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Dirk Czarnitzki and Julie Delanote

Zentrum für Europäische
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Dirk Czarnitzki[a] and Julie Delanote[b]

a) KU Leuven, Dept. of Managerial Economics, Strategy and Innovation, Belgium; Center for R&D Monitoring (ECOOM) at KU Leuven, and ZEW Mannheim, Germany
b) KU Leuven, Dept. of Managerial Economics, Strategy and Innovation, Belgium, and Center for R&D Monitoring (ECOOM) at KU Leuven, Belgium

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Abstract

This paper integrates innovation input and output effects of R&D subsidies into a modified Crépon–Duguet–Mairesse (CDM) model. Our results largely confirm insights of the input additionality literature, i.e. public subsidies complement private R&D investment. In addition, results point to positive output effects of both purely privately funded and subsidy–induced R&D. Furthermore, we do not find evidence of a premium or discount of subsidy–induced R&D in terms of its marginal contribution on new product sales when compared to purely privately financed R&D.

Keywords: CDM model, R&D, subsidies, innovation policy

JEL–Classification: C14, C30, O38

Contact details:
Dirk Czarnitzki, KU Leuven, Faculty of Business and Economics
Naamsestraat 69
3000 Leuven, Belgium
E-Mail: dirk.czarnitzki@kuleuven.be

Julie Delanote, KU Leuven, Faculty of Business and Economics
Naamsestraat 69
3000 Leuven, Belgium
E-Mail: julie.delanote@kuleuven.be

1 Introduction

The beneficial effect of business R&D efforts on technological change and growth has been widely acknowledged by scholars and policy makers (Romer, 1990; Mansfield, 1988, 1962; Aghion and Howitt, 1998; Scherer, 1965; Geroski and Toker, 1996). For this reason, governments in industrialized countries spend considerable amounts of money for supporting R&D activities of firms which is mainly justified by the will to overcome presumed market failures (Nelson, 1959; Arrow, 1962; Stiglitz and Weiss, 1981) that lead to an underinvestment in R&D from a social point of view. One of the main governmental instruments in this context are public R&D grants. Based upon policy and academic interest towards this topic, evaluating the effects of such policy instruments has a long tradition in empirical innovation research (see David et al., 2000; Cerulli, 2010; Zúñiga Vicente et al., 2014 for surveys).

So far, the main focus in the literature has been on input additionality of R&D grants, while only some studies assess their impact on output. Rarely, the interrelated nature of these input and output stages has been accounted for by using a simultaneous equation model. Consequently, this paper takes a more structural approach in order to integrate both stages into one econometric model. This is done by applying a conceptually new variant of the Crépon–Duguet–Mairesse (CDM) framework (Crépon et al., 1998). The resulting model allows to estimate input and output additionality effects of subsidies and, in particular, whether subsidized projects generate a discount or premium in terms of innovation outcome when compared to the non–subsidized, i.e. purely privately financed, projects.

The remainder of the paper is organized as follows: the next section sketches the framework of this paper, both conceptually and methodologically. The third section presents the econometric model. Data and variables are discussed in section 4 and section 5 discusses the empirical implementation and results before concluding.

2 Background

2.1 Conceptual background

Figure 1 shows a representation of how subsidies may impact the input and output stages of R&D. First, a firm may choose to apply for a R&D subsidy, and the public agency decides whether or not to grant a subsidy. Furthermore the agency also decides on the subsidy rate, i.e. the share of the total cost of the proposed project that will be covered by the subsidy (see e.g. Takalo et al., 2013 for a structural model on the decision process).[1] When learning about the amount of public R&D becoming available, the firm will decide on how much to invest in R&D privately. Policy makers hope that subsidizing R&D has a positive effect on the amount firms invest privately. The policy makers logic is intuitive: the firm would not have conducted the project without the subsidy; due to the positive decision on the public R&D grant, however, the firm then conducts the project in addition to others that it would have implemented even in absence of subsidies. As the subsidy never covers the full cost of the proposed R&D project, the government expects that also private R&D increases as response to the R&D grant. As a result, both the public and the private R&D will generate additional innovation output and thus foster technological change in the future. In Figure 1 this is depicted as innovation output in period $t + 1$.

However, this positive picture on how subsidies help to spur innovation and technological progress may not apply in reality for two reasons. First, the firms might apply with projects that they would even conduct at the same scale if no subsidies were granted. In this case, the subsidy scheme would be subject to so-called full crowding–out effects and no additional R&D projects would be conducted in the economy. Instead, the granted public funds would simply replace parts of the private investment. Second, even if the subsidized firms implement the subsidized projects in addition to

[1]The maximum subsidy rate is usually limited to 50% of the total project cost in the EU, but there are exceptions for small and medium–sized firms and for firms in structurally weak regions (so–called Objective 1 regions) where the maximum subsidy rate may exceed 50%.

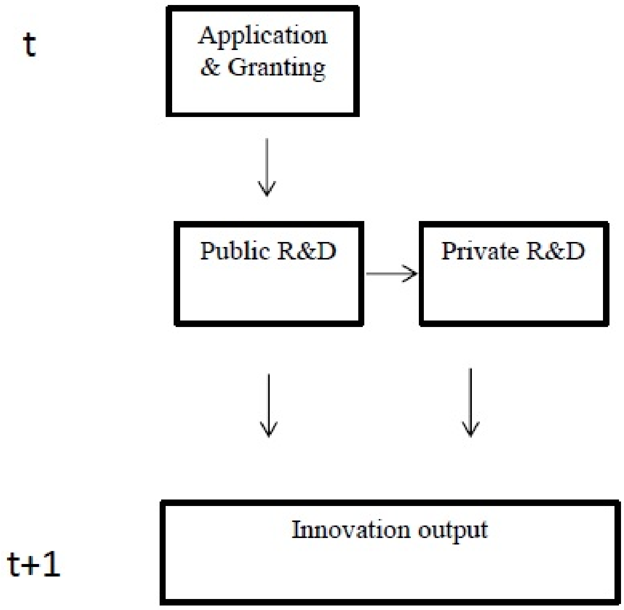

Figure 1: subsidy-extension of CDM framework

their other R&D activities as expected by the government, and so-called input additionality is thus present, the publicly invested R&D may not necessarily also lead to output additionality, that is, more innovation. As Goolsbee (1998) argues, the granted subsidies might be redirected to higher wages of researchers instead of hiring new staff and/or investing this money in other research–related assets. If higher wages do not coincide with higher marginal productivity of R&D labor, one would find evidence for input additionality but not output additionality. Furthermore, the subsidized R&D project might be riskier than the R&D projects that are funded fully privately (see David et al., 2000), and therefore the failure rate might be high, and thus no output additionality may be present either.

Moreover, it is questionable whether the contribution of public R&D to output additionality at the firm-level is higher or lower than the private marginal productivity. There are reasons for both: given the arguments above on factors that may limit the output additionality of subsidized R&D, it could, on the one hand, be argued that subsidized R&D has a lower marginal productivity than purely privately financed R&D activity. On the other hand, subsidized R&D projects may also show a higher productivity: the subsidies analyzed in this study are selective, i.e. they are not automatically granted but the project proposals are assessed by experts. Therefore the granted projects are winners of a peer-review projects and therefore firms might have submitted their most promising ideas which may then result in high productivity. In addition, subsidized R&D projects might be closely followed and monitored by the public agency, which could imply a better management of the subsidized R&D projects and this might have a beneficial impact on the innovative output (Barney et al., 2001; Colombo and Grilli, 2005; Teece and Pisano, 1994). Another argument towards a potential output premium of subsidized R&D over private R&D is the so-called signaling effect whereby R&D subsidies act as a quality signal to potential investors and clients of the firm who could as a result be more likely to invest in the project, increasing its chances of success (Lerner, 1999).

The outlined conceptual background thus suggests three main research questions that can only be answered empirically:

1. Do subsidies stimulate additional private investment into R&D?

2. Does publicly funded R&D (and the possibly additionally induced private R&D) lead to output additionality?

3. Is the output additionality of public R&D higher or lower than the one of privately financed R&D?[2]

2.2 Previous literature

The first quantitative evaluation of R&D policies has been carried out as early as 1957 by Blank and Stigler. After the US R&D budget was significantly raised during the 1950s Blank and Stigler (1957) questioned the relationship between publicly

[2]Note that we focus in this paper solely on the effects subsidies may have on the beneficiary firm itself. We do not investigate whether a potential increase in R&D spending generates positive spillover effects to other members of society which is the standard justification for government intervention in the market for R&D.

funded and private R&D. Since then, the literature on quantitative evaluation became vast, especially after the year 2000 when surveys about the state of the art were published (see the surveys by David et al., 2000; Klette et al., 2000). The survey authors critically reviewed the literature and identified methodological shortcomings in existing studies. In particular, selection bias and endogeneity of subsidies in an R&D investment equation had not been adequately modeled in many early empirical studies.[3] Since then, the literature on the evaluation of innovation subsidies was revived and many papers using modern micro-econometric techniques were published (see Cerulli, 2010; Zúñiga Vicente et al., 2014 for surveys).

The main focus in literature has been on input additionality of subsidies, mainly based upon a dichotomous subsidy variable (see e.g. Busom, 2000; Lach, 2002; Almus and Czarnitzki, 2003; Duguet, 2004; Gonzales et al., 2005; Gonzales and Pazo, 2008; Czarnitzki and Lopes Bento, 2012). Only a few papers focus on the effect of R&D subsidies on R&D output. Czarnitzki and Hussinger (2004); Czarnitzki and Licht (2006); Hussinger (2008); Czarnitzki and Delanote (2015) for example, use the estimated private and treatment effect obtained from a matching estimator or other selection model in an output equation in order to measure the effect of private and public R&D on innovation output. These papers, however, applied more reduced-form-type models rather than incorporating R&D subsidy variables into a more structural approach such as the CDM model, which is consequently the main contribution of this paper. Thereby, we do not only add to the subsidy evaluation literature, but also to the structural models based upon the framework developed by Crépon et al. (1998).

[3] Firms receiving a subsidy might be different from companies that do not receive a subsidy: some firms might be more likely to apply for public funding than others; some firms might consider the administrative burden or the information sharing conditional upon being subsidized as reasons not to apply. In addition, funding agencies typically follow a picking-the winner strategy, i.e. firms that are highly innovative and conduct a lot of R&D might be more likely to get a subsidy. In other words, subsidies become an endogenous variable in any equation on innovation-related activities.

3 Extending the CDM model: assessing output additionality of subsidies

The CDM model introduced by Crépon, Duguet and Mairesse in 1998 (Crépon et al., 1998) is essentially a refinement of the knowledge production function framework (Griliches, 1979). The original CDM model had three stages: (i) the firms' choice to engage in innovation activities or not, (ii) an R&D/innovation investment equation (as measured by R&D intensity), and (iii) an innovation output stage and/or labor productivity. In our application, we focus on the input and output additionality of subsidies in the innovation process and therefore omit the first stage of the original CDM model on the firms' decision to engage in innovation.[4] Consequently, the most basic representation of both R&D input ($R\&D$) and output ($Output$) stages could be modeled as follows:

$$
\begin{aligned}
R\&D &= z_2'\omega + \varepsilon_2 \\
& \searrow \\
Output &= \beta_1 R\&D + z_1'\theta + \varepsilon_1
\end{aligned}
$$

where z_1 and z_2 refer to vectors of explanatory variables, β_1,θ and ω are the coefficient vectors to be estimated and ε_1 and ε_2 denote the error terms.

Starting from the last equation, the output stage, $R\&D$ captures the full amount invested in R&D, i.e. both subsidies and privately financed R&D. In this context, however, we are interested in the effect of the components of this full R&D input, publicly induced R&D and the purely private R&D.

In order to estimate the output additionality of subsidies, the current literature is dominated by ad–hoc approaches instead of a more structural approach as suggested in this paper. Before turning to the structural approach using the CDM framework,

[4]The empirical study will be limited to firms that engaged in innovation activities.

we briefly discuss ad-hoc approaches which help to motivate our model.

- Approach 1: Dummy variable approach
  One intuitive starting point for estimating output additionality is a dummy variable approach, where an (innovation) output measure is simply regressed on R&D input and a dummy variable, $DSUB$ indicating wether a firm received a subsidy, as well as the interaction of the subsidy dummy and R&D inputs.

$$Output = \beta_1 R\&D + \beta_2 DSUB + \beta_3 DSUB \times R\&D + z_1'\theta + \varepsilon_1 \tag{1}$$

  This approach is sometimes considered as allowing to conclude that a premium (discount) is present if β_3 would turn out to be positive (negative), that is, the subsidy would affect the marginal productivity of R&D upwards (downwards). However, the dummy variable approach neglects that subsidies are not constant across firms, and also that $R\&D$ is itself a function of the subsidy. As subsidies are usually varying in terms of the absolute monetary amount granted, this approach can in fact not allow to conclude whether subsidized R&D is more or less productive then privately financed projects.

- Approach 2: Separate R&D input from subsidized amount
  Another intuition for estimating output additionality could be to subtract the subsidies from the R&D input and to estimate two separate coefficients.

$$Output = \beta_1 (R\&D - SUB) + \beta_2 SUB + z_1'\theta + \varepsilon_1 \tag{2}$$

  where $R\&D$ denotes the amount of R&D input and SUB the amount of subsidies received. This specification would, on first sight, allow to conclude whether *any* output additionality is present, that is, if β_2 is larger than zero, and, moreover, if the subsidized R&D is more productive than the purely privately financed one if $\beta_2 > \beta_1$, and vice versa. However, this approach still neglects that even the term $(R\&D - SUB)$ is a function of the subsidy, as the whole literature about treatment effects revolves around the question to what extent additional private investment is stimulated by granting subsidies, especially as subsidies are typically distributed as 'matching grants', that is, the government pays only a share of the total cost of a project.[5]

As $R\&D - SUB$ may not correspond to the R&D investment which is not subsidy–induced, because the subsidy is expected to trigger also a higher private investment, the estimation equation has to be modified further in order to account for the existing treatment effects debate. Therefore we suggest to estimate following output equation

$$Output = \beta_1(R\&D - \alpha SUB) + \beta_2 \alpha SUB + z_1'\theta + \varepsilon_1 \tag{3}$$

where αSUB corresponds to a firm-specific treatment effect, i.e. the amount received by the funding agency ánd the potential additional spending due to this subsidy. The α is estimated in a previous equation by specifying that

$$R\&D = \alpha SUB + z_2'\omega + \varepsilon_2. \tag{4}$$

In order to account for the literature on treatment effects estimation, it has to be taken into account that SUB may itself be an endogenous regressor in the R&D input equation and therefore, one would need to instrument this variable. Thus, the final model is a recursive system of three equations, where the first equation could be written as follows:

$$SUB = z_3'\delta + \varepsilon_3. \tag{5}$$

Econometric implementation

If the error terms, ε_1, ε_2 and ε_3 were not correlated with each other, this recursive system of equations could be estimated sequentially by independent OLS regressions. As this is unlikely to hold, though, consistent estimation requires an instrumental

[5]We show regression results of these not fully correct approaches in the appendix in Table A.3.

variable approach, i.e. it is required that $z_1 \neq z_2 \neq z_3$ or in other words, z_3 must contain instruments that are not in z_2 and both z_3 and z_2 must contain instruments that are not part of z_1 for model identification.

This system of equations could be estimated using limited information estimators, such as 2SLS, where each equation is estimated separately using the appropriate instruments. Because of the recursive nature of the system, we opt here for the so-called control function approach. We estimate the first equation by OLS and obtain $\hat{\varepsilon}_3$. This is then used to estimate the 2nd equation including the first stage residuals with OLS:

$$R\&D = \alpha SUB + z_2'\omega + \rho_1\hat{\varepsilon}_3 + \varepsilon_2 \tag{6}$$

In order to estimate the 3rd equation consistently, we have to plug in the residuals of both preceding stages:

$$Output = \beta_1(R\&D - \alpha SUB) + \beta_2\alpha SUB + z_1'\theta + \rho_3\hat{\varepsilon}_3 + \rho_2\hat{\varepsilon}_2 + \varepsilon_1 \tag{7}$$

In order to test whether subsidies generate an output premium over privately financed R&D, we present the premium/discount component itself in line with Griliches (1986).[6] Following this, β_2 can be set equal to a premium/discount component, let's say $(1 + \gamma_2)$ in which γ_2 represents the actual amount of the premium/discount, times the slope of the private R&D, $(R\&D - \alpha SUB)$, β_1. In other words, β_2 then equals $(1 + \gamma_2) \times \beta_1$. In line with this, we rewrite the output equation:

$$Output = \beta_1\left[(R\&D - \alpha SUB) + (1 + \gamma_2)\alpha SUB\right] + z_1'\theta + \rho_3\hat{\varepsilon_3} + \rho_2\hat{\varepsilon_2} + \varepsilon_1 \tag{8}$$

As the regressor $(R\&D - \alpha SUB)$ cannot be observed directly, we first have to estimate a reduced form of the equation, and back out the structural parameters after

[6]In a (knowledge) production function, Griliches allowed to look at the effect of different components of R&D by weighting one of the terms (say $R\&D_2$) differently than the other, labeled as $R\&D_1$ in this example. The full R&D term can then be decomposed as follows: $R\&D* = R\&D_1 + (1 + \delta)R\&D_2$, where δ corresponds to an output premium or discount of this second R&D term.

estimation. We therefore rearrange this equation as follows:

$$\begin{aligned} Output &= \beta_1 R\&D + \gamma_2 \beta_1 \alpha SUB + z_1' \theta + \rho_3 \hat{\varepsilon_3} + \rho_2 \hat{\varepsilon_2} + \varepsilon_1 \quad (9) \\ &= \beta_1 R\&D + \pi SUB + z_1' \theta + \rho_3 \hat{\varepsilon_3} + \rho_2 \hat{\varepsilon_2} + \varepsilon_1 \quad (10) \end{aligned}$$

where $\pi = \gamma_2 \beta_1 \alpha$. The γ_2 can then straightforwardly be backed out as follows: $\frac{\pi}{\beta_1 \alpha}$. Testing whether there is a premium (discount) amounts to testing whether γ_2 is larger (smaller) than zero. The coefficient β_2 itself, pointing to *any* output additionality equals $(1 + \gamma_2) \times \beta_1 = \beta_1 + \frac{\pi}{\alpha}$.

Since the model estimated by means of the control function approach will produce biased standard errors and as the coefficient α is only identified in the 2nd equation where R&D inputs are a function of the subsidies, the standard errors in the sequence of innovation input and output equations will be computed via bootstrapping, based upon 200 bootstrap replications.

4 Data, variables and descriptive statistics

4.1 Data sources

The data used in this paper combine firm-level data with detailed subsidy data. The firm-level data consists of the Flemish Community Innovation Survey (CIS) provided by the Centre for R&D Monitoring (ECOOM) from KU Leuven and additional firm-level data obtained from the Belfirst database published by Bureau van Dijk. The CIS is a survey that is largely harmonized across the different European member states in order to get a coherent view on innovation inputs and outputs. Next to information on the innovative activity of the companies, the CIS data also provide general information on the companies, such as sales, number of employees, founding year and so forth. The CIS data over the years 2004-2010 were complemented with the Belfirst database which basically contains accounting data for the population of Belgian firms.

These firm-level data were merged with detailed subsidy information obtained from the agency 'Innovatie door Wetenschap en Technologie' (IWT).[7] These data contain detailed information on subsidy grants for the population of Flemish firms. For all firms, we know whether they applied for R&D grants, the grant decision, the amount of subsidies granted and the duration of the funded projects.

The sample used in the regressions is thus a random sample of firms included in the CIS data which were supplemented with accounting and subsidy data. The CIS data allows to identify firms that innovated or attempted to innovate, i.e. they introduced at least one product or process innovation or have ongoing innovation activities or had started innovation projects but abandoned them. We restrict the sample to possible innovators as firms that never even attempted to innovate are irrelevant for the estimation of the efficacy and efficiency of R&D subsidies. After dropping observations with missing values or outliers in relevant variables, we end up with an unbalanced panel of 2,472 observations corresponding to 1,521 different firms.

4.2 Variables

The dependent variables in this study are measures of innovation output, input and subsidies. Innovation output is examined based upon a variable reflecting the percentage of sales due to new products; $TURNNEW = \frac{\text{sales due to new products}}{\text{total sales}} \times 100$.

As common in the literature, innovation input is measured as R&D intensity. On the one hand, one can focus solely on internal R&D expenditures as it is mostly done in the existing literature. On the other hand, one can look at total R&D expenditures of firms, including both internal and external R&D. While the main focus of input additionality studies is on private R&D expenditures, the measure of total R&D expenditures is also included in this analysis as subsidy recipients may also contract-out

[7]The IWT administers the R&D subsidy schemes in Flanders. The scope of its existing funding programs is quite broad as it supports a wide range of activities of small as well as large companies, universities, third level education institutions and other Flemish innovative organizations, individually or collectively. More ample background information on the agency and its activities can be found on the website of the agency, www.iwt.be, as well as in Larosse (2004).

some of their R&D activities. Consequently, we use two alternative measures in the empirical analysis, RDint and RDtot which are calculated as $\frac{\text{R\&D expenditures}}{\text{total sales}} \times 100$, where R&D expenditures refers either to internal R&D, RDint, or total R&D, RDtot.

Subsidies are the final dependent variable in our model. As we have detailed information on the starting period of the subsidization, the end period and the total amount granted, we can calculate the amount of subsidies received per year, IWTSUB.[8] Based upon this variable, subsidy intensity is calculated, relative to sales of the firm: $IWTSUBINT = \frac{\text{IWTSUB}}{\text{total sales}} \times 100$.

As outlined above in the methodology section, we need candidates for instrumental variables for both the subsidy and R&D input equations. In order to account for the possible endogeneity of subsidies, several relevant variables are used. One of these is the stock of past project applications a firm has filed (APPSTOCK). This variable is constructed using the perpetual inventory method applying a 15% rate of obsolescence.[9] This variable accounts for the firm's experience with the Flemish subsidy system. In general, a firm that has applied before for a subsidy might be more likely to apply again because the firm is acquainted with the application procedure. As a consequence, its chances of getting a subsidy are in general higher than for a firm not having a history of applying. As this variable may be correlated with firm size and we will separately control for size, we use APPSTOCK divided by employment in the regression analysis.

In the same vein, SRATE_FIRM reflects the stock of success rates of previous applications (also using a 15% rate of obsolescence). This variable reflects to what extent a firm had a successful interaction with the granting agency.

SRATE_OTHER is a similar variable to SRATE_FIRM but captures the previous success of application of all other firms within the same industry, region and size

[8]The yearly amount of subsidies is calculated based upon a monthly redistribution of the total subsidy grant. E.g. if a firm starts a subsidized project in April 2012 that ends in December 2013, 9/21 of the total amount will be allotted to 2012 and 12/21 to 2013.

[9]The perpetual inventory method calculates the stock of a specific variable (VAR_t) in time t, let's name this STOCK_t as follows: $\text{STOCK}_t = (1 - \delta) \times \text{STOCK}_{t-1} + \text{VAR}_t$, where δ refers to the applied discount rate or rate of obsolescence.

group, the latter being defined by whether a firm can be categorized as an SME or not. This variable is supposed to capture the effect competitors might have on the application process of a firm. At the same time, this variable reflects to what extent the firm's main competitors are likely to get funding. The presented variables are all supposed to determine the subsidy variable IWTSUBINT but should not depend the firm's investment decision or innovation outcome.

As instrumental variables in the R&D equation, we first use a variable related to the financial situation of the firm. We use the firms' firm's debt ratio (DEBT) (relative to capital and reserves) as a high debt ratio may limit the firms' opportunities to invest into R&D, but it should have no direct impact on the product market success on the innovations. In addition, we add a long-term lag of the firms' patent stocks (PSold), i.e. the stock of applications that are at least five years old. We also use its squared value (PSold2) to allow non-linearities. This old patent stock reflects the long term history of innovation activities. This past involvement in innovation is likely to strongly influence both the probability to receive subsidies and R&D expenditures. However, the old patents may be mostly obsolete for current product sales[10]. In line with this view, it has already often been argued that a large fraction of patents are "worthless" or become it in a short period of time (Griliches, 1998). Newer patents, however, can be expected to have a positive effect on innovation sales as they supposedly prevent others from imitating the product. Therefore, we insert PSnew and its square (PSnew2) in all equations. The patent stock variables are constructed based upon the PATSTAT database, scaled by employment and constructed using the perpetual inventory method applying a 15% rate of obsolescence of knowledge.

Other explanatory variables are included in all equations. A first set of variables controls for firm size and age having an impact on innovation input and output. Firm size is measured by the log of employment (lnEMP). Similarly, in order to control for the firm's age, the logarithm of this variable is included the estimations (lnAGE).

[10] Admittedly, the pharmaceutical industry may be an exception, as a single patent may correspond almost to a product and development phases of drugs after patent filings may be long. However, for most industries patents more than five years old may be almost obsolete

The GP dummy indicates whether a firm is part of a group. Group firms might be different from independent firms in their innovation input and innovation output as they are integrated in a broader group of firms. Network effects might thus lead to higher R&D investments and output. At the same time however, this might depend on the integration of the firm in the group and its flexibility. When it comes to subsidies, group members might be less likely to receive subsidies as independent firms are advantaged in some policy programs (i.e. SME funding programs). On the other hand, their probability of applying might be higher due to network effects, which might positively impact the probability of receiving subsidies. Group members with foreign headquarters should be considered independently of national groups due to their presence on foreign territory, therefore a dummy FOREIGN is included (for a discussion on multinationals and innovation see e.g. Castellani and Zanfei, 2006). In addition, the dummy EXPORT, reflecting whether a firm is exporting, is included in order to capture international presence, which might be positively related to innovation activities of any kind as exporters are exposed to more intense competition than other firms. Finally a set of province dummies captures location effects, industry dummies account for other non-observed differences among industries and time dummies capture business cycle effects.[11]

Note that all time-varying variables enter the regression as lagged values to avoid simultaneity bias.

4.3 Descriptive statistics

Table 1 shows some descriptive statistics for the firms included in this study, split by whether a firm received a subsidy or not.[12]

Column 3 presents the significance levels of two-sided t-tests on differences between mean values of the variables of subsidized and unsubsidized firms. Subsidized firms are, on average, larger, more likely to be exporters and part of a group. They are

[11] An overview of the industry structure is given in table A.1 in appendix.

[12] The IWTSUBINT variable is thus 0 for all unsubsidized firms by construction.

Table 1: Descriptive Statistics

	(1)				(2)				(3)
	Unsubsidized firms (n = 2154)				**Subsidized firms (n = 318)**				**t-test, H0: mean (1) = mean (2)**
Variable	Mean	Std.Dev.	Min	Max	Mean	Std.Dev.	Min	Max	
DEBT	3.537	5.533	0	67.690	3.116	5.280	0	67.970	
EMP	136.997	285.310	1	5820	383.261	808.290	1	5116	***
PSnew	0.002	0.018	0	0.586	0.012	0.048	0	0.600	***
PSold	0.002	0.015	0	0.320	0.012	0.037	0	0.400	***
EXPORT	0.754	0.431	0	1	0.912	0.284	0	1	***
GP	0.573	0.495	0	1	0.642	0.480	0	1	**
FOREIGN	0.308	0.462	0	1	0.267	0.443	0	1	
AGE	27.788	20.451	1	225	27.420	23.588	2	147	
APPSTOCK	0.007	0.049	0	1.445	0.044	0.094	0	0.680	***
SRATE_OTHER	0.561	0.443	0	1	0.687	0.392	0	1	***
SRATE_FIRM	0.002	0.053	0	1.85	0.255	0.574	0	1.85	***
IWTSUBINT	*0*	*0*	*0*	*0*	0.971	2.267	0.001	19.555	NA
RDint	1.080	3.876	0	50	5.162	8.760	0	49.862	***
RDtot	1.239	4.188	0	50	5.960	9.818	0	49.862	***
TURNNEW	8.146	18.941	0	100	18.108	24.136	0	100	***

* p<0.10, ** p<0.05, *** p<0.01

also more likely to have a history of innovation, reflected by a larger patent stock. In line with expectations, the summary statistics also show that subsidized firms have a larger stock of both past project applications and application success rates. On average, close competitors of subsidized firms are more likely to have higher application success rates. With respect to the outcome variables, subsidized firms seem to have higher R&D intensities as well as a larger innovation output.

5 Empirical implementation and results

5.1 Innovation inputs

In this section we focus on input additionality effects of subsidies on the innovation input decisions of firms. Table 2 presents the impact of IWT subsidies as measured by subsidy intensity on internal R&D intensity, RDint, in column 1 and total R&D intensity, RDtot, in column 2. As the subsidy variable is possibly endogenous in this equation it has been instrumented as outlined above. The first stage of this IV regression is shown in Table A.2 in the appendix. All excluded instruments are positive and significant in the first stage and the regression does not suffer from a possible weak instrument bias, as the F-test on joint significance of the instrumental variables in the first stage amounts to a value of 12.74.

We also find support for the common opinion that the subsidy variable is an endogenous regressor in the R&D equation as the residuals of the first stage regression, $\hat{\varepsilon}_3$ are significantly different from zero in the regression; at least at the 10% significance level (see Table 2).[13]

The results of the R&D equation confirm a positive significant impact of the subsidy intensity on innovation input both when this latter is measured as internal R&D intensity and as total R&D intensity. Full crowding out can thus be rejected as subsidies do seem to stimulate innovation expenditures.

In order to test whether partial crowding out can be rejected, the following logic can be applied. If the subsidy rate would amount to 50% we should expect that the estimated coefficient of the subsidy variable in the R&D equation amounts at least to the value 2, because the firm would need to finance the same amount as the subsidy itself from private resources if the project is implemented to full extent.[14] More generally, the estimated coefficient should be larger than the inverse of the subsidy rate (1/SR). The average subsidy rate in our framework is 43.395%, implying that total R&D investment should increase by at least 2.304 times the subsidies received. The results presented in table 2 suggest that this is indeed the case: the estimated coefficient is 3.046.[15]

[13]We also computed the Hansen J-test and did not reject the hypothesis that the instruments are exogenous, i.e. the instruments are not only relevant in the first stage but also valid in terms of statistical requirements.

[14]Note that R&D spending in our case is all money invested, i.e. including the subsidy. If we would have measured R&D net of the subsidy the relevant test in the example outlined above would be whether the estimated coefficient is larger than the value 1.

[15]Strictly speaking we cannot reject the hypothesis of some crowding–out as a t-test reveals that the estimated coefficient of 3.046 is not significantly larger than 2.304. However, this is not the main focus of the paper and results suggest that the subsidy certainly increases private R&D investment by an economically significant factor.

Table 2: Innovation input equations

	(1) RDint	(2) RDtot
IWTSUBINT	2.569***	3.046***
	(0.402)	(0.593)
DEBT	-0.038***	-0.038**
	(0.012)	(0.016)
lnEMP	0.198***	0.238***
	(0.073)	(0.087)
PSnew	25.267**	28.960**
	(10.950)	(11.965)
PSnew2	-55.502***	-74.175***
	(21.160)	(23.633)
PSold	20.972*	34.118*
	(11.726)	(18.100)
PSold2	-95.165**	-131.593**
	(38.265)	(54.596)
EXPORT	0.636***	0.678***
	(0.219)	(0.236)
GP	0.329	0.394*
	(0.206)	(0.227)
FOREIGN	-0.301	-0.226
	(0.274)	(0.309)
lnAGE	-0.317***	-0.346***
	(0.115)	(0.131)
Constant	0.180	0.103
	(0.484)	(0.554)
N	2472	2472
$\hat{\varepsilon}_3$	-0.779*	-1.156*
	(0.460)	(0.683)
Test on joint significance of		
- Industry	$\chi^2(11) = 110.31$***	$\chi^2(11) = 111.64$***
- Time	$\chi^2(2) = 1.94$	$\chi^2(2) = 1.59$
- Region	$\chi^2(4) = 3.86$	$\chi^2(4) = 3.91$
Test on joint significance of DEBT, PSold, PSold2	17.79***	12.94***

Standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

The coefficients of the other control variables are, in general, in line with expectations. Patent stock, both old and new, seems to have a curvilinear effect on innovation inputs. Larger firms seem to have a higher innovation input and in line with expectations on their international presence, exporters invest more into innovation activities. In addition, the older the firm, the less it invests in innovation activities on average. Group members seem to have a slightly higher total R&D intensity, ceteris paribus.

Finally, the test on the joint significance of DEBT and the old patent stocks show that they may well serve as instrumental variables for the output equation as they have a strong, joint influence on R&D investment (see Table 2).

5.2 Innovation outputs

This section assesses the impact of private R&D inputs on output and analyzes to what extent a premium or discount can be found of the subsidized projects with respect to innovation output at the firm level. Table 3 presents the results of this estimation. The first column presents results when the calculation of the R&D variables is based upon internal R&D intensity (RDint) and column 2 when this is based upon total R&D intensity (RDtot).

Results show that the private part of both total R&D expenditures and internal R&D expenditures has a positive significant effect on innovation output as reflected by the coefficient of RDint and RDtot respectively. IWTSUBINT is not significant. However, as described extensively introduced before, this coefficient should not be interpreted, as it is the reduced form coefficient π. Instead, in a first step, the structural parameter, β_2, referring to the coefficient of subsidy induced R&D, can be calculated as introduced above: $\beta_2 = \beta_1 + \frac{\pi}{\alpha}$. Results in table 3 show that the subsidy induced R&D investment has a positive significant effect on output.

Another question in this study is whether this lower coefficient of subsidized R&D reflects a lower productivity when compared to the privately invested R&D. Therefore, we could test whether β_2 is significantly different from β_1, or in the logic of the Griliches approach on discounts or premia, we are interested in the structural param-

Table 3: Innovation output equations

	Output Equation	
	(1)	(2)
RDint	3.559**	
	(1.641)	
RDtot		3.410**
		(1.571)
IWTSUBINT	-3.883	-5.212
	(4.449)	(4.566)
lnEMP	0.878	0.757
	(0.593)	(0.622)
PSnew	-17.320	-39.239
	(76.823)	(78.217)
PSnew2	-11.087	59.380
	(194.907)	(230.117)
EXPORT	2.574*	2.506
	(1.551)	(1.588)
GP	-1.526	-1.752
	(1.200)	(1.361)
FOREIGN	-1.072	-1.315
	(1.477)	(1.521)
lnAGE	-0.832	-0.798
	(0.794)	(0.873)
Constant	3.853	4.273
	(3.363)	(3.394)
N	2472	2472
Bootstrap replications	200	
β_2	2.048**	1.699**
	(0.960)	(0.772)
γ_2 (=discount/premium)	-0.425	-0.502
	(1.992)	(0.660)
$\hat{\varepsilon}_3$	-0.623	0.632
	(2.521)	(2.617)
$\hat{\varepsilon}_2$	-2.801*	-2.765*
	(1.638)	(1.569)
Test on joint significance of		
- Industry	$\chi^2(11) = 44.32$***	$\chi^2(11) = 45.50$***
- Time	$\chi^2(2) = 3.08$	$\chi^2(2) = 2.92$
- Region	$\chi^2(4) = 3.29$	$\chi^2(4) = 3.32$

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

eter ($\gamma_2 = \frac{\pi}{\beta_1 \alpha}$).

For the output equation with R&D input measured as RDint, we find $\gamma_2 = (\frac{-3.883}{3.559*2.569}) = 0.425$, suggesting thus a discount of subsidized R&D regarding the marginal productivity effect of 42.5% with respect to privately financed R&D when internal R&D speding is used as regressor. Similarly, a discount of 50.2% is suggested with respect to total R&D intensity (γ_2 = ($\frac{-5.212}{3.410*3.046}$)). However, as shown in table 3, these coefficients are insignificant, i.e. statistically we do not reject the hypothesis that privately financed R&D and subsidized R&D have equal marginal productivity effects.

In sum, results point to a positive significant effect on innovation output of both purely private and subsidy induced R&D. Furthermore, we do not find evidence of a lower effect of this latter component compared to privately financed R&D in terms of generated sales due to new products.

There is thus no conclusive evidence supporting either one of the arguments outlined above, in favor of expecting a discount or suggesting a premium of subsidy induced R&D relative to private R&D in terms of innovative output.

6 Conclusion

This paper models input and output additionality in a structural model. It extends the Crépon Duguet Mairesse (CDM) framework by incorporating subsidies as a determinant of both the input and output equations. Thereby, this study adds to the CDM framework, the widely spread input additionality literature and the less investigated output additionality strand of research. This is done by explicitly modeling the interdependency between subsidies, innovation input and output.

The empirical study is carried out using Flemish Innovation Survey data coupled with detailed subsidy data. In line with a lot of the prevalent literature, the empirical analysis finds evidence for input additionality of subsidies. In general, crowding–out can thus be rejected and public incentive schemes seem to increase R&D spending in the business sector.

In addition, this analysis reveals that, in general, an increase in private R&D inputs leads to higher innovative performance. In addition, subsidy induced R&D, encompassing both the subsidy and the additional R&D investment due to this subsidy, also increases sales due to new products. Furthermore, there is no evidence of a lower or higher productivity of public R&D compared to private R&D. Statistically both components of firms R&D activities have similar marginal effects on sales with new products. There is thus no evidence suggesting that policy makers either select projects with lower private value or that subsidized projects fail much more frequently than others.

Of course, our study has a number of caveats that remain for further research. A specific shortcoming of this study is that the subsidy application and granting decision stages are not incorporated separately as in Takalo et al., 2013), for instance. As in numerous other studies of this kind, it would be valuable to have access to more balanced panel data that allow to control for unobserved firm-specific effects in the regressions. In addition, future research could further extend this model to heterogeneous treatment effects in the input stage, i.e. the estimation of firm-specific α_i, and the output stage.

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Appendices

Table A.1: Industry structure

Industry	Description	♯OBS
1	Manufacture of food products, beverages and tobacco	245
2	Manufacture of textiles	109
3	Manufacture of wood and wood products; manufacture of pulp, paper and paper products; publishing and printing;	105
4	Manufacture of coke, refined petroleum products and nuclear fuel; Manufacture of chemicals, chemical products and man-made fibres; Manufacture of rubber and plastic products	263
5	Manufacture of basic metals and fabricated metal products	231
6	Manufacture of machinery and equipment n.e.c.; Manufacture of transport equipment	311
7	Manufacture of electrical and optical equipment	127
8	Fishing; mining and quarrying; Mineral products; Furniture; other industries; Waste collection, treatment and disposal activities; materials recovery; Other services	254
9	Wholesale and retail trade; repair of motor vehicles and motorcycles	320
10	Transportation, storage	175
11	Research & Development; other business services	182
12	ICT and related services	150
Total Number of Observations: 2,472		

Table A.2: First stage : Subsidy regression

	(1) IWTSUBINT
APPSTOCK	4.669**
	(2.304)
SRATE_OTHER	0.105***
	(0.033)
SRATE_FIRM	0.864***
	(0.256)
DEBT	0.004
	(0.003)
lnEMP	-0.018
	(0.015)
PSnew	-0.566
	(3.340)
PSnew2	13.893*
	(8.426)
PSold	-3.698
	(4.130)
PSold2	23.002
	(20.562)
EXPORT	0.044
	(0.039)
GP	-0.058
	(0.037)
FOREIGN	0.073*
	(0.039)
lnAGE	-0.028
	(0.019)
Constant	0.014
	(0.082)
N	2472
Test on joint significance of	
Industry	$\chi^2(11) = 45.12$***
Time	$\chi^2(2) = 1.99$
Region	$\chi^2(4) = 18.14$***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Columns 1 and 4 of Table A.3 show an OLS regression of the output equation without accounting for the endogeneity of the R&D input and without including the subsidy variable. Columns 2 and 5 show OLS regressions where subsidies are included and the R&D variables are interacted with the subsidies. Columns 3 and 6 present the regressions where R&D expenditure is calculated net of subsidies and subsidies are included as a separate regressor. All of these equations are estimating the marginal effects of R&D and subsidies not correctly as we argue in Section 3 of the paper.

Table A.3: 'Naive' OLS innovation output equations

	(1)	(2)	(3)	(4)	(5)	(6)
RDint	0.841***	0.985***				
	(0.128)	(0.197)				
RDintnosub			0.782***			
			(0.143)			
RDtot				0.732***	0.868***	
				(0.114)	(0.179)	
RDtotnosub						0.673***
						(0.128)
IWTSUBINT			1.739			1.720
			(1.077)			(1.061)
DSUB		6.252***			6.275***	
		(1.590)			(1.591)	
RDintDSUB		-0.499**				
		(0.247)				
RDtotDSUB					-0.452**	
					(0.222)	
lnEMP	1.299***	1.105***	1.345***	1.293***	1.103***	1.344***
	(0.388)	(0.396)	(0.389)	(0.390)	(0.397)	(0.391)
PSnew	74.257*	57.176	73.662*	71.650*	56.034	71.303*
	(41.736)	(42.594)	(41.587)	(42.124)	(42.881)	(41.897)
PSnew2	-145.870**	-108.381	-157.744**	-136.385*	-103.402	-150.224**
	(73.335)	(75.245)	(73.093)	(74.614)	(76.141)	(74.070)
EXPORT	4.608***	4.300***	4.564***	4.634***	4.325***	4.585***
	(0.858)	(0.863)	(0.857)	(0.857)	(0.862)	(0.857)
GP	-0.665	-0.708	-0.627	-0.685	-0.742	-0.641
	(1.011)	(1.011)	(1.012)	(1.012)	(1.012)	(1.012)
FOREIGN	-1.885*	-1.567	-1.919*	-1.963*	-1.640	-1.995*
	(1.075)	(1.080)	(1.069)	(1.076)	(1.081)	(1.070)
lnAGE	-1.761***	-1.702***	-1.730***	-1.770***	-1.700***	-1.736***
	(0.563)	(0.564)	(0.562)	(0.566)	(0.566)	(0.565)
Constant	4.199*	4.612*	4.012	4.260*	4.612*	4.051
	(2.537)	(2.533)	(2.547)	(2.543)	(2.535)	(2.553)
N	2472	2472	2472	2472	2472	2472
Test on joint significance of						
- Industry F(11)	4.74***	4.53***	4.75***	4.78***	4.56***	4.80***
- Time F(2)	1.47	1.79	1.61	1.49	1.77	1.63
- Region F(4)	1.44	1.48	1.32	1.44	1.47	1.31

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01