UK and EU subsidies and private RD investment: Is there input additionality?

Ugur, Mehmet and Trushin, Eshref and Solomon, Edna

University of Greenwich, Durham University

4 November 2015

UK and EU subsidies and private R&D investment: Is there input additionality?

Mehmet Ugur[a], Eshref Trushin[b] and Edna Solomon[a]

Abstract

This paper investigates the effects of UK and EU subsidies on privately-funded R&D intensity of a sample of 39,730 UK firms. The sample consists of R&D-active firms surveyed in at least one year from 1998-2012. The results are obtained from 4 different estimators, with different degrees of control for selection and time-constant fixed effects: (i) pooled OLS without selection correction; (ii) fixed-effect (within-group) estimation without selection correction; (iii) pooled OLS with selection correction; and (iv) fixed-effect estimation with selection correction. We report that UK subsidies are not associated with additionality in privately -funded R&D intensity in the full sample, and the additionality effect in manufacturing is too small to be conomically significant. In contrast, EU subsidy is associated with an additionality effect of 2% in both samples. Ordered-Heckman estimations of leverage indicate that an increase in UK subsidy intensity (subsidy/total R&D) is not likely to make a difference to private R&D effort in any of the subsidy intensity classes demarcated by 4 quartiles of the intensity distribution. However, an increase in EU subsidy intensity is associated with leverage in subsidy intensity class 3, which corresponds to subsidy intensity values within the 3rd quartile of the distribution.

Keywords: Innovation, R&D, subsidies, additionality
JEL classification: C41, D21, D22, L1, 03

[a]University of Greenwich Business School; [b]Durham University Business School
Corresponding author: M.Ugur@gre.ac.uk

Acknowledgement and Disclaimer:
We thank the Economic and Social Research Council (ESRC) for funding the research for this paper. We also thank the UK Data Service for the support they provided in accessing BERD data. This paper contains statistical data from ONS which is Crown Copyright. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates.

UK and EU subsidies and private R&D investment: Is there input additionality?

1. Introduction

Public support for business R&D is usually justified on the basis of market failures due to inappropriability of knowledge, increasing returns on R&D and R&D return uncertainty (Arrow, 1962; 1996). To the extent that knowledge has a public good character, knowledge produced by a firm can spillover to other firms and deter the investor from undertaking the optimal level of R&D investment. In addition, information may be characterized by increasing returns to scale, conducive to very low marginal costs relative to average cost. For welfare maximisation, this property may require free provision of information but poses the serious issue of incentive compatibility in the production of information. Finally, R&D investment is associated with a high degree of uncertainty - not only with respect to success in generating new knowledge but also with respect to using the new knowledge in the production of new goods and services. For these reasons, governments have devised various schemes to provide direct or indirect support for R&D investments.

Yet, the case for supporting R&D activities is not as straightforward as the neoclassical approach summarised above would suggest. From an evolutionary perspective, knowledge cannot be absorbed unless imitating firms invest in R&D in the first place (Cohen and Levinthal, 1989). If this is the case, public support may lead to excess investment. Excess R&D investment can also occur when firms engage in 'patent races'. Dasgupta and Stiglitz (1980), Dasgupta (1988), and D'Aspremont and Jacquemin (1988) demonstrate that inter-firm competition for obtaining intellectual property protection may result in higher-than-optimum levels of R&D investment and part of that investment may entail sunk cost when the patent race is lost. Finally, the public good character of R&D may be overstated. A firm can use a wide range of tools to protect its inventions, including patents and secrecy (Nadiri, 1993). Therefore, the level of positive externalities may be low and/or industry-specific; and the case for supporting R&D activities may be less straightforward than it might appear in the first instance.

These theoretical perspectives imply that direct public support for business R&D may or may not be effective in inducing firms either to undertake the optimal level of R&D investment or to create additionality on top of the public subsidy. Because of this ambiguity, a large volume of empirical work has been undertaken to find out how various public support schemes have affected firm behaviour with respect to R&D effort. A number of reviews of this literature exists. While Hall and Van Reenen (2000) review the literature on *indirect support* schemes, David, Hall and Toole (2000) review the literature on *direct support* schemes. More recently, Cerulli (2010) provides a review of the models and estimators widely used in the empirical literature.

The aim of this study is to add to existing knowledge in three areas. First, we provide evidence on UK firms with a view to bridge the evidence gap on a country that have well-established direct and indirect support mechanisms for business R&D. In 2009, the UK occupied the top 8th place among OECD countries ranked on the basis of direct and indirect support for business R&D as a percentage of GDP. This is lower than the United States (US) at the 5th place, but above Sweden, Norway and Germany the 11th, 13th and 18th place, respectively. Yet, and to the best of our knowledge, there has been no study investigating the consequences of UK support schemes for input additionality.[1] Secondly, we control for selection in line with the existing literature, but we contribute to existing work by providing novel evidence based on a conditional mean approach that corrects for firm-specific effects in both the selection and outcome models. Third, we go beyond the current practice and demonstrate how the relationship between subsidy and the R&D effort differs between firms when the latters are divided into latent classes based on subsidy intensity (subsidy/privately-funded R&D).

2. A brief review of the empirical literature

Following the pioneering work by Blank and Stigler (1957), a large body of empirical work has utilised a variety of datasets and different estimation methods to ascertain whether public and private R&D investments are complementary or substitutes. The policy-relevant question is whether public support for R&D is associated with additionality or crowding-out effects on privately-funded R&D investment. The literature has evolved over time, starting with estimations of structural models without control for selection, going through structural models with selection and finally the emergence of matching models based on propensity scores (Cerulli, 2010). David et al. (2000) is an early review of the literature on direct public support schemes and private R&D effort. Given the time of publication, this review focuses mainly on studies that used structural models without control for selections. Out of 14 firm-level studies reviewed, only 4 used a selection equation or some instrumental variable (IV) estimator. In terms of findings, 3 studies report complementarity (additionality), 5 studies report substitution (crowding-out) effects, and the remaining 6 report mixed/heterogeneous findings driven by differences in the sample or model chosen. The majority of the studies that reported crowding-out effects were based on US firm-level data. The reviewers conjecture that the relative lack of complementarity in the US data may be due to underlying differences between the US and continental European funding regimes.

Later reviews also report mixed findings in the empirical literature. Drawing on a sample of 28 studies that utilize firm-level data, Garcia-Quevedo (2004) reports that 7 studies find additionality, 10 studies find no significant subsidy effects and 11 find crowding-out effects. Dimos and Pugh (2014) is a meta-analysis study based on 52 studies published from 2000-March 2013. With respect to 300 effect-size estimates from 27 studies where additionality and crowding-out effects can be separated, they report that 164 effect-size estimates indicate additionality whilst 136 estimates indicate no effect (117) or crowding out (19). Overall, the balance of evidence remains ambiguous.

[1] We have identified only one study – a Department for Business, Innovation and Skills (BIS) analysis paper on output additionality (BIS, 2014). The only study on input additionality was Buxton (1975), based on industry data.

However, focusing mainly on recent studies that control for selection or utilise matching methods we observe an increase in the number of findings indicating additionality effects. For example, in their evaluation of the technology development funds in Latin America, Hall and Maffioli (2008) report strong evidence of additionality. Similary Czatrnitzki and Lopes-Bento (2012) also report additionality effect in Flanders, using the fourth Community Innovation Survey (CIS4) and matching methodology. Other studies in the area input additionality include Czarnitzki and Hussinger (2004) who report a additionality findings with respect to R&D intensity of German firms; Hussinger (2008) who uses semi-parametric selection models and report additionality among German firms; Duguet (2004) who report a similar finding for R&D intensity of French fimrs; and and Aerts and Schmidt (2008) who utilise a conditional difference-in-difference estimator for repeated cross-section data and report a positive treatment effect on firm R&D effort in Germany and Flanders. All of these studies reject total crowding out, but they also report evidence of partial crowding out.

What emerges from these recent studies is an evident clustering of the additionality findings with respect to firm-level data from a few continental European countries (mainly Germany and Flanders). This raises the issue of data overlap and dependence between findings cannot be ruled out. However, it also raises the issue identified by David, Hall and Toole (2000) – namely whether the funding regimes in these countries are different and more conducive to additionality compared to others. Addressing these issues are beyond the scope of this study, but they reinforce the need to add to the evidence base by investigating the effects of subsidies in a country that has not featured in the literature over the last couple of decades.

3. Funding regime, data and method

Business expenditure on research and development (BERD) in the UK is relatively low compared to other OECD countries, even after adjusting for inter-country structural differences. Another feature of the UK BERD landscape is that R&D activity tends to be concentrated in terms of size as well as technology classes (Hughes and Mina, 2012). Direct and indirect public support for business R&D is around 0.16 per cent of GDP and this is higher than most other OECD countries, excluding the US, Korea, Canada and France. Whilst the US relies more heavily on direct support, the UK government relies on both direct and indirect support with equal measures (National Audit office, 2013).

Direct public support for business R&D includes funding from (or originating within) UK government departments, their agencies and non-departmental public bodies (e.g. *Technology Strategy Board* or its successor, *Innovate UK*). Given this landscape, different selection criteria may have been used during our estimation period from 1998-2012 – partly due to multiplicity of funding bodies and the change in the rules over time. Therefore, we do not have a clearly-defined set of funding rules that can be used to model the selection of firms for direct support. Instead, we rely on the funding rules used by *Innovate UK* as a prototype that we assume to be representative over the estimation period.

Innovate UK is a public agency that reports to the Department for Business, Innovation and Skills (BIS), but operates at arm's length from the UK Government. It provides funding for business-led projects with the objective of stimulating R&D and innovation activity, and encouraging the development of innovative products, processes and services with future commercial potential. All business entities (excluding research organisations, charities and public sector organisations) are eligible to apply for funding. Part-funding by the agency depends on firm size and type project, as indicated in Table 1 below.

Table 1: Funding rates as percentage of eligible project costs – *Innovate UK* 2014

Applicant firm size	Fundamental research	Feasibility studies	Industrial research	Experimental development
Micro (<10 employees) OR Small (<50 employees)	100%	70%	60%	35%
Medium (<250 employees)	100%	60%	60%	35%
Large (250+ employees)	100%	50%	50%	25%

Source: https://www.gov.uk/government/organisations/innovate-uk

Fundamental research is eligible for full project cost funding irrespective of the firm size. It is defined as "theoretical work undertaken primarily to acquire new knowledge … without any direct practical application or use in view." For all other research types small and medium-sized firms are eligible for somewhat higher funding rates - usually 10% more of the project cost compared to large firms. **Industrial research** is funded at a rate of 60 and 50 percent of the project cost for SMEs and large firms, respectively. It is defined as "investigation aimed at the acquisition of new knowledge and skills for developing new products, processes or services or for bringing about a significant improvement in existing products, processes or services." **Experimental development research** is funded at lower rates (35/25 split) as it is closer to imitation and rather than innovation. It is defined as the acquiring, combining or using of existing knowledge for the purpose of planning for new, altered or improved products, processes or services. Finally, **technical feasibility studies** are funded at relatively higher rates for micro businesses and are defined as research to analyse and evaluate the potential of a new project. Feasibility studies are expected primarily to assist firms to work, either individually or collaboratively, with other industrial or research organisations on Research & Development that requires an initial study prior to a subsequent and larger R&D project. Given these rules, firms can apply for part-funding at or below the indicated rates and indicating the composition of the total project along the four types of research indicated above. The agency decides on whether to fund and the amount of part funding, taking into account the project documentation and other information about the applicant.

As far as eligibility and funding rules are concerned, the regime is transparent. However, *Innovate UK* does not publish information about how they set funding priorities - with the exception of references to policy documents published by BIS. In addition, the Business Research and Development Database (BERD) provides information on UK government funding received, but does not provide information on successful and unsuccessful applications. Another area where public information is lacking concerns implementation monitoring. There may be an accounting-based audit process, but we do not know how *Innovate UK* ensures that part-funding is spent in accordance with project objectives; and whether funding recipients are graded in terms of compliance with the conditions of the part-funding or on the basis of some performance indicators over the project life. Absence of such information has important implications for modelling the selection decisions (see below).

In this study, we use data from BERD – a repeated annual survey designed to measure R&D expenditure and employment in UK businesses. Throughout the estimation period (1998-2012), the BERD survey has been based on a random sample stratified by product group and employment size-bands. The sample itself is drawn from a sampling frame that consists of all firms known to be R&D-active through information from HMRC R&D Tax credit claimants, other sources of administrative data, community innovation surveys (CIS) and responses to a survey question about R&D activity in the Annual Business Survey (ABS). As of 2011, the sampling frame consisted of 25, 511 firms.

The stratified sample consists of about 400 large firms that account for about 80% of UK business R&D expenditures (sampled 1:1); size-band2-firms (100-399 employees) sampled 1:5 and size-band3-firms (0-99 employees) sampled approximately at a rate of 1:20. The largest 400 firms receive a long survey form, with detailed questions on R&D types (e.g., total, intramural, extramural, current, capital, basic, applied R&D) and sources of funding (e.g., privately-funded R&D, and public R&D support received from the UK government and the European Commission separately). Other firms receive a short survey form with questions on total, intramural and extramural R&D only. Despite the difference between the question sets, BERD reports detailed breakdown of R&D types, employment of R&D personnel and other related data for all firms. Missing data for smaller firms is imputed from third-party sources or estimated by the Office of National Statistics (ONS). (See ONS, 2012). Annual figures for total R&D expenditures and UK government support are given in Table 2 below.

Table 2 indicates that BERD's coverage has expanded steadily over time, with a total number of firms in the panel from 1998-2012 standing at 39,730. Firm appearance in the dataset ranges from 1-15 years. Subsidy intensity (direct government support as percentage of total R&D) has fallen form around 10% in 1998 to 7% in 2012.

Table 2: Total R&D expenditures and UK government subsidies: 1998-2012 (£ mn.)
(Source BERD Database)

Year	Number of firms (enterprises)	Total R&D (£ mn.)	Central-government-funded R&D (£ mn.)	Support intensity (%)
1998	8,350	10900	1048.834	9.62
1999	7,678	11600	1133.149	9.77
2000	8,630	11800	950.585	8.06
2001	8,656	12200	742.585	6.09
2002	10,930	12900	805.517	6.24
2003	8,926	11900	975.956	8.20
2004	11,752	14500	1312.154	9.05
2005	12,969	15600	1125.116	7.21
2006	16,849	16600	1042.328	6.28
2007	19,911	18300	1039.612	5.68
2008	16,970	19300	1040.349	5.39
2009	19,046	18900	1288.505	6.82
2010	18,592	19500	1383.028	7.09
2011	20,556	20500	1488.232	7.26
2012	22,169	20100	1338.957	6.66
Total firm/year observation	***39,730***	***2.35E+08***	***16714909***	***7.12***

Table 3 below presents the summary statistics for the estimation sample, including all relevant variables. The table reports summary statistics for firm/year observations when UK subsidy is and is NOT received.[2]

The first observation to make is that the UK government support regime is highly generous: UK firms have received government support in 92% [(=195,151/(195,151+16,429)] of the

[2] Minimum and maximum values are excluded to comply with non-disclosure requirements of the data host. We do not provide a similar table for cases when EU subsidy is and is NOT received to save space.

firm/year observations. The average UK subsidy intensity is 0.07 (7%), with a third-quartile value of 9% and a 95th-percentile value of 28%. In other words, the UK regime provides close-

Table 3: Summary statistics – 1998-2012

	Firm/year observation when UK subsidy is received			Firm/year observation when UK subsidy is NOT received		
	Observation	Mean	Std. Dev.	Obs	Mean	Std. Dev.
UK subsidy dummy	195,151	1.00	0.00	16,429	0.00	0.00
EU subsidy dummy	195,151	0.80	0.40	16,429	0.14	0.35
Privately funded R&D (£'000)	195,138	556.20	15424.28	16,405	6.59E+03	4.63E+04
Total R&D (£ '000)	195,151	638.56	16457.67	16,429	6.59E+03	4.62E+04
Privately funded R&D intensity	193,730	0.80	36.23	16,039	1.40	32.99
Total R&D intensity	193,742	0.90	37.56	16,063	1.40	32.98
Deflated private R&D	195,138	622.19	16848.80	16,405	7.36E+03	5.04E+04
Deflated total R&D	195,138	715.22	18037.17	16,428	7357.57	50361.51
UK central government support (£'000)	195,151	78.51	2945.44	16,429	0.00	0.00
EU support (£ '000)	195,138	3.81	126.87	16,405	6.74	202.00
UK subsidy intensity	195,151	0.07	0.09	13,051	0.00	0.00
EU subsidy intensity	195,138	0.01	0.03	13,050	0.02	0.06
Multiple subsidy dummy	195,151	0.80	0.40	16,429	0.00	0.00
Turnover (£ '000)	195,150	2.70E+04	4.15E+05	16,429	1.44E+05	1.05E+06
Deflated turnover (£'000)	195,016	2.88E+04	4.81E+05	16,422	1.69E+05	1.29E+06
Deflated turnover growth	187,038	0.02	0.67	15,594	0.03	0.69
Age	195,151	16.71	10.39	16,429	18.81	10.30
Employment (count)	195,150	146.12	1884.73	16,429	648.83	4828.83
UK ownership dummy	195,151	0.88	0.33	16,429	0.78	0.41
Herfindahl index (3-digit)	195,150	0.10	0.11	16,429	0.13	0.14
Herfindahl index squared	195,150	0.02	0.06	16,429	0.04	0.09
Capital R&D intensity	193,742	0.04	2.03	16,063	0.09	5.18
Capital R&D int. Sq.	193,742	4.12	1006.27	16,063	26.83	2860.29
R&D personnel (scientists and technicians) (count)	195,151	5.66	83.64	16,429	36.97	154.80
Defence-related R&D activity dummy	195,151	0.59	0.49	16,429	0.24	0.42
Pavitt class1	195,151	0.34	0.47	16,429	0.18	0.38
Pavitt class2	195,151	0.22	0.42	16,429	0.11	0.31
Pavitt class3	195,151	0.10	0.30	16,429	0.14	0.34
Pavitt class4	195,151	0.28	0.45	16,429	0.43	0.50
Pavitt class5	195,151	0.06	0.23	16,429	0.14	0.35
Average effective real exchange rates	195,151	92.21	9.48	16,429	95.80	7.86
Crisis dummy (=1 after 2007)	195,151	0.47	0.50	16,429	0.34	0.47
Log (FTSE-100)	195,138	7.93	0.13	16,428	7.96	0.12

to-maximum levels of subsidy only to the top 5% of the successful applicants. The third observation is that the R&D intensity of subsidy-receiving firm/year observations (0.8) is lower than that of non-subsidized year/firm observations (1.4). However, the mean conceals a high degree of skewness as the respective median values are 0.03 and 0.01.

Table 3 also indicates that non-subsidized firms are usually larger and older; and have higher level of R&D investment in R&D-related capital such as lab equipment and buildings. Non-subsidized firm/year observations are also associated with higher levels R&D personnel on average. Finally, more than one-third (36%) of the R&D-active firms in the UK are in the science-based Pavitt technology class – Pavitt 1 that includes industries such as chemicals, information technology, office machinery, precision instruments, and medical and optical instruments industries.

We use this estimation sample and a structural model with selection to estimate the effects of both UK and European Union (EU) subsidies on privately-funded R&D investment. Subsidy is endogenous because it depends on the decisions of the firms to apply for UK and/or EU funding and on the decisions of the UK/EU to grant support to successful applicants.

First-generation structural models (Lichtenberg, 1987) build on a demand and supply framework compatible with profit maximization, but they treat the subsidy as exogenous. Even they relax the assumption of exogenous subsidy, all they can do is to use instrumental variable (IV) techniques such as three-stage least-squares (3SLS) (Wallsten, 2000). The 3SLS estimator allows for correlation between the error terms of the selection and outcome equations, but the exogeneity of the instrument for subsidy is non-testable because the model is just-identified. Hence the 3SLS approach benefits from theory-driven outcome model inherited from the structural models, but it still does not address the issue subsidy endogeneity satisfactorily.

Endogeneity of the subsidy may be due to three reasons. First, the firm's R&D effort and the level of subsidy granted may be determined simultaneously. In other words, the decision of the funding agency may be dependent on the firm's R&D effort. If the funding agency selects firms on perceived R&D effort, the OLS estimate for subsidy's effect on R&D effort will be biased upward. Otherwise, the OLS estimate will be biased downward (Heckman, 1978; Wooldridge, 2002; Cerulli, 2010). Secondly, endogeneity may be due to ommitted variable bias that arises when the researcher does not have the necessary information about crucial variables (e.g., project quality) that affect subsidy. Finally, the data may be subject to measurement error, leading to correlation between the error term and the regressors.

The 'structural model with selection' or the 'endogenous binary selection model' we adopt here can address the issue of subsidy endogeneity satisfactorily, provided that the error terms of R&D effort and selection models are distributed normally. In what follows, we draw on Busom (2000) and Takalo et al (2013) to specify the binary selection model.

Let F^* denotes the unobserved net profit of the firm, **Z** the vector of observable variables that determine net profit, and u the error term. Then the firm's net profit function can be stated as follows:

$$F^* = f(\mathbf{Z}, u) \qquad (1)$$

Firm's decision to apply for subsidy or abstain depends on F^*. The firm decides to apply if profits net of application costs are positive. Otherwise it abstains - as stated below.

$$I_f = \begin{cases} 1 \; if \; F^* \geq 0 \\ 0 \; if \; F^* < 0 \end{cases} \qquad (2)$$

The funding agency's behaviour is modelled analogously, with G* denoting the objective function of the agency, **W** is the vector of observable factors that affect the agency decision, and v the error term.

$$G^* = g(\mathbf{W}, u) \qquad (3)$$

Firm's decision to apply for subsidy or abstain depends on F^*. The firm decides to apply if profits net of application costs are positive. Otherwise it abstains - as stated below.

$$I_g = \begin{cases} 1 \; if \; G^* \geq 0 \\ 0 \; if \; G^* < 0 \end{cases} \qquad (4)$$

In the data, we do not observe the firm's and the agency's decisions separately. Instead, we observe the final outcome of granting or not granting of (hence obtaining and not obtaining) the subsidy. Denoting this outcome by I, we can write:

$$I = I_f . I_g = \begin{cases} 1 \; if \; F^* \geq 0 \; and \; G^* \geq 0 \\ 0 \qquad\qquad Otherwise \end{cases} \qquad (5a)$$

Using the equivalents of F* and G* from (2) and (4), we can re-write (5a) as follows:

$$I = I_f . I_g = \begin{cases} 1 \; if \; h(\mathbf{Z}, \mathbf{W}, u, v) \geq 0 \\ 0 \; if \; h(\mathbf{Z}, \mathbf{W}, u, v) < 0 \end{cases} \qquad (5b)$$

Here *h(.)* is a function of observables in **Z** and **W**, and of the error terms u and v.

Now let's specify the firm's behavioural equation (i.e., the R&D outcome equation) as follows:

$$RD = \mu + \mathbf{X}\alpha + \gamma I + \varepsilon \qquad (6)$$

Here, RD is observed only for firms participating in the public funding competition (when I = 1) or only for non-participants (when I = 0). In other words, 'non-participants' are the basis for the estimation of the participants' unobservable counterfactual. Combining (5b) and (6), letting **Q** = [**Z**, **W**], and denoting firms with subscript *i*, the system of equations for estimation becomes:

$$\begin{cases} RD_i = \mu_i + \mathbf{X}_i\alpha + \gamma I_i + \varepsilon_i \\ I_i^* = \theta + \mathbf{Q}_i\beta + e_i \\ I_i = \begin{cases} 1 \; if \; I_i^* \geq 0 \\ 0 \; if \; I_i^* < 0 \end{cases} \\ Cov(\varepsilon_i, e_i) = \rho \neq 0 \end{cases} \tag{7}$$

Compared with matching or OLS models that assume selection on observables, model (7) has the advantage of taking into account the effect of unobservables. This is done by assuming non-zero correlation between the error terms of the outcome and selection equations – i.e., by assuming that $Cov(\varepsilon_i, e_i) = \rho \neq 0$. This assumption, however, is not sufficient for consistent estimation if some unobservables affect both the firm's R&D effort and its treatment status (receipt or non-receipt of subsidy) *simultaneously*. This is the case because we condition the selection and outcome equations only on a set of observable covariates (**X** and **Q**).

Reverting to IV techniques may be appropriate – but at the expense of not being able to test for the exogeneity of the instrument for subsidy. This is the case unless we have more than one instrument. The problem here is that it is already difficult to find one valid instrument in the kind of data available in this research filed. The good news is that the endogenous binary selection model provides a way out because it is a non-linear system – i.e., it consists of binary selection equation estimated by probit and an outcome equation estimated by (pooled) OLS after taking account of the endogenous subsidy (Cerulli, 2010). Another advantage of endogenous binary selection model is that it can be used with both binary and continuous subsidy variables if necessary. If the subsidy variable is continuous, the selection model can be estimated with a tobit estimator and the invesre-Mills ratio from the tobit estimation can be added to the outcome model.

The endogenous binary selection model in (7) can be estimated via two-step or maximum likelihood (ML) procedures. Both procedures assume joint normality for the error terms of the outcome and selection equations (ε_i and e_i). Under joint normality, both estimators are similar in terms of efficiency. However, the ML estimator is relatively less efficient if the dual normality condition is violated (Cerulli, 2010). Therefore, we use the two-step estimator. Once estimated, the model yields consistent estimates for the subsidy coefficient (γ).

In both models, the coefficient on subsidy (γ) is an indicator of the effect of public support on privately-funded R&D investments. However, it is not a precise estimate if the treatment is interacted with covariates in the outcome equation. To obtain the treatment effect when treatment is interacted with covariates in the outcome model, we need to take the expected value of the difference between the outcomes of treated and non-treated firms and the covariates with which the treatment variable is interacted. Denoting the R&D effort of the treated firms with RD_{1i} and that of the non-treated firms with RD_{0i}, and recalling that the R&D effort is a function of the covariates in vector **X**, we can write:

$$ATE = E(RD_{1i} - RD_{0i}) = E\{E(RD_{1i} - RD_{0i}|\mathbf{x}_i, \boldsymbol{\varepsilon}_{0i}, \boldsymbol{\varepsilon}_{1i})\}$$
$$= E\{\mathbf{x}_i(\gamma_i - \gamma_0)\} \quad (8)$$

The **ATE** in (8) is the average difference of the treatment potential outcomes and the control (non-treated) potential outcomes on the 'whole' population of both recipients and non-recipients of the public support.

On the other hand, **ATET** is the average difference of the treatment potential outcomes and the control potential outcomes on the treated population. It is estimated in accordance with (9) below.

$$ATET = E(RD_{1i} - RD_{0i} \mid I_i = 1) = E\{E(RD_{1i} - RD_{0i} \mid \mathbf{x}_i, \mathbf{w}, I_i = 1)\}$$
$$= E\left\{\mathbf{x}_i(\gamma_i - \gamma_0) + (\rho_1\sigma_1 - \rho_0\sigma_0)\emptyset\frac{(\mathbf{w}_i\beta)}{\Phi(\mathbf{w}_i\beta)} \mid I_i = 1\right\} \quad (9)$$

Although the structural selection model (7) takes account of endogenous selection, it has two shortcomings. First, consistent estimation of the subsidy's effect on R&D effort crucially depends on correct specification of the selection and outcome models. As indicated above, usually we do not have sufficient information about the funding regime. Even if we do, there is no commonly-agreed set of covariates that should enter the behavioural equation for the funding agency. The second problem is due to time-constant firm effects that may be due to systematic differences between firms that are not observed/measured in the data. Such firm effects may be due to differences in management quality or other path-dependent characteristics – which remain constant over time for each firm but vary across firms. If time-invariant effects exist and if they are correlated with the regressors, pooled OLS estimates from (7) will be biased.

Wooldridge (1995) propose a conditional mean approach to correct for firm-specific effects in the selection and outcome models. The approach involves estimating inverse-Mills ratios for each year of the time dimension. This involves estimation of T probit selection models, where T is the number of years over which the firms are observed. The model can be specified as follows:

$$RD_{it} = \eta_i + \mathrm{x'}_{it}\alpha + \gamma I_{it} + \varepsilon_{it} \quad \text{(outcome equation); and}$$
$$I_{it} = \theta_i + \mathrm{z'}_{it}\beta + u_{it} \quad \text{(selection equation)}$$
$$Cov(\eta_i, \mathrm{x'}_{it}) \neq 0; and\ Cov(\theta_i, \mathrm{z'}_{it}) \neq 0 \quad (10)$$

η_i and θ_i are unobserved firm-specific effects. The firm-specific effect in the outcome equation (η_i) can be eliminated by using a fixed-effect (within-group) estimator. However, the firm-specific effect in the selection model (θ_i) cannot be eliminated with the same method because the selection model is non-linear and estimated with a probit estimator. Wooldridge (1995) draws on Chamberlain's conditional mean theorem and demonstrates that the unobserved θ_i can be substituted by inverse-Mills ratio obtained from T cross-section probit estimations. Then the outcome model to be estimated boils down to:

$$RD_{it} = \eta_i + x'_{it}\alpha + \gamma I_{it} + \delta(Inv\_Mills)_{it} + v_{it} \qquad (11)$$

Model (11) can be estimated consistently using a fixed-effect estimator. The coefficient on the intervention variable (γ) will be unbiased because its estimation takes account of the selection rule through inclusion of the inverse-Mills ratio and is carried out after eliminating the firm-specific effects (η_i). However, and just as it was the case with respect to the endogenous binary selection model, the consistency of the estimate for the subsidy effect depends on correct specification of the selection and outcome equations. Given that correct model specification is essential for consistent estimates, we use the same set of covariates for the selection and outcome equations in both endogenous binary selection and conditional mean estimations. Then, the difference between the two can be interpreted as the bias that arises from failure to eliminate the firm-specific time-constant effects in the estimation of the endogenous binary selection model.

Given these methodological considerations, we will provide estimates based on different estimators. This is to verify if the 'treatment effect' (i.e., the effect of subsidy receipt on privately-funded R&D) differs between estimators, depending on whether they control for endogeneity of the subsidy and eliminate the time-constant firm effects. The results will include OLS and fixed-effect estimates not corrected for selection bias, followed by structural selection model estimations from (7) and selection-corrected fixed-effect estimates from (11). Given that we have a panel dataset, our preferred estimator is Wooldridge's fixed-effect estimator, which corrects for endogeneity of the subsidy and is carried out after eliminating the time-constant firm effects.

The estimations results will provide an indication of whether UK government or EU support has a complementary or substitution effect on firm's private R&D intensity. Having established whether we observe a complementary or substitution effect, we will also check whether the effect of subsidy on R&D effort varies between firms with different levels of subsidy intensity. In other words, we will try to identify the class(es) of firms where subsidy intensity is more (or less) likely to leverage private R&D investment. This is an important issue given that the R&D intensity of UK firms has been and is still low in comparison to international standards (Hughes and Milna, 2012).

To address this question, we use an ordered-probit selection model proposed by Chiburis and Lokshin (2007). This model allows for sorting the firms into J+1 classes of 0, 1, 2, … J on the basis of an ordered-probit selection rule where the latent selection variable (z_i*) is not observable but the categorical variable (z_i) that depends on particular realisations of the latent variable is observed in the data. Then, we can specify the selection rule as follows (Chiburis and Lokshin, 2007):

$$z^* = \beta' w_i + u_i \text{ ; and}$$

$$z_i = \begin{cases} 0 \;\; if -\infty < z_i < \mu_1 \\ 1 \;\; if \quad \mu_1 < z_i < \mu_2 \\ 2 \;\; if \quad \mu_2 < z_i < \mu_3 \\ . \\ . \\ \text{J} \;\; if \quad \mu_J < z_i < \infty \end{cases} \tag{12a}$$

The latent selection variable refers to subsidy intensity. In other words, we assume that firms belong to different classes of subsidy intensity as a result of a two-way selection process that we do not observe: selection by the firm to apply for subsidy and selection the funding agency to award the successful applicant. Given this setting, the outcome (R&D effort) is a linear function of a set of covariates in $\mathbf{x_i}$ and the coefficients (α_0, ... α_j) vary between categorical classes of z_i. Then, the R&D effort equation can be written as follows:

$$RD_i = \begin{cases} \alpha'_0 \mathrm{x}_i + \varepsilon_{i0} \;\; if\; z_i = 0 \\ \alpha'_1 \mathrm{x}_i + \varepsilon_{i1} \;\; if\; z_i = 1 \\ \alpha'_2 \mathrm{x}_i + \varepsilon_{i2} \;\; if\; z_i = 2 \\ \;. \\ \;. \\ \alpha'_J \mathrm{x}_i + \varepsilon_{iJ} \;\; if\; z_i = J \end{cases} \tag{12b}$$

Here the categorical variable $z_i = 0$ is the class of firms that do not receive subsidy in a particular year; and the remaining classes *1, … J* are sorted on the basis of increasing subsidy intensity. The latter is defined as the ratio of UK or EU public support to total R&D expenditures, depending on which support scheme is investigated. The model in (12a) and (12b) can be estimated through a two-step procedure or via maximum likelihood (ML). The necessary condition for consistent estimation of the model is the same as the selection model in (7) above: the error terms of the selection and outcome equations (u_i and ε_i) must satisfy the condition of joint normality. The two-step procedure is more efficient than ML if normality condition is violated. Therefore, we estimate the model with a two-step consistent estimator.

We define the subsidy intensity classes as follows: $zi = 0$ is the group consisting of firm/year observations when subsidy intensity is zero; $zi = 1$ is the group consisting of firm/year observations where subsidy intensity is greater than zero but less than or equal to the value at the first quartile; $zi = 2$ is the group consisting of firm/year observations where subsidy intensity is between the first-quartile and median values; $zi = 3$ is the group consisting of firm/year observations where subsidy intensity is between the median and third-quartile value; and $zi = 4$ is the group consisting of firm/year observations where subsidy intensity is equal to or greater than the value at the third quartile.

Results

Given the methodological framework above, the selection and outcome models we estimate are as follows:

$$
\begin{aligned}
Sub\_dum_{it} = {} & \beta_0 + \beta_1 size\_dum_{it} + \beta_2 startup\_dum_{it} + \beta_3 lcap\_RD\_int_{it-1} \\
& + \beta_4 l^2 cap\_RD\_int_{it-1} + \beta_5 lRD\_pers_{it-1} + \beta_6 l^2 RD\_pers_{it-1} \\
& + \beta_7 lempl_{it-1} + \beta_8 l^2 empl_{it-1} + \beta_9 growth_{it} + \beta_{10} \mathrm{def}\_RD_{it} \\
& + \beta_{11} Pavitt1_{it} + \beta_{12} Pavitt2_{it} + \beta_{13} Pavitt3_{it} + \beta_{14} Pavitt4_{it} + u_{it}
\end{aligned}
$$

(Selection equation)

$$
\begin{aligned}
Priv\_RD\_int_{it} = {} & \alpha_0 + \gamma Sub\_dum_{it} \quad \alpha_1 loutput_{it} + \alpha_2 l^2 output_{it} + \alpha_3 lage_{it} \\
& + \alpha_4 l^2 age_{it} + \alpha_5 lempl_{it} + \alpha_6 l^2 empl_{it} + \alpha_7 uk\_owned_{it} + \alpha_8 HI_{it} \\
& + \alpha_9 \mathrm{HI\_sq}_{it} + \alpha_{10} Pavitt1_{it} + \alpha_{11} Pavitt2_{it} + \alpha_{12} Pavitt3_{it} \\
& + \alpha_{13} Pavitt4_{it} + \alpha_{14} AEER_{it} + \alpha_{15} crisis_{it} + \alpha_{16} lFTSE_{it} + \alpha_{17} multi\_sub_{it} \\
& + \alpha_{18} inverse\_Mills + \varepsilon_{it}
\end{aligned}
$$

(Outcome equation)

In the selection model, we assume that the funding agency selects applicants on the basis of certain firm characteristics, including size (a dummy that distinguish between SMEs with less than 250 employees); whether the firm is a startup (i.e., it is born in 1998 or thereafter); intensity of R&D investment in research labs and equipment and its square; number of R&D personnel (i.e., scientists and technicians) employed and its square; firm age and its square; number of employees and its square; growth rate of deflated turnover between year t-1 and t; whether the firm is engaged in defence-related R&D; and the firm's membership of Pavitt technology classes. A prefix (*l*) indicates that the variable is in logs, a prefix (l^2) indicates squared value of the logged variable, and a subscript (t-1) indicates that the variable is lagged one year. The lagged value is used as we assume that the funding agency examines the firm's annual statements in its evaluation of the applications. The squared values (the quadratic terms) are included to establish whether the funding agency's selection decisions change at different levels of the firm characteristic in question.

Covariates in the selection model are chosen on the basis of information about funding criteria/priorities indicated in technology strategy documents published by BIS, various funding schemes/competitions publicised on the *Innovate UK* website, and from modelling work in the relevant literature. As indicated above, there is no commonly-agreed set of covariates that should enter the selection model; and correct specification of the latter is necessary for consistent estimates.

A similar approach has been adopted in specifying the outcome model. The level of deflated output (turnover) and its square is included because they can be considered as proxies for the cash flow available to the firm. In the R&D investment literature, cash flow is usually reported to be a significant determinant of R&D investment (Brown et al., 2009; Hall et al., 1998). Age is also a frequently-cited determinant of R&D investment, with older firms reported to have lower innovation intensities (Huergo and Jaumandreu, 2004; Balasubramanian and Lee, 2008). There is also a long-standing debate about whether firm size and innovation intensity are related (see, Cohen et al., 1987; Shefer and Frenkel, 2005; and Tsai and Wang, 2005). Concentration at 3-digit industry level is included in line with Schumpeterian models of competition and innovation (Aghion et al, 2005; Polder and Veldhuizen, 2012).

Finally, we include dummies for Pavitt technology classes, treating the unclassified industries (Pavitt5) as the excluded category. Pavitt class 1 consists of firms in science-based industries (e.g., chemicals, office machinery, precision, medical and optical instruments industries, ICT, etc.). Pavitt class 2 consists of industries that are specialized suppliers of technology or capital goods to other industries (e.g., mechanical engineering industries, manufacturers of electrical machinery, equipment hire&lease industries, and business services suppliers, etc.). Pavitt class 3 consists of scale-intensive industries such as pulp&paper, transport vehicles, mineral oil refining industries, financial intermediaries, etc.). Pavitt class 4 consists of technology-supplier-dominated industries such as textiles & clothing, food & drink, fabricated metals, etc.

Table 4 below presents *Probit* estimation results for the selection model. The exclusion restriction is ensured by using a size dummy that features in the selection of both UK government and the European union funding rule. This dummy is equal 1 if the firm is classified as small-to-medium-sized (SME) in both regimes; and zero otherwise. This dummy is not included in the outcome models. When checked in conjunction with other covariates in the outcome model, the size dummy is not correlated with the private R&D intensity, which is the dependent variable. Hence, we are satisfied that the size dummy complies with the necessary condition for exclusion restriction.

Comparing the UK and EU selection, we can see that both funding regimes exercise similar selection criteria – with few exceptions. Focusing on similarities, we observe that both regimes favour growth firms, firms with engagement in defence R&D, and firms within Pavitt classes 1 -3 (i.e., sciences-based, specialized suppliers and scale-intensive firms). However, the probability of receiving UK subsidy is higher than that of receiving EU subsidies for growth firms and firm with engagement in defence R&D. In contrast, and although both regimes favour firms in Pavitt class 1 – 3, the EU is more likely to grants subsidies to firms in these classes compared to the UK government.

Table 4: Probit estimation of the selection model

(Dependent variable: Subsidy dummy)

Regressor	Description/measurement	UK subsidy	EU subsidy
Size dummy	=1 if firm employment < 250	0.116***	0.0698***
		(0.0233)	(0.0189)
Start-up firm	= 1 if new entrant	0.147***	-0.0866***
		(0.0144)	(0.00923)
Lagged Capital R&D int.	Log (int. +1), lagged 1 year	-0.379***	-0.224***
		(0.0815)	(0.0657)
Lagged Capital R&D int. sq.	Log squared, lagged 1 year	0.0547**	0.0180
		(0.0234)	(0.0201)
R&D personnel	Log, lagged 1 year	-0.126***	-0.106***
		(0.00445)	(0.00337)
R&D personel sq.	Log squared, lagged 1 year	-0.0452***	-0.0350***
		(0.000716)	(0.000589)
Growth	Growth of deflated t/over	0.0176**	0.0144**
		(0.00884)	(0.00605)
Employment	Log, lagged 1 year	-0.101***	-0.0229**
		(0.0128)	(0.00927)
Employment sq.	Log squared, lagged 1 year	0.0176***	0.0133***
		(0.00151)	(0.00120)
Defense R&D active	= 1 if firm engages in defense R&D	0.688***	0.251***
		(0.0125)	(0.00802)
Pavitt class1	Science-based	0.671***	1.784***
		(0.0246)	(0.0177)
Pavitt class2	Specialized supplier of tech.	0.598***	1.278***
		(0.0252)	(0.0167)
Pavitt class3	Scale-intensive	0.233***	0.841***
		(0.0244)	(0.0177)
Pavitt class4	Supplier-dominated	0.0245	0.168***
		(0.0211)	(0.0153)
Constant	Constant	1.121***	-0.318***
		(0.0416)	(0.0299)
sigma		0.269	0.293
Rho		0.827	0.796
Lambda (sigma*Rho)		0.223***	0.233***
		(0.00405)	(0.00505)
Observations		162733	162733

Excluded category for Pavitt classes is class 5, which consists of un-classified industries

Another similarity concerns the U-shaped relationship between the probability of receiving subsidies and some firm characteristics such as intensity of capital R&D spending, number of R&D personnel (scientists and technicians) and size in terms of employment count. Even though both UK and US subsidy regimes favour SMEs (with a size dummy coefficient of (0.116 and 0.07, respectively), the probability of granting subsidy decreases when employment size increases from a low threshold. After the turning point, large firms are more likely to receive subsidies. A similar pattern is observable with respect to capital R&D intensity and number of R&D personnel employed. These findings indicate that both support regimes are more likely to provide support to firms at both ends of the relevant scale.

There is only one firm characteristic with respect to which selection in both regimes diverges: start up companies. Whilst the UK regime is more likely to support start-ups, the EU regime is less likely to do so.

The final observation on Table 4 relates to estimates of unobservable heterogeneity. The estimate *Rho* provides an indication about the correlation between the error terms in the selection and outcome equations. The positive value in the UK and EU regimes (0.827 and 0.796, respectively) indicates that unobservable factors that raise R&D intensity are correlated positively with the unobservables that increase the probability of applying for and receiving a subsidy. Given that the correlation is high, it can be inferred that both UK and EU regimes are essentially picking up winners on the basis of some information that is not measured in the data. The high level of correlations between the unobservables also indicate that the estimates of the treatment (subsidy) effect will be biased upward in both pooled OLS and fixed-effect estimates that do not control for selection.

On the other hand, *sigma* is an estimate of the standard deviation for the error term in the outcome equation. It indicates the extent of variation in the unobservables for both subsidized and non-subsidized groups.

The second set of estimation results (Table 5) relate to the outcome equation and are based on four estimators: (1) pooled OLS with no selection correction; (2) fixed-effects with no selection correction; (3) pooled OLS with correction for selection on observable and unobservables; and fixed-effects with selection correction for observables and unobservables. The coefficient on the UK subsidy dummy is negative and significant in 3 out 4 estimations, indicating that firms substitute the subsidy for privately-funded R&D. However, the first two results are biased upward since they do not take account of selection. The third does take account of selection and indicates a high level of crowding out, but it does not take account of firm-specific effects that may be correlated with the covariates. Therefore, we prefer the estimate from model (4), which indicate that subsidies do not have any effect on private R&D effort.

Table 5: Effect of UK subsidy on Private R&D intensity – full sample
(Dependent variable: Log of Private R&D intensity)

	(1)	(2)	(3)	(4)
UK subsidy dummy	-0.0442***	-0.0133***	-0.462***	0.00284
	(0.00629)	(0.00413)	(0.00808)	(0.00466)
Log (Deflated turnover)	-0.437***	-0.517***	-0.433***	-0.523***
	(0.00643)	(0.00847)	(0.00139)	(0.00972)
Log(Def. turnover sq.)	0.0215***	0.0254***	0.0210***	0.0256***
	(0.000388)	(0.000603)	(0.000104)	(0.000691)
Log(Age)	0.0115*	0.137***	-0.00142	0.178***
	(0.00698)	(0.0123)	(0.00667)	(0.0225)
Log^2(Age)	-0.00848***	-0.0234***	-0.00688***	-0.0247***
	(0.00138)	(0.00282)	(0.00130)	(0.00469)
Log(Employment)	0.381***	0.242***	0.405***	0.251***
	(0.00770)	(0.00800)	(0.00182)	(0.00878)
Log^2(Employment)	-0.0357***	-0.0240***	-0.0393***	-0.0246***
	(0.000789)	(0.000948)	(0.000237)	(0.00103)
UK ownership dummy	-0.0119***	0.00620*	-0.00541***	0.00676*
	(0.00383)	(0.00328)	(0.00194)	(0.00355)
Herfindahl index	0.0696***	-0.0269	0.0820***	0.0267
	(0.0217)	(0.0174)	(0.0157)	(0.0190)
Herfindahl index sq.	-0.0733**	0.0111	-0.0810***	-0.0484*
	(0.0363)	(0.0240)	(0.0244)	(0.0259)
Pavitt class1	0.113***	0.0285	0.147***	0.0483**
	(0.00990)	(0.0200)	(0.00918)	(0.0233)
Pavitt class2	0.0340***	-0.00803	0.0739***	0.00938
	(0.00777)	(0.0166)	(0.00789)	(0.0187)
Pavitt class3	0.0538***	0.00637	0.0749***	0.0136
	(0.00782)	(0.0170)	(0.00769)	(0.0189)
Pavitt class4	0.00853	-0.00180	0.0303***	0.000856
	(0.00690)	(0.0156)	(0.00726)	(0.0172)
Aver. Real Eff. Exch. Rate	-0.00316***	-0.00240***	-0.00306***	-0.00261***
	(0.000176)	(0.000168)	(0.000205)	(0.000194)
Crisis dummy	-0.0222***	-0.0258***	-0.0138***	-0.0372***
	(0.00328)	(0.00318)	(0.00387)	(0.00406)
Log(FTSE-100)	-0.0506***	-0.0628***	-0.0385***	-0.0797***
	(0.00465)	(0.00484)	(0.00499)	(0.00551)
Multiple subsidy dummy	-0.00254	0.00807***	-0.00382**	0.00380**
	(0.00263)	(0.00168)	(0.00194)	(0.00174)
Inverse Mills - UK				0.0809***
				(0.00608)
Constant	2.072***	2.424***	2.293***	2.444***
	(0.0480)	(0.0612)	(0.0451)	(0.0784)
lambda			0.223**	
sigma			0.269	0.328
rho			0.827	0.675
Observation	209652	209652	162733	162733

Cluster-robust standard errors are in parentheses. All estimations include 2-digit industry dummies. Time dummies are not included as the crisis dummy, the FTSE-100 and the average effective exchange rates capture time variation. (1) and (2) are pooled OLS and Fixed-effect without selection correction; (3) is pooled OLS with selection correction; and (4) is FE with selection correction. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 below replicates the same set of estimations for EU subsidy. For the same reasons indicated above, we prefer the estimate from model (4). In contrast to UK subsidies, EU subsidies have an additionality effect as the coefficient on EU subsidy is positive and significant. This result suggests that the UK selection regime can learn from EU experience in order to leverage more private R&D effort from supported firms.

Table 6: Effect of EU R&D subsidy on Private R&D intensity – full sample
(Dependent variable: Log of Private R&D intensity)

	(1)	(2)	(3)	(4)
EU subsidy dummy	0.0314**	0.0128**	-0.370***	0.0207***
	(0.0136)	(0.00546)	(0.0117)	(0.00789)
Log (Deflated turnover)	-0.437***	-0.517***	-0.434***	-0.523***
	(0.00643)	(0.00847)	(0.00143)	(0.00973)
Log(Def. turnover sq.)	0.0215***	0.0254***	0.0212***	0.0256***
	(0.000387)	(0.000603)	(0.000106)	(0.000693)
Log(Age)	0.0119*	0.138***	0.00433	0.204***
	(0.00700)	(0.0123)	(0.00673)	(0.0225)
Log^2(Age)	-0.00865***	-0.0240***	-0.00668***	-0.0344***
	(0.00139)	(0.00279)	(0.00131)	(0.00460)
Log(Employment)	0.381***	0.242***	0.404***	0.249***
	(0.00767)	(0.00799)	(0.00193)	(0.00877)
Log^2(Employment)	-0.0356***	-0.0239***	-0.0385***	-0.0240***
	(0.000781)	(0.000948)	(0.000249)	(0.00103)
UK ownership dummy	-0.0124***	0.00626*	-0.00599***	0.00684*
	(0.00388)	(0.00328)	(0.00196)	(0.00357)
Herfindahl index	0.0674***	-0.0273	0.0919***	0.0289
	(0.0216)	(0.0175)	(0.0157)	(0.0191)
Herfindahl index sq.	-0.0705*	0.0119	-0.0916***	-0.0489*
	(0.0360)	(0.0240)	(0.0243)	(0.0260)
Pavitt class1	0.111***	0.0282	0.313***	0.0478**
	(0.00990)	(0.0200)	(0.0101)	(0.0233)
Pavitt class2	0.0320***	-0.00802	0.208***	0.00917
	(0.00773)	(0.0166)	(0.00858)	(0.0184)
Pavitt class3	0.0516***	0.00632	0.182***	0.0167
	(0.00780)	(0.0170)	(0.00811)	(0.0187)
Pavitt class4	0.00644	-0.00165	0.0560***	0.00390
	(0.00687)	(0.0156)	(0.00726)	(0.0169)
Aver. Real Eff. Exch. Rate	-0.00290***	-0.00232***	-0.00244***	-0.00183***
	(0.000169)	(0.000165)	(0.000203)	(0.000174)
Crisis dummy	-0.0197***	-0.0238***	-0.00701*	-0.0171***
	(0.00323)	(0.00300)	(0.00388)	(0.00341)
Log(FTSE-100)	-0.0451***	-0.0609***	-0.0400***	-0.0609***
	(0.00457)	(0.00474)	(0.00501)	(0.00531)
Multiple subsidy dummy	-0.0470***	-0.00728	-0.0450***	-0.0149*
	(0.0137)	(0.00536)	(0.00762)	(0.00767)
Inverse Mills - EU				0.0138***
				(0.00253)
Constant	1.971***	2.391***	1.989***	2.223***
	(0.0444)	(0.0594)	(0.0443)	(0.0747)
lambda			0.233	
sigma		0.332	0.293	0.330
rho		0.657	0.796	0.677
N	209652	209652	162733	162733

Cluster-robust standard errors are in parentheses. All estimations include 2-digit industry dummies. Time dummies are not included as the crisis dummy, the FTSE-100 and the average effective exchange rates capture time variation. (1) and (2) are pooled OLS and Fixed-effect without selection correction; (3) is pooled OLS with selection correction; and (4) is FE with selection correction. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Tables A1 and A2 in the *Appendix* replicate the estimations in Tables 5 and 6, using data for firms in the manufacturing sector only. Results from the preferred estimator (i.e., the fixed-effect estimator corrected for selection) also indicate an additionality effect in the case of EU subsidy: an effect of 0.0192 in manufacturing compared to 0.0207 in the full sample. There is also an additionality effect associated with UK subsidy in the manufacturing sector too; but the effect is much smaller (0.009). These findings indicate that when a firm switches from a non-subsidised to a subsidised status, its privately-funded R&D intensity increases by 2% in the case of EU subsidy in the manufacturing sample or the full sample. However UK subsidy has no effect in the full sample, and the additionality effect is less than 1% (0.9%) in the manufacturing sector. Overall, these findings indicate that the EU regime is more successful in leveraging additionality compared to the UK regime.

Having estimated the effects of UK and EU subsidies on privately-funded R&D intensity, we have estimated the ordered-Heckman model (12a and 12b) with a view to identify the variation in the relationship between subsidy intensity and private R&D intensity. The results are presented in Tables 7 and 8 (for UK and EU subsidy intensity classes, respectively). The coefficient on the UK or EU subsidy intensity is an estimate of leverage – i.e., an estimate of the extent to which UK or EU funders can leverage additional private R&D effort if they increase the subsidy intensity by 1% in each class.

Results in Table 7 below indicate that UK funders would be unable to leverage additional private R&D effort in any of the subsidy intensity classes. In fact, a 1% increase in UK subsidy intensity is associated with additional crowding-out effects of -1.732% in subsidy intensity class 2 and a crowding-out effect of -0.131% in intensity class 4. In contrast, an increase of 1% in EU subsidy intensity can leverage an additional private R&D intensity by 4.833% in subsidy intensity class 3. Nevertheless, an increase of 1% in EU subsidy intensity is associated with a high degree of crowding out (-18.46%) in subsidy intensity class 2. The results from both UK and EU subsidy intensity classes are consistent in the sense that subsidy intensity class 2 is the least likely to class for leveraging additional R&D effort by increasing the generosity of the subsidy granted.

Table 7: Ordered Heckman estimates for UK subsidy intensity classes:
[Dependant variable: Log (Private R&D intensity + 1)

	Class 1	**Class 2**	**Class 3**	**Class 4**
Log(UK subsidy intensity + 1)	-0.328	-1.702***	-0.0335	-0.131***
	(0.553)	(0.304)	(0.0666)	(0.0161)
Log (Deflated turnover)	-0.401***	-0.485***	-0.401***	-0.523***
	(0.00272)	(0.00266)	(0.00247)	(0.00281)
Log(Def. turnover sq.)	0.0194***	0.0253***	0.0212***	0.0272***
	(0.000194)	(0.000210)	(0.000191)	(0.000251)
Log(Age)	-0.0228***	-0.0274***	-0.0288***	-0.0508***
	(0.00211)	(0.00221)	(0.00216)	(0.00256)
Log(Employment)	0.322***	0.403***	0.354***	0.474***
	(0.00318)	(0.00353)	(0.00329)	(0.00393)
Log^2(Employment)	-0.0298***	-0.0418***	-0.0370***	-0.0479***
	(0.000386)	(0.000463)	(0.000437)	(0.000554)
UK ownership dummy	-0.00646**	0.000542	-0.00111	0.00717
	(0.00297)	(0.00355)	(0.00386)	(0.00531)
Herfindahl index	-0.0619**	-0.0300	0.0368	-0.0172
	(0.0284)	(0.0342)	(0.0292)	(0.0376)
Herfindahl index sq.	0.124***	0.0564	-0.0611	0.0399
	(0.0452)	(0.0565)	(0.0455)	(0.0642)
Pavitt class1	0.130***	0.106***	0.0695***	0.0388
	(0.0159)	(0.0201)	(0.0244)	(0.0513)
Pavitt class2	0.0516***	0.0243	0.0473***	0.0255
	(0.0159)	(0.0178)	(0.0122)	(0.0214)
Pavitt class3	0.0958***	0.0281*	0.0517***	-0.00788
	(0.0150)	(0.0155)	(0.0137)	(0.0227)
Pavitt class4	0.0507***	0.0174	0.0454***	0.0421**
	(0.0139)	(0.0160)	(0.0130)	(0.0171)
Aver. Real Eff. Exch. Rate	-0.000771**	-0.000489	-0.00254***	-0.0121***
	(0.000339)	(0.000689)	(0.000546)	(0.000548)
Crisis dummy	-0.0154***	-0.0253*	-0.0335***	0.0320***
	(0.00569)	(0.0135)	(0.0104)	(0.0104)
Log(FTSE-100)	0.00565	0.0136	0.0606***	-0.110***
	(0.00819)	(0.0107)	(0.0116)	(0.0132)
Multiple subsidy dummy	0.00514	0.0142***	-0.0296***	0.114***
	(0.00351)	(0.00458)	(0.00395)	(0.00681)
Constant	1.330***	1.523***	0.956***	3.387***
	(0.132)	(0.130)	(0.0789)	(0.119)
lambda	0.0191***	0.0273***	-0.00473	0.116***
	(0.00449)	(0.00541)	(0.00616)	(0.00905)
Observation	161829	161829	161829	161829

Categorical class with 0 (zero) subsidy intensity is excluded. *Class 1* is consists of firm/year observations where subsidy intensity is greater than zero but less than or equal to the value at the first quartile; *Class 2* refers to subsidy intensity between the first-quartile and median values; *Class 3* refers to subsidy intensity between the median and third-quartile value; and *Class 4* refers to subsidy intensity equal to or greater than the value at the third quartile.

Table 8: Ordered Heckman estimates for EU subsidy intensity classes:
[Dependant variable: Log (Private R&D intensity + 1)]

	Class 1	Class 2	Class 3	Class 4
Log (EU subsidy intensity + 1)	-0.635	-18.46***	4.833***	-0.736***
	(3.672)	(1.925)	(0.545)	(0.0470)
Log (Deflated turnover)	-0.430***	-0.349***	-0.486***	-0.610***
	(0.00266)	(0.00259)	(0.00313)	(0.00346)
Log(Def. turnover sq.)	0.0216***	0.0175***	0.0252***	0.0321***
	(0.000190)	(0.000194)	(0.000253)	(0.000342)
Log(Age)	-0.0240***	-0.0273***	-0.0421***	-0.0453***
	(0.00201)	(0.00217)	(0.00291)	(0.00317)
Log(Employment)	0.349***	0.288***	0.460***	0.613***
	(0.00344)	(0.00327)	(0.00479)	(0.00603)
Log^2(Employment)	-0.0335***	-0.0279***	-0.0461***	-0.0615***
	(0.000397)	(0.000413)	(0.000604)	(0.000786)
UK ownership dummy	-0.00428*	-0.000629	0.00120	-0.0210***
	(0.00260)	(0.00334)	(0.00506)	(0.00679)
Herfindahl index	-0.0362	0.0630**	0.588***	-0.292***
	(0.0287)	(0.0302)	(0.0447)	(0.0433)
Herfindahl index sq.	0.0790	-0.0471	-0.748***	0.418***
	(0.0509)	(0.0440)	(0.0732)	(0.0861)
Pavitt class1	-0.0104	0.0369**	-0.0539*	0.0795
	(0.0272)	(0.0171)	(0.0292)	(0.0822)
Pavitt class2	-0.0445*	0.0333**	-0.0697***	-0.00659
	(0.0243)	(0.0141)	(0.0237)	(0.0446)
Pavitt class3	-0.0129	0.0463***	-0.00103	0.0270
	(0.0235)	(0.0153)	(0.0236)	(0.0437)
Pavitt class4	0.0306	0.0726***	0.0270	0.0244
	(0.0233)	(0.0160)	(0.0212)	(0.0306)
Aver. Real Eff. Exch. Rate	-0.000873**	0.00257***	-0.00289***	-0.0249***
	(0.000361)	(0.000491)	(0.000540)	(0.00158)
Crisis dummy	-0.0140*	0.0303***	0.0358***	-0.214***
	(0.00741)	(0.00867)	(0.0107)	(0.0316)
Log(FTSE-100)	0.00699	-0.0542***	-0.0783***	-0.0669***
	(0.00843)	(0.00884)	(0.0156)	(0.0152)
Multiple subsidy dummy	-0.0656***	-0.123***	-0.210***	-0.123***
	(0.0201)	(0.0146)	(0.0230)	(0.0168)
Constant	1.401***	1.469***	2.573***	5.159***
	(0.0975)	(0.0698)	(0.135)	(0.220)
lambda	-0.0960***	-0.0363***	-0.0969***	-0.0626***
	(0.00718)	(0.00548)	(0.0113)	(0.0173)
Observation	161829	161829	161829	161829

So far, we have interpreted the results with respect to the relationship between subsidy and private R&D effort only. However, our estimation results indicate that private R&D intensity is also related to wide range of other firm-level, industry-level and macroeconomic variables. Results from the full sample and from the manufacturing sample depict a consistent picture with respect to the effects of these covariates. Whilst turnover (as a proxy for cash flow) has a U-shaped relationship with R&D intensity; age and size (measured by employment headcount) and market concentration all have an inverted-U relationship. In the case of industry-level factors, we observe that private R&D intensity is consistently higher in Pavitt technology classes 1 – 3 compared to the excluded category of unclassified technology class. Finally, private R&D intensity is lower during the post-crisis period (2008-2012), when the currency experiences real appreciation, and the FTSE-100 index increases. (These findings and their relationships with the existing literature will be discussed later.

Conclusions

We have investigated the effects of UK and EU subsidies on privately-funded R&D intensity of a sample of about 22,000 UK firms. The sample consists of R&D-active firms surveyed in at least one year from 1998-2012. The results are obtained from 4 different estimators, with different degrees of control for selection and time-constant fixed effects: (i) pooled OLS without selection correction; (ii) fixed-effect (within-group) estimation without selection correction; (iii) pooled OLS with selection correction; and (iv) fixed-effect estimation with selection correction. We report that UK subsidies are not associated with additionality in privately -funded R&D intensity in the full sample, and the additionality effect in manufacturing is too small to be conomically significant. In contrast, EU subsidy is associated with an additionality effect of 2% in both samples. Ordered-Heckman estimations of leverage indicate that an increase in UK subsidy intensity (subsidy/total R&D) is not likely to make a difference to private R&D effort in any of the subsidy intensity classes demarcated by 4 quartiles of the subsidy intensity of the distribution. However, an increase in EU subsidy intensity is associated with leverage in subsidy intensity class 3, which corresponds to intensity values within the 3rd quartile of the distribution.

Estimation results also indicate that private R&D intensity is related to wide range of other firm-level, industry-level and macroeconomic variables. Results from the full sample and from the manufacturing sample depict a consistent picture with respect to the effects of these covariates. Whilst turnover (as a proxy for cash flow) has a U-shaped relationship with R&D intensity; age and size (measured by employment headcount) and market concentration all have an inverted-U relationship. In the case of industry-level factors, we observe that private R&D intensity is consistently higher in Pavitt technology classes 1 – 3 compared to the excluded category of unclassified technology class. Finally, private R&D intensity is lower during the post-crisis period (2008-2012), when the currency experiences real appreciation, and the FTSE-100 index increases.

References

Aerts K. and T. Schmidt (2008), Two for the price of one? Additionality effects of R&D subsidies: A comparison between Flanders and Germany, *Research Policy* 37, 806-822.

Aerts, K. and D. Czarnitzki (2006), The Impact of Public R&D–Funding in Flanders, IWT Study No. 54, Brussels.

Aghion, P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt. (2005). Competition and Innovation: An Inverted-U Relationship. *Quarterly Journal of Economics*, 120(5), 701-728.

Almus, M. and D. Czarnitzki (2003), The effects of public R&D subsidies on firms' innovation activities: the case of Eastern Germany, *Journal of Business and Economic Statistics* 21(2), 226-236.

Angrist, J.D. (1998), Estimating the labor market impact of voluntary military service using social security data, *Econometrica* 66, 249-288.

Arrow, K.J. (1962), Economic Welfare and the Allocation of Resources for Invention, in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, National Bureau of Economic Research, Conference Series, Princeton: Princeton University Press, 609-625.

Arrow, K.J. (1996), The Economics of Information: An Exposition, *Empirica* 23(2), 119-128.

Arrow, K.J. (1999), Information and the organization of industry, in: G. Chichilnisky (ed.), *Markets, Information, and Uncertainty*. Essays in Economic Theory in Honor of Kenneth J. Arrow, Cambridge: Cambridge University Press, pp. 19-25.

Arrow, K.J. and R.C. Lind (1970), Uncertainty and the Evaluation of Public Investment Decisions, *American Economic Review*, 60, 364-378.

Balasubramanian, N., & Lee, J. (2008). Firm age and innovation. *Industrial and Corporate Change*, *17*(5), 1019-1047.

Becker, B. and Hall, S.G. (2013) Do R&D strategies in high-tech sectors differ from those in low-tech sectors? An alternative approach to testing the pooling assumption. *Economic Change and Restructuring* 46: 183–202.

BIS (Department for Business Innovation and Skills) (2011), *Innovation and Research Strategy for Growth*, December 2011. Available at: www.bis.gov.uk/assets/BISCore/innovation/docs/I/11-1387-innovation-and-research-strategy-for-growth.pdf .

BIS (Department for Business Innovation and Skills) (2014), Estimating the effect of UK direct public support for innovation, BIS Analysis Paper no. 4. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/369

650/bis-14-1168-estimating-the-effect-of-uk-direct-public-support-for-innovation-bis-analysis-paper-number-04.pdf

Blank, D.M., Stigler, G.J., 1957. *The Demand and Supply of Scientific Personnel*. National Bureau of Economic Research, New York.

Brown, J. R., Fazzari, S. M., & Petersen, B. C. (2009). Financing innovation and growth: Cash flow, external equity, and the 1990s R&D boom. *The Journal of Finance*, *64*(1), 151-185.

Busom, I. (2000), An empirical evaluation of the effects of R&D subsidies, *Economics of Innovation and New Technology* 9(2), 111-148.

Buxton, A. J. (1975). The process of technical change in UK manufacturing. *Applied Economics*, *7*(1), 53-71.

Cerulli, G. (2010), Modelling and measuring the effect of public subsidies on business R&D: a critical review of the economic literature, *Economic Record* 86, 421-449.

Chiburis, R., & Lokshin, M. (2007). Maximum likelihood and two-step estimation of an ordered-probit selection model. *Stata Journal*, *7*(2), 167-182.

Cohen, W. M., Levin, R. C., & Mowery, D. C. (1987). Firm Size and R&D Intensity: A Re-examination. *Journal of Industrial Economics*, *35*(4), 543-65.

Czarnitzki, D. (2006), Research and development in small and medium-sized enterprises: the role of financial constraints and public funding, *Scottish Journal of Political Economy* 53(3), 335-257.

Czarnitzki, D. and A.A. Toole (2007), Business R&D and the interplay of R&D subsidies and product market uncertainty, *Review of Industrial Organization* 31(3), 169-181.

Czarnitzki, D. and A.A. Toole (2011), Patent Protection, Market Uncertainty, and R&D Investment, *Review of Economics and Statistics* 93(1), 147-159.

Czarnitzki, D. and C. Lopes-Bento (2011a), Evaluation of Public R&D Policies: A Cross-Country Comparison, *World Review of Science, Technology and Sustainable Development*, forthcoming.

Czarnitzki, D. and C. Lopes-Bento (2011b), Innovation Subsidies: Does the Funding Source Matter for Innovation Intensity and Performance? Empirical Evidence from Germany, *ZEW Discussion Paper No. 11-053*, Mannheim.

Czarnitzki, D. and C. Lopes-Bento (2012). Value for money? New microeconometric evidence on public R&D grants in Flanders, ZEW Discussion Papers, No. 12-034, http://nbn-resolving.de/urn:nbn:de:bsz:180-madoc-323085

Czarnitzki, D. and G. Licht (2006), Additionality of Public R&D Grants in a Transition Economy: The Case of Eastern Germany, *Economics of Transition* 14(1), 101-131.

Czarnitzki, D. and H. Hottenrott (2011), Financial Constraints: Routine versus Cutting Edge R&D Investment, *Journal of Economics and Management Strategy* 20(1), 121-157.

Czarnitzki, D. and K. Hussinger (2004), The Link between R&D Subsidies, R&D Spending and Technological Performance, *ZEW Discussion Paper No. 04-56*, Mannheim.
Czarnitzki, D., H. Hottenrott and S. Thorwarth (2011), Industrial Research versus Development Investment: The Implications of Financial Constraints, *Cambridge Journal of Economics* 35(3), 527-544.

David, P.A., B.H. Hall and A.A. Toole (2000), Is public R&D a complement or substitute forprivate R&D? A review of the econometric evidence, Research Policy 29(4-5), 497-529.

Dehejia, R.H. and S. Wahba (1999), Causal effects in nonexperimental studies: reevaluating the evaluation of training programs, Journal of the American Statistical Association 94, 1053-1062.

Dixit, A.K. and R.S. Pindyck, Investment under Uncertainty, *Princeton Univ. Press*, Princeton, NJ.

Duguet, E. (2004), Are R&D subsidies a substitute or a complement to privately funded R&D? Evidence from France using propensity score methods for non-experimental data, *Revue d'Economie Politique* 114(2), 263-292.

Garcia, A. and P. Mohnen (2010), Impact of government support on R&D and innovation, *UNU-MERIT Working Paper Series 034*, United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology, Maastricht.

García-Quevedo, J. (2004). Do public subsidies complement business R&D? A meta-analysis of the econometric evidence. *Kyklos*, 57(1), 87-102.

Gerfin M. and M. Lechner (2002), A Microeconometric Evaluation of Active Labour Market Policy in Switzerland, *Economic Journal* 112, 845 -893.

González, X., Jaumandreu, J. and Pazó, C. (2005), Barriers to innovation and subsidy effectiveness, *RAND Journal of Economics* 36(4), 930-949.

Griliches Z. (1990), Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature* XXVIII, 1661–1707.

Griliches, Z. and J. Mairesse (1984), Productivity and R&D at the firm level, in: R&D, *Patents and Productivity*, Griliches Z (ed.). University of Chicago Press: Chicago, IL; 339–374

Hall, B.H. (1990), The impact of corporate restructuring on industrial research and development, *Brooking Papers on Economic Activity* (1), 85–136.

Hall, B.H. (2002), The financing of Research and Development, *Oxford Review of Economic Policy*, 18, 35-51.

Hall, B.H. and A. Maffioli (2008), Evaluating the impact of technology development funds in emerging economies: evidence from Latin America, *European Journal of Development Research* 20(2), 172-198.

Hall, B.H. and J. Lerner (2010), The financing of R&D and innovation, in: B.H. Hall and N. Rosenberg (eds.), *Handbook of the economics of innovation,* Vol. 1, Amsterdam: Elsevier, 609- 639.

Hall, B.H. and J. Van Reenen (2000), How effective are fiscal incentives for R&D? *Research Policy* 29, 449-469.

Hall, B.K. J. Mairesse, L. Branstetter and B. Crepon (1998). Does cash flow cause investment and R&D: An exploration using panel data for French, Japanese and United States scientific firms. In D. Audretsch and A. Thurik (eds), *Innovation, Industry Evolution and Employment*. Cambridge University Press.

Haskel, J., & Wallis, G. (2013). Public support for innovation, intangible investment and productivity growth in the UK market sector. *Economics letters*, *119*(2), 195-198.

Heckman, J. J., H. Ichimura and P. Todd (1997), Matching as an econometric evaluation estimator: evidence from evaluating a job training program, *Review of Economic Studies* 64(4), 605-654.

Heckman, J. J., R. J. Lalonde and J. A. Smith (1999), The economics and econometrics of active labour market programs, in: A. Aschenfelter and D. Card (eds.), *Handbook of Labour Economics*, Amsterdam, 3, 1866-2097.

Heckman, J.J. (1978), 'Dummy Endogenous Variables in a Simultaneous Equation System', *Econometrica*, 46, 931–59.

Heckman, J.J., H. Ichimura and P. Todd (1998a), Matching as an econometric evaluation estimator, *Review of Economic Studies* 65(2), 261-294.

Heckman, J.J., H. Ichimura, J.A. Smith and P. Todd (1998b), Characterizing selection bias using experimental data, *Econometrics* 66, 1017-1098.

Holland, P.W. (1986), Statistics and Causal Inference, *Journal of the American Statistical. Association* 81, 945–960.

Huergo, E., & Jaumandreu, J. (2004). How does probability of innovation change with firm age? *Small Business Economics*, *22*(3-4), 193-207.

Hughes, A., and A. Mina (2012), *The UK R&D Landscape*. Enhancing Value Task Force Report. http://www.jbs.cam.ac.uk/fileadmin/user_upload/centre-for-business-research/downloads/special-reports/specialreport-ukr_dlandscape.pdf

Hussinger, K. (2008), R&D and Subsidies at the Firm Level: An Application of Parametric and Semi-Parametric Two-Step Selection Models, *Journal of Applied Econometrics* 23, 729-747.

Imbens, G.W. (2000), The role of the propensity score in estimating dose-response functions, *Biometrika* 87, 706–710.

Imbens, G.W. and J.M. Wooldridge (2009), Recent developments in the econometrics of program evaluation, *Journal of Economic Literature* 47, 5-86.

Jaffe, A.B. (1986), Technological opportunity and spillovers of R&D: evidence from firm's patent, profits, and market value, American Economic Review 76 (5), 984–1001.

Lach, S. (2002), Do R&D subsidies stimulate or displace private R&D? Evidence from Israel, *Journal of Industrial Economics* 50(4), 369-390.

Lamberton, D. M. (1996), 'Introduction: 'Threatened Wreckage' or New Paradigm?', in Donald M. Lamberton (Ed.), *The Economics of Communication and Information*, Cheltham UK and Brookfield US: Edward Elgar, pp. xiii-xxviii.

Larosse, J. (2001), Conceptual and Empirical Challenges of Evaluating the Effectiveness of Innovation Policies with 'Behavioural Additionality', Case of IWT R&D Subsidies, IWTFlanders, Belgium.

Lechner, M. (1999), Earnings and employment effects of continuous off-the-job training in East Germany after reunification, *Journal of Business and Economics Statistics* 17, 74-90.

Lechner, M. (2000), An evaluation of public sector sponsored continuous vocational training in East Germany, *Journal of Human Resources* 35, 347-375.

Lechner, M. (2001), Identification and Estimation of Causal Effects of Multiple Treatments under the Conditional Independence Assumption, in M. Lechner and F. Pfeiffer (eds.), *Econometric Evaluation of Labour Market Policies*, Physica, Heidelberg, 43-58.

Maddala, G.S. (1983), *Limited Dependent and Qualitative Variables in Econometrics*. Cambridge University Press, Cambridge.

Nelson, R.R. (1959), The Simple Economics of Basic Scientific Research, *Journal of Political Economy* 49, 297-306.

OECD (1993), *The Proposed Standard Practice for Surveys of Research and Experimental Development - Frascati Manual*, Paris.

OECD/Eurostat (2005), *Guidelines for Collecting and Interpreting Innovation Data – the Oslo Manu*al, 3rd edition, Paris.

ONS (2012), *Coverage of the Business Enterprise Research & Development survey*, Office of National Statistics, http://www.ons.gov.uk/ons/guide-method/method-quality/specific/business-and-energy/research---development-surveys/information-note--coverage-of-the-business-enterprise-r-d-survey.pdf

Polder M. and Veldhuizen E. (2012) Innovation and competition in the Netherlands: testing the inverted U for industries and firms, *Journal of Industry, Competition and Trade*, 12(1), pp. 67-91.

Rosenbaum, P.R. and D.B. Rubin (1983), The central role of the propensity score observational studies for causal effects, *Biometrica* 70, 41-55.

Rubin, D.B. (1977), Assignment to treatment group on the basis of covariate, *Journal of Educational Statistics* 2, 1-26.

Rubin, D.B. (2008), For objective causal inference, design trumps analysis,*The Annals of Applied Statistics* 2(3), 808-840.

Schumpeter, J. (1942), *Capitalism, Socialism and Democracy*, Harper and Row, New York.
Smith, J.A. and P.E. Todd (2005), Does matching overcome LaLonde's critique of nonexperimental estimators?, *Journal of Econometrics* 125, 305-353.

Shefer, D., & Frenkel, A. (2005). R&D, firm size and innovation: an empirical analysis. *Technovation*, *25*(1), 25-32.

Takalo, T., T. Tanayama and O. Toivanen (2013), Estimating the benefits of targeted R&D subsidies, *Review of Economics and Statistics*, 95(1), 255–272.

Tsai, K. H., & Wang, J. C. (2005). Does R&D performance decline with firm size?—A re-examination in terms of elasticity. *Research Policy*, *34*(6), 966-976.

Wallsten S.J. (2000), The effects of government-industry R&D programs on private R&D: the case Small Business Innovation Research Program, *RAND Journal of Economics* 31(1), 82-100.

Zúñiga-Vicente, José Ángel, et al. "Assessing the effect of public subsidies on firm R&D investment: a survey." *Journal of Economic Surveys* 28.1 (2014): 36-67.

Appendix

Table A1: UK subsidy and privately-funded R&D effort – Manufacturing.

	(1)	(2)	(3)	(4)
UK_sub_dum	-0.00339	0.00578**	-0.171***	0.00880***
	(0.00332)	(0.00241)	(0.00827)	(0.00242)
Log (Deflated turnover)	-0.309***	-0.391***	-0.288***	-0.374***
	(0.0169)	(0.0300)	(0.00192)	(0.0336)
Log(Def. turnover sq.)	0.0145***	0.0176***	0.0134***	0.0168***
	(0.000920)	(0.00173)	(0.000125)	(0.00196)
Log(Age)	-0.0604***	-0.0142	-0.0643***	-0.0187
	(0.0152)	(0.0321)	(0.00823)	(0.0467)
Log^2(Age)	0.00765***	0.00648	0.00834***	0.00913
	(0.00262)	(0.00610)	(0.00149)	(0.00887)
Log(Employment)	0.231***	0.154***	0.226***	0.154***
	(0.0143)	(0.0133)	(0.00213)	(0.0152)
Log^2(Employment)	-0.0201***	-0.0123***	-0.0200***	-0.0124***
	(0.00147)	(0.00148)	(0.000253)	(0.00172)
UK ownership dummy	-0.00415*	0.0000595	-0.00318**	0.00178
	(0.00239)	(0.00250)	(0.00147)	(0.00236)
Herfindahl index	0.0179	-0.0123	0.0136	-0.00981
	(0.0182)	(0.0185)	(0.0160)	(0.0196)
Herfindahl index sq.	-0.0253	0.00203	-0.00543	-0.00550
	(0.0328)	(0.0304)	(0.0320)	(0.0328)
Pavitt class1	0.0844***	0.0227	0.114***	-0.0115
	(0.0127)	(0.0269)	(0.00974)	(0.0185)
Pavitt class2	0.0594***	0.0152	0.0842***	-0.0106
	(0.0114)	(0.0249)	(0.00935)	(0.0148)
Pavitt class3	0.0824***	0.0277	0.100***	-0.00437
	(0.0108)	(0.0246)	(0.00894)	(0.0142)
Pavitt class4	0.0321***	0.0163	0.0519***	-0.00890
	(0.00951)	(0.0232)	(0.00892)	(0.0108)
Aver. Real Eff. Exch. Rate	0.000267	0.000420***	0.000599***	-0.0000322
	(0.000190)	(0.000159)	(0.000187)	(0.000165)
Crisis dummy	0.0144***	0.00853***	0.0191***	-0.00378
	(0.00362)	(0.00304)	(0.00351)	(0.00374)
Log(FTSE-100)	-0.00449	-0.00547	-0.00368	-0.0112***
	(0.00447)	(0.00407)	(0.00422)	(0.00424)
Multiple subsidy dummy	0.00497**	0.00605***	0.00648***	0.00490***
	(0.00208)	(0.00152)	(0.00164)	(0.00158)
Inverse Mills - UK				0.0225***
				(0.00447)
Constant	1.028***	1.574***	1.096***	1.603***
	(0.0585)	(0.113)	(0.0376)	(0.132)
Observation	82628	82628	68091	68091
lambda			0.0888	
sigma		0.221	0.147	0.204
rho		0.744	0.605	0.739

Cluster-robust standard errors are in parentheses. All estimations include 2-digit industry dummies. Time dummies are not included as the crisis dummy, the FTSE-100 and the average effective exchange rates capture time variation. (1) and (2) are pooled OLS and Fixed-effect without selection correction; (3) is pooled OLS with selection correction; and (4) is FE with selection correction. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: EU subsidy and privately-funded R&D effort – Manufacturing.

	(1)	(2)	(3)	(4)
EU subsidy dummy	0.0152*	0.0106	-0.0637***	0.0192**
	(0.00814)	(0.00871)	(0.00930)	(0.00805)
Log (Deflated turnover)	-0.309***	-0.391***	-0.289***	-0.374***
	(0.0169)	(0.0300)	(0.00192)	(0.0336)
Log(Def. turnover sq.)	0.0146***	0.0176***	0.0135***	0.0167***
	(0.000920)	(0.00173)	(0.000126)	(0.00195)
Log(Age)	-0.0603***	-0.0160	-0.0580***	-0.0101
	(0.0152)	(0.0320)	(0.00821)	(0.0461)
Log^2(Age)	0.00764***	0.00711	0.00750***	0.00636
	(0.00262)	(0.00608)	(0.00148)	(0.00861)
Log(Employment)	0.232***	0.154***	0.225***	0.155***
	(0.0143)	(0.0133)	(0.00214)	(0.0152)
Log^2(Employment)	-0.0201***	-0.0123***	-0.0197***	-0.0124***
	(0.00147)	(0.00148)	(0.000253)	(0.00172)
UK ownership dummy	-0.00416*	0.000000540	-0.00302**	0.00168
	(0.00239)	(0.00250)	(0.00148)	(0.00237)
Herfindahl index	0.0178	-0.0119	0.0193	-0.0103
	(0.0182)	(0.0185)	(0.0161)	(0.0197)
Herfindahl index sq.	-0.0251	0.00253	-0.0163	-0.00479
	(0.0329)	(0.0304)	(0.0324)	(0.0329)
Pavitt class1	0.0844***	0.0219	0.147***	-0.00450
	(0.0127)	(0.0268)	(0.0104)	(0.0184)
Pavitt class2	0.0593***	0.0144	0.121***	-0.00597
	(0.0114)	(0.0249)	(0.0101)	(0.0147)
Pavitt class3	0.0824***	0.0268	0.133***	0.0000838
	(0.0108)	(0.0246)	(0.00945)	(0.0141)
Pavitt class4	0.0320***	0.0155	0.0752***	-0.00777
	(0.00950)	(0.0232)	(0.00916)	(0.0107)
Aver. Real Eff. Exch. Rate	0.000318*	0.000345**	0.000380**	0.00000880
	(0.000184)	(0.000156)	(0.000186)	(0.000153)
Crisis dummy	0.0154***	0.00662**	0.0142***	-0.00301
	(0.00354)	(0.00283)	(0.00349)	(0.00318)
Log(FTSE-100)	-0.00430	-0.00660	-0.00318	-0.000953
	(0.00447)	(0.00402)	(0.00422)	(0.00446)
Multiple subsidy dummy	-0.0109	-0.00279	-0.0110	-0.0110
	(0.00819)	(0.00845)	(0.00709)	(0.00792)
Inverse Mills - EU				0.0129***
				(0.00275)
Constant	1.016***	1.595***	0.974***	1.513***
	(0.0584)	(0.113)	(0.0368)	(0.124)
Observation	82628	82628	68091	68091
lambda			0.0474	
sigma		0.220	0.143	0.204
rho		0.744	0.330	0.740

Cluster-robust standard errors are in parentheses. All estimations include 2-digit industry dummies. Time dummies are not included as the crisis dummy, the FTSE-100 and the average effective exchange rates capture time variation. (1) and (2) are pooled OLS and Fixed-effect without selection correction; (3) is pooled OLS with selection correction; and (4) is FE with selection correction. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$