
Total	1368	295	0.22	0.16	0.13	0.23	0.50	0.77
Small	293	52	0.18	0.15	0.10	0.37	0.39	0.67
Medium	540	96	0.18	0.14	0.11	0.26	0.38	0.64
Large	535	147	0.28	0.20	0.18	0.15	0.68	0.89

5. Analysis and results

Following the discussion above, the model is estimated in two stages. In the first stage, the propensity to receive public funding and the determination of the amount of funding provided are estimated using the Heckman two-step approach (see Heckman, 1976). We assume that the government's funding decision is based on a variety of available information on firm characteristics prior to the current period: total (private and publicly funded) R&D expenditures, R&D cooperation with public research, R&D cooperation with other firms, the number of patent applications, number employees and industry, size and year dummies, c.f. column 2 in table 2.

Since we only have R&D funding data for every other year, we use variables for period t-2. It would be preferable to have data for t-1, but given the high autocorrelation in many of these variables, period t-2 provides a good proxy. The amount of government funding in period t is assumed to be determined by lagged values of privately funded R&D, public funding, patent applications and number employees. In addition, following Wallsten (2000), we assume that government funding is affected by overall funding budgets. We calculate the budget variable as the total amount of public funding distributed within the firm's industry. See the results in column 1 in table 2.

We are interested in level effects here, i.e. what is the effect of a one unit (1 DKK) increase in public funding on privately funded R&D. However to reduce problems with heteroscedasticity, all variables (with the exception of dummy variables and the selectivity correction variable) are expressed in logs.

In the second stage, the main equation is estimated. In order to examine the role of selectivity and simultaneity bias in more detail, we use three different approaches to estimate the equation for privately funded R&D. First, the equation is estimated using OLS without attempting to correct for selection, cf. column 3. Second, the Mill's ratio from the first stage is included in the equation and the standard errors are bootstrapped (column 4) and third both the Mill's ratio and the predicted value of public funding are included (column 5). Finally, the entire model is estimated using Instrument Variables where the Mill's ratio is also included to correct for selection bias (column 6).

In addition to publicly funded R&D in time t, the lagged value of privately funded R&D is also included in order to capture the high autocorrelation for R&D expenditures. Also included are the number of patent applications, number employees, dummies for R&D cooperation with public research institutes and other firms, and size, industry and time dummies.

The entire model is estimated for total public funding (table 2), domestic public funding (table 3) and foreign (predominantly EU) public funding (table 4). Considering first the Heckman for public funding, it can be seen that patents and firm size have positive significant impact on the propensity to receive funding, as do both cooperation with public research institutions and with other firms. However, the amount of R&D expenditures has weak if any effect on the propensity to receive funding[2]. Both lagged values of private and public R&D have strong impact on amount of public funding. The budget variable for industry level funding also has a strong, positive influence on funding amounts. And, while patents seem to affect the funding decision, we do not find any evidence that they impact the amount of public funding.

The remaining four columns in table 2 show results of the main equation for the effect of public funding on privately funded R&D. The Mill's ratio is highly significant in all equations, indicating the presence of an inverse selection bias (negative parameter estimate), i.e. unobserved characteristics determine that the higher the propensity to receive public funding, the lower is the privately funded R&D. However, the impact from the inclusion of the selectivity variable on the other coefficient estimates is very small and differences in coefficient estimates for the different methods are clearly not statistically significant. A comparison of the elasticity coefficient for public funding using OLS and

[2] The same results were found when separating total R&D into publicly and privately funded R&D.

OLS correcting for selection bias (i.e. column 3 versus 5), shows that the inclusion of the Mill's ratio results in a fall from 0.09 to 0.08. In other words, an increase in public funding leads on average to an 8 percent increase in privately funded R&D. Hence, we find here that public R&D funding is a complement for private R&D – and that public funding result in an increase in overall R&D that is larger than the funding amounts themselves.

Table 2. Results of total public funding on business R&D

Parameter	$Ln(G\text{-}fund_t)$	P(G-fund>0)	------------------ Ln(R&D-exp$_{priv.,t}$) ------------------			
	Heckman Two-step		OLS	Boot	OLS	IV
	1	2	3	4	5	6
Ln(R&D-exp$_{priv}$)$_{t-1}$	0.222***		0.670***	0.623***	0.634***	0.624***
	(0.050)		(0.036)	(0.071)	(0.039)	(0.068)
Ln(G-fund)$_{t-1}$	0.715***					
	(0.057)					
Ln(Pub. budget)$_t$	0.252***					
	(0.064)					
(Patent appl.)$_t$	-0.007		0.006**	0.006**	0.005*	0.006***
	(0.004)		(0.003)	(0.003)	(0.003)	(0.002)
Ln(# employee)$_t$	0.004	0.116*	0.263***	0.199**	0.199**	0.201**
	(0.110)	(0.068)	(0.073)	(0.080)	(0.078)	(0.079)
Ln(R&D-exp$_{total}$)$_{t-1}$		0.053				
		(0.033)				
Coop($_{publ.\ R\&D\ inst}$)$_{t-1}$		0.475***				
		(0.120)				
Coop($_{private}$)$_{t-1}$		0.582***				
		(0.100)				
(Patent appl.)$_{t-1}$		0.022***				
		(0.008)				
Ln(G-fund)$_t$			0.090***		0.082***	0.115**
			(0.031)		(0.031)	(0.052)
Ln(G-fund$_{pred.}$)$_t$				0.113**		
				(0.049)		
Coop($_{private}$)$_t$			0.349**	0.195	0.201	0.196
			(0.140)	(0.160)	(0.160)	(0.140)
Coop($_{publ.\ R\&D\ inst}$)$_t$			-0.046	-0.083	-0.097	-0.105
			(0.150)	(0.150)	(0.150)	(0.150)
Mills ratio				-0.551**	-0.556**	-0.528**
				(0.240)	(0.240)	(0.220)
Observations	1325		295	1368	295	295
R^2			0.85	0.85	0.85	0.85
LR test (P-value)	0.688					

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Lag t-1 corresponds to 2 years due to the data measuring schedule. A constant and industry, size and year dummies are included in each model except in column 1 where industry dummies are not included. See also table A.1.

As expected, lagged private R&D is significant with a high positive coefficient. This also indicates the importance of accounting for this autocorrelation in private R&D. For example, earlier examinations reveal that the exclusion of lagged private R&D leads to large increases in coefficient estimates for public funding, likely due to bias. It can also be seen that patents are positively related with the level of private R&D. Looking at R&D cooperation, cooperation with public research institutes (universities or government research) is not significantly related to private R&D. Cooperation with other firms is shown to have a significant positive impact on private R&D in the basic OLS regression, however this effect disappears when the Mill's ratio is introduced in the equation.

Column 4 shows the estimates using the predicted value of public funding from the Heckman equation while column 6 shows the IV estimates using Two Stage Least Squares. In both cases, comparing the results in columns 3 and 5 with the corresponding results in columns 4 and 6 the control for simultaneity bias results in a slight increase in elasticity coefficient estimates from approximately 0.08 to 0.11.

In order to examine the robustness of these results, the models were estimated for two subsamples: the first where highest and lowest 5 % removed in terms of share of public funding to total R&D and the second where the highest and lowest 5 % of observations in terms of R&D expenditures to employees were removed. In both cases, the results were very similar to those presented above. The results are given in the Appendix tables A.1 and A.2. Although some minor changes in parameter estimates the overall impression is that the results found In Table 2 are robust in relation to outliers in data.

Tables 3 and 4 shows the results for the same model as referred in table 2, but for domestic and foreign public funding separately. As for total funding, a Heckman equation was estimated for domestic funding and for foreign (predominantly EU) funding.

Table 3. Results of total domestic public funding on business R&D

Parameter	$LN(G\text{-}fund_t)$	P(G-fund>0)	------------------ $Ln(R\&D\text{-}exp_{priv.,t})$ ------------------			
	Heckman Two-step		OLS	Boot	OLS	IV
	1	2	3	4	5	6
$Ln(R\&D\text{-}exp_{priv.})_{t-1}$	0.187***		0.664***	0.594***	0.613***	0.602***
	(0.057)		(0.041)	(0.080)	(0.046)	(0.078)
$Ln(G\text{-}fund)_{t-1}$	0.755***					
	(0.062)					
$Ln(Pub.\ budget_{Dom.})_t$	0.365***					
	(0.066)					
$(Patent\ appl.)_t$	-0.004		0.007**	0.007*	0.006*	0.006***
	(0.005)		(0.003)	(0.004)	(0.003)	(0.002)
$Ln(\#\ employee)_t$	0.124	0.119*	0.211**	0.112	0.117	0.118
	(0.130)	(0.071)	(0.090)	(0.100)	(0.098)	(0.096)
$Ln(R\&D\text{-}exp_{total})_{t-1}$		0.063*				
		(0.034)				
$Coop(_{publ.\ R\&D\ inst})_{t-1}$		0.305**				
		(0.130)				
$Coop(_{private})_{t-1}$		0.497***				
		(0.11)				
$(Patent\ appl.)_{t-1}$		0.012**				
		(0.005)				
$Ln(G\text{-}fund_{Dom.})_t$			0.075**		0.072**	0.114***
			(0.034)		(0.034)	(0.043)
$Ln(G\text{-}fund_{Dom.,pred.})_t$				0.140***		
				(0.052)		
$Coop(_{private})_t$			0.392**	0.155	0.180	0.181
			(0.180)	(0.190)	(0.200)	(0.180)
$Coop(_{publ.\ R\&D\ inst})_t$			-0.032	-0.030	-0.071	-0.094
			(0.180)	(0.160)	(0.180)	(0.170)
Mills ratio				-0.691*	-0.773**	-0.756**
				(0.360)	(0.340)	(0.340)
Observations	1325		224	1368	224	224
R^2			0.85	0.86	0.86	0.86
LR test (P-value)	0.152					

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Lag t-1 corresponds to 2 years due to the data measuring schedule. A constant and industry, size and year dummies are included in each model except in column 1 where industry dummies are not included. See also table A.1.

The results for domestic funding are very similar to those for total funding. The estimated elasticity for domestic funding is around 7 percent and, as above, the Mill's ratio is highly significant though its introduction does not alter the coefficient estimate for domestic funding. The elasticity estimate for public funding for instrumented values is higher. When using the predicted value of domestic funding from the Heckman equation, the coefficient estimate almost doubles, to 0.14, while the estimate using 2SLS is almost identical to that for total funding, at 0.11.

Coefficient estimates for foreign (mainly EU) public funding is somewhat higher than for domestic funding. And, in contrast to the other cases, the introduction of the Mill's ratio has a somewhat larger impact here, leading to a fall in the elasticity coefficient for public funding from around 0.13 to 0.10. Hence, while the difference is not great, it would appear that EU funding has a slightly larger impact on overall R&D investments than domestic funding.

Table 4. Results of total foreign public funding on business R&D

Parameter	$Ln(G\text{-}fund_t)$	P(G-fund>0)	------------------ $Ln(R\&D\text{-}exp_{priv.,t})$ ------------------			
	Heckman Two-step		OLS	Boot	OLS	IV
	1	2	3	4	5	6
$Ln(R\&D\text{-}exp_{priv.})_{t-1}$	0.213***		0.675***	0.601***	0.614***	0.613***
	(0.063)		(0.044)	(0.100)	(0.052)	(0.097)
$Ln(G\text{-}fund)_{t-1}$	0.551***					
	(0.064)					
$Ln(Pub.\ budget_{For.})_t$	0.459***					
	(0.078)					
$(Patent\ appl.)_t$	-0.008*		0.004	0.004	0.004	0.004*
	(0.005)		(0.003)	(0.004)	(0.003)	(0.002)
$Ln(\#employee)_t$	0.059	0.029	0.274***	0.227**	0.235***	0.236***
	(0.120)	(0.075)	(0.085)	(0.089)	(0.086)	(0.088)
$Ln(RD\text{-}exp_{total})_{t-1}$		0.134***				
		(0.038)				
$Coop(_{publ.\ R\&D\ inst})_{t-1}$		0.475***				
		(0.140)				
$Coop(_{private})_{t-1}$		0.525***				
		(0.130)				
$(Patent\ appl.)_{t-1}$		0.015**				
		(0.006)				
$Ln(G\text{-}fund_{For.})_t$			0.124***		0.098**	0.111
			(0.042)		(0.043)	(0.069)
$Ln(G\text{-}fund_{For.,pred.})_t$				0.136		
				(0.091)		
$Coop(_{private})_t$			0.275	0.155	0.138	0.139
			(0.170)	(0.200)	(0.180)	(0.190)
$Coop(_{publ.\ R\&D\ inst})_t$			-0.239	-0.275	-0.281	-0.285
			(0.180)	(0.200)	(0.180)	(0.200)
Mills ratio				-0.599*	-0.566**	-0.545*
				(0.320)	(0.260)	(0.320)
Observations	1325		183	1368	183	183
R^2			0.86	0.86	0.87	0.87
LR test (P-value)	0.825					

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Lag t-1 corresponds to 2 years due to the data measuring schedule. A constant and industry, size and year dummies are included in each model except in column 1 where industry dummies are not included. See also table A.1.

6. Discussion and conclusions

Over many decades it has been discussed whether public support to business R&D actually decreased the self finance share of business R&D, i.e. acted as a substitute with crowding out effects. Even though a potential crowding out effect was present, an argument for public funding has been that the crowding out was less than 100 %, so the net effect was more national performed R&D.

The present analysis on a large Danish data set with firms over several years rejects any evidence of crowding out. Instead, the study finds robust and very significant evidence for complementarity between public funding and firm R&D. There is not full complementarity but the elasticity between public funding and business R&D is found to be around 0.1, robust against outliers, sample trimming as well as splitting in domestic and foreign funding. Hence, public funding creates economic additionality in business R&D in from of extra R&D activities.

From a policy point of view, an implementation of a policy that increases business R&D could consist of increased public funding. The study found no evidence of differences in behavior or responsiveness among the firms, so either supporting more R&D active firms or supporting R&D firms more will have a positive additional effect on business R&D in Denmark.

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Appendix

Table A.1 Results after removing the highest and lowest 5% share of firms by funding relative to total R&D expenditures

Parameter	Ln(G-fund$_t$)	P(G-fund>0)	------------------ Ln(R&D-exp$_{priv.,t}$) ------------------			
	Heckit		OLS	Boot	OLS	IV
Ln(R&D-exp$_{priv}$)$_{t-1}$	0.255***		0.644***	0.598***	0.605***	0.605***
	(0.047)		(0.039)	(0.082)	(0.041)	(0.076)
Ln(G-fund)$_{t-1}$	0.697***					
	(0.053)					
Ln(Pub. budget)$_t$	0.219***					
	(0.057)					
(Patent appl.)$_t$	-0.004		0.007**	0.006	0.006*	0.006***
	(0.004)		(0.003)	(0.005)	(0.003)	(0.002)
Ln(# employee)$_t$	0.003	0.123*	0.287***	0.231***	0.225***	0.225***
	(0.096)	(0.069)	(0.074)	(0.081)	(0.078)	(0.077)
Ln(R&D-exp$_{total}$)$_{t-1}$		0.045				
		(0.034)				
Coop($_{publ.\ R\&D\ inst}$)$_{t-1}$		0.463***				
		(0.130)				
Coop($_{private}$)$_{t-1}$		0.627***				
		(0.110)				
(Patent appl.)$_{t-1}$		0.022**				
		(0.009)				
Ln(G-fund)$_t$			0.157***		0.151***	0.151**
			(0.036)		(0.036)	(0.060)
Ln(Gfund$_{pred.}$)$_t$				0.152**		
				(0.059)		
Coop($_{private}$)$_t$			0.286*	0.120	0.120	0.120
			(0.150)	(0.170)	(0.160)	(0.150)
Coop($_{publ.\ R\&D\ inst}$)$_t$			-0.091	-0.108	-0.144	-0.144
			(0.150)	(0.160)	(0.150)	(0.150)
Mills ratio				-0.560**	-0.575**	-0.575**
				(0.240)	(0.230)	(0.220)
Year99	0.035	1.126***	0.192	-0.091	-0.093	-0.093
	(0.220)	(0.160)	(0.160)	(0.200)	(0.200)	(0.200)
Year01	-0.241	0.673***	0.286*	0.053	0.057	0.057
	(0.220)	(0.140)	(0.170)	(0.170)	(0.190)	(0.160)
Year03	0.120	0.355**	0.261	0.164	0.169	0.169
	(0.230)	(0.150)	(0.180)	(0.150)	(0.180)	(0.150)
<49 employees	0.099	-0.085	0.385	0.342	0.360	0.360
	(0.360)	(0.260)	(0.280)	(0.280)	(0.280)	(0.280)
50-249 employees	0.174	0.005	0.074	0.053	0.057	0.057
	(0.220)	(0.150)	(0.170)	(0.160)	(0.170)	(0.150)
Nacegr15		0.268	0.073	-0.032	-0.012	-0.012
		(0.210)	(0.240)	(0.200)	(0.24)	(0.190)
Nacegr29		0.160	-0.068	-0.091	-0.078	-0.078
		(0.160)	(0.190)	(0.130)	(0.190)	(0.140)
Nacegr31		0.209	0.548*	0.419	0.484*	0.484
		(0.240)	(0.280)	(0.410)	(0.280)	(0.390)
Nacegr33		-0.051	0.121	0.284	0.227	0.227
		(0.190)	(0.250)	(0.250)	(0.250)	(0.240)
Nacegr36		0.241	-0.098	-0.117	-0.141	-0.141
		(0.200)	(0.230)	(0.190)	(0.230)	(0.190)
Nacegr51		0.392*	-0.085	-0.106	-0.144	-0.144
		(0.200)	(0.240)	(0.260)	(0.240)	(0.260)
Nacegr72		0.292	0.242	0.316	0.251	0.251
		(0.200)	(0.260)	(0.220)	(0.260)	(0.220)
Nacegr73		1.372***	0.424*	-0.027	-0.074	-0.073
		(0.21)	(0.220)	(0.310)	(0.300)	(0.280)
Nacegr74		0.957***	-0.368**	-0.729***	-0.724***	-0.724***
		(0.160)	(0.180)	(0.260)	(0.230)	(0.230)
Observations	1294		264	1337	264	264
R^2			0.85	0.85	0.85	0.85
LR test (P-value)	0.817					

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Lag t-1 corresponds to 2 years due to the data measuring schedule. A constant is also included in all models.

Table A.2 Results after removing the lowest and highest 5% share of firms by R&D per employee

Parameter	Ln(G-fund$_t$)	P(G-fund>0)	Ln(R&D-exp$_{priv.,t}$) OLS	Boot	OLS	IV
	Heckit					
Ln(R&D-exp$_{priv}$)$_{t-1}$	0.247***		0.630***	0.536***	0.562***	0.539***
	(0.055)		(0.036)	(0.074)	(0.039)	(0.071)
Ln(G-fund)$_{t-1}$	0.742***					
	(0.058)					
Ln(Pub. budget)$_t$	0.234***					
	(0.062)					
(Patent appl.)$_t$	-0.008*		0.006**	0.005*	0.004*	0.005***
	(0.0042)		(0.003)	(0.003)	(0.003)	(0.002)
Ln(# employee)$_t$	-0.060	0.075	0.290***	0.231***	0.225***	0.233***
	(0.100)	(0.075)	(0.066)	(0.069)	(0.066)	(0.066)
Ln(R&D-exp$_{total}$)$_{t-1}$		0.077**				
		(0.039)				
Coop($_{publ.\ R\&D\ inst}$)$_{t-1}$		0.434***				
		(0.130)				
Coop($_{private}$)$_{t-1}$		0.579***				
		(0.110)				
(Patent appl.)$_{t-1}$		0.030***				
		(0.011)				
Ln(G-fund)$_t$			0.066**		0.049*	0.128***
			(0.029)		(0.029)	(0.045)
Ln(Gfund$_{pred.}$)				0.125***		
				(0.043)		
Coop($_{private}$)$_t$			0.341***	0.118	0.135	0.127
			(0.130)	(0.140)	(0.140)	(0.140)
Coop($_{publ.\ R\&D\ inst}$)$_t$			-0.088	-0.129	-0.142	-0.164
			(0.140)	(0.150)	(0.130)	(0.150)
Mills ratio				-0.742***	-0.786***	-0.702***
				(0.210)	(0.200)	(0.200)
Year99	0.543**	0.849***	0.130	-0.185	-0.111	-0.183
	(0.220)	(0.160)	(0.140)	(0.170)	(0.150)	(0.170)
Year01	0.321	0.494***	0.162	-0.099	-0.051	-0.092
	(0.220)	(0.140)	(0.140)	(0.140)	(0.150)	(0.140)
Year03	0.584**	0.153	0.047	-0.044	0.015	-0.042
	(0.240)	(0.150)	(0.150)	(0.130)	(0.150)	(0.140)
<49 employees	0.054	-0.086	-0.062	-0.110	-0.152	-0.100
	(0.400)	(0.270)	(0.250)	(0.270)	(0.240)	(0.250)
50-249 employees	0.377	-0.068	-0.018	-0.024	-0.011	-0.024
	(0.240)	(0.150)	(0.150)	(0.140)	(0.150)	(0.130)
Nacegr15		0.245	-0.044	-0.161	-0.167	-0.148
		(0.220)	(0.230)	(0.210)	(0.220)	(0.200)
Nacegr29		0.159	-0.199	-0.282**	-0.261	-0.246*
		(0.160)	(0.160)	(0.130)	(0.160)	(0.140)
Nacegr31		0.179	0.581**	0.468	0.487**	0.547**
		(0.240)	(0.240)	(0.290)	(0.240)	(0.270)
Nacegr33		-0.028	0.148	0.259	0.285	0.235
		(0.190)	(0.210)	(0.240)	(0.210)	(0.240)
Nacegr36		0.330	-0.220	-0.357*	-0.332	-0.375**
		(0.200)	(0.210)	(0.190)	(0.200)	(0.190)
Nacegr51		0.348*	-0.162	-0.197	-0.211	-0.232
		(0.210)	(0.220)	(0.260)	(0.210)	(0.260)
Nacegr72		0.296	0.333	0.266	0.337	0.250
		(0.200)	(0.220)	(0.210)	(0.220)	(0.200)
Nacegr73		1.724***	0.291	-0.637**	-0.511*	-0.620***
		(0.260)	(0.200)	(0.250)	(0.290)	(0.230)
Nacegr74		1.037***	-0.303*	-0.957***	-0.805***	-0.942***
		(0.160)	(0.160)	(0.230)	(0.200)	(0.220)
Observations	1163		263	1163	263	263
R^2			0.88	0.89	0.89	0.88
LR test (P-value)	0.399					

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Lag t-1 corresponds to 2 years due to the data measuring schedule. A constant is also included in all models.