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Assessing the policy mix of public support to business R & D

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ABSTRACT

This paper investigates whether the effectiveness of public support to business R & D increases or decreases when firms benefit from different support schemes. Data on the amount received by individual firms in the available support schemes in Belgium, over the period 2003–2011, are matched with other firm-level data. Estimations of this panel of firms permit to account for the time dimension and selection mechanism in public support as well as for observed and unobserved firm heterogeneity. Results on the impact of public support appear to depend on the econometric specification and estimation procedure that is considered. Robust results indicate that the effectiveness of R & D support decreases when firms benefit from different schemes at the same time, especially when firms combine subsidies with several tax benefits.

1. Introduction

Public financial support to business R & D increased in most OECD countries over the last decade. Government expenditures for R & D shifted from public towards private research, especially through the introduction, or the increase in the generosity, of tax incentives. Despite the apparent general popularity of tax benefits, there are still substantial differences in the extent to which countries opt between direct and indirect financial support to business R & D.[1] Whereas countries such as Belgium, Canada, France and the Netherlands increasingly favour tax incentives, countries such as Estonia, Germany, Mexico, Sweden and Switzerland only provide direct support. Even in times of austerity policies, the budgetary cost of government support to business R & D has risen in most OECD countries (OECD, 2016).

Fig. 1 shows total public support to business R & D as a percentage of GDP in 2014, or the latest year available, for OECD countries, with a breakdown between direct and indirect support (on the left-hand side Y-axis) and Gross domestic Expenditure on R & D (GERD), also as a percentage of GDP on the right-hand side Y-axis.

Although public support and GERD are positively correlated,[2] some of the most R & D intensive countries spend relatively little on public support and tend to rely mostly − or only − on direct support, such as Finland, Germany, Sweden and Switzerland.

The differences in the generosity and the policy mix of public support to business R & D suggest disagreement among policy-makers as to the effectiveness of public support in general and individual policy instruments more specifically. Dimos and Pugh (2016) argue that there are indeed no definitive guidelines, theoretically or empirically, on the effectiveness of public subsidies in stimulating business R & D. Their meta-regression analysis of 52 micro-level studies indicates that subsidies do seem to stimulate R & D efforts of private firms but the effect is only limited. Two other recent meta-regression analyses, by Castellacci and Lie (2015) and Gaillard-Ladinska et al. (2015), also indicate a statistically significant but modest impact of tax incentives on R & D efforts of private firms. In their conclusions, Castellacci and Lie (2015) point out that most studies assess the impact of tax credits and subsidies separately and advocate that future studies should assess the effectiveness of the combination of policy instruments. Busom et al. (2015) and Guerzoni and Raiteri (2015) point out that most studies on public support to R & D assess the impact of individual support schemes although in most countries firms can receive subsidies as well as tax benefits.

This paper assesses the effectiveness of public support to business R & D in Belgium by considering jointly all available policy instruments. As shown in Fig. 1, Belgium is by now the most generous OECD country in terms of public support to business R & D. In 2012, public support in Belgium was evenly split between direct and indirect support. Moreover, indirect support to business R & D in Belgium also consists in different types of tax benefits.

The number of studies that have considered the combination of

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[1] The OECD considers grants; government support in equity and debt financing and public procurement as direct public support to business R & D and tax incentives such as tax credits; R & D allowances; reductions in wage taxes and social security contributions of R & D personnel and accelerated depreciation of R & D capital; as indirect public support to business R & D (OECD, 2016, p. 174). This paper only considers financial support provided to firms. Public funding of research by universities or public research institutes, which can benefit private companies and is sometimes considered as indirect support (for example, Guellec and van Pottelsberghe de La Potterie, 2003), is not considered in this paper.

[2] For the 33 countries considered, correlation between total support and GERD is 0.44, which is statistically significant at 1%.

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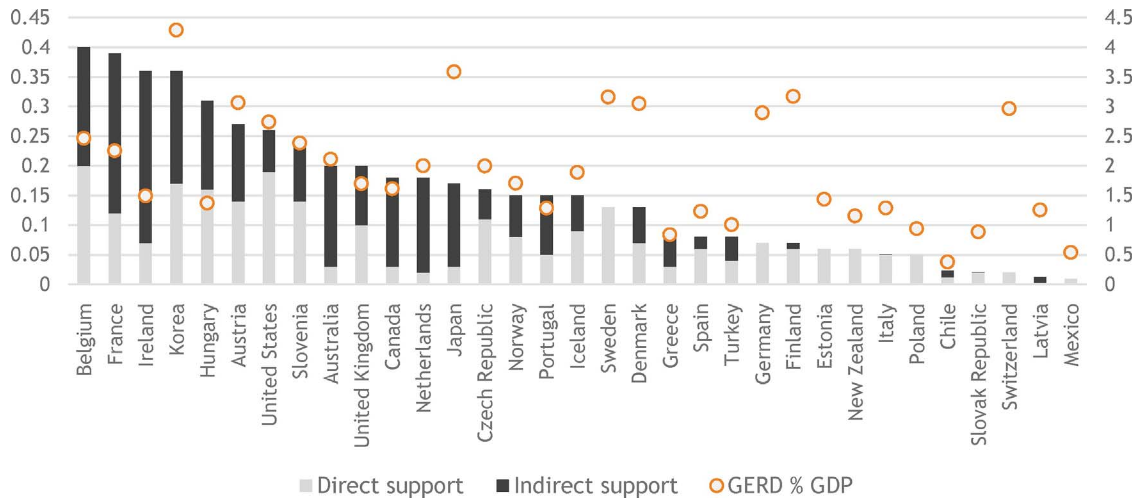

Fig. 1. Direct and indirect public support to business R & D and GERD in% GDP in 2014.
Note: Public support in% of GDP on left-hand side Y-axis and GERD in% GDP on right-hand side Y-axis. Only OECD countries with data available for all variables are considered. Direct public support: grants, loans and public procurement, indirect public support: tax incentives.
Source: OECD, R & D Tax Incentive Indicators, http://oe.cd/rdtax and Main Science and Technology Indicators, www.oecd.org/sti/msti.htm, July 2016. All observations apply to 2014 or the latest available year (see source for details).

different R & D support schemes is rather limited. In contrast with most of these studies, this paper considers a continuous variable for public support instead of a binary or categorical variable and uses panel estimation to account for the time dimension of R & D expenditures and support as well as unobserved firm heterogeneity whereas the potential selection bias in public support is acknowledged through the estimation of a selection model.

The paper is organized as follows. Section 2 discusses the role of the policy mix of public support to business R & D. Section 3 proposes the econometric procedure to assess the additionality of individual policy instruments and their combination. The data used for estimation are discussed in section 4. Estimation results are reported in Section 5 and Section 6 summarizes and concludes.

2. The policy mix of public support to business R & D[3]

The diversity in the relative use of direct and indirect support but also in the mix of policy instruments used by countries to support R & D performed by firms is indicative of the lack of consensus as to which instruments are most effective in raising business R & D. As mentioned in the introduction, recent meta-regression analyses confirm that subsidies and tax incentives appear to stimulate R & D efforts by private firms but only to a limited extent. Whereas recent studies that assess the effectiveness of public support tend to acknowledge unobserved firm heterogeneity and selection mechanisms in public support, some issues have clearly not received sufficient attention. As mentioned in the introduction, Busom et al. (2015) and Guerzoni and Raiteri (2015) recently argued that the estimation of single policy instruments, without controlling for other available instruments, may result in a hidden treatment bias.

Guellec and van Pottelsberghe de La Potterie (2003) provide evidence, for 17 OECD countries over the period 1981–1996, that direct funding as well as tax incentives are effective in increasing business-financed R & D but that increasing one form of support reduces the effectiveness of the other form of support. Only few firm-level studies followed up on this early cross-country aggregate level indication that direct and indirect public support to business R & D could be substitutes.

Hægeland and Møen (2007a) were among the first to use firm-level data to assess the interaction between subsidies and the R & D tax credit in Norway. Their results suggest that direct and indirect support are complements. More recently, Czarnitzki and Lopes-Bento (2014) also find indications of complementarity between R & D subsidies granted by the German government and research support by the European Commission. The estimation on French data by Guerzoni and Raiteri (2015) suggests that different R & D policy instruments are most effective when they interact. Marino et al. (2016), also using French data, on the other hand conclude that the combination of the French tax credit with R & D subsidies reduces the additionality of public support. All recent studies that assess the policy mix of policy instruments in support of R & D consider a binary or categorical treatment variable. Dimos and Pugh (2016) point out that the use of this type of variable precludes a full assessment of the additionality of public support. The use of binary treatment variables is often due to the lack of data on the amount of support. For this study data are used from the Belgian Policy Mix R & D database, which contains information on the amount received by individual firms, in all existing schemes of public support to R & D (subsidies and different types of tax benefits). The database contains additional firm-level data that permits to construct a panel of firms and account for the time dimension (including years before the introduction of the tax benefits) as well as observed and unobserved firm heterogeneity. Given the 50/50 share of direct and indirect support but also the different types of tax benefits for R & D that can be combined, Belgium seems an appropriate country to assess the effectiveness of different individual instruments but also to investigate whether the different support schemes tend to reinforce or weaken one another.

As a result of state reforms in the 1980s and the 1990s, most competencies in science and technology in Belgium now reside at the level of the three regions: Brussels-Capital Region, Flanders and the Walloon Region. The regions provide substantial direct support to R & D and innovation by firms, mainly through subsidies. To fulfil its commitment to a 3% target for R & D intensity, the Belgian federal government introduced several tax incentives in support of business R & D. Following the recommendations of Van Pottelsberghe et al. (2003), who evaluated the rather unsuccessful tax allowance for additional employees in scientific research in Belgium − which was abolished as

[3] In the categorization of the policy mix for innovation of Borrás and Edquist (2013), this paper only considers the second category of three categories of instruments (financial instruments) that aim at increasing the first of four innovation activities (the provision of knowledge inputs).

of tax year 2008 − the federal government introduced new tax incentives from 2005 onwards. The most popular measure is the partial exemption from advance payment of the withholding tax on the wages of R & D employees. There are currently four possibilities for companies to obtain such a partial exemption:

- for R & D personnel in companies that cooperate in research with a university, a higher education institution in the European Economic Area or a scientific institution registered by the Council of Ministers (as of 1 October 2005);
- for Young Innovative Companies (YIC)[4] (as of 1 July 2006);
- for R & D personnel with a PhD degree in exact or applied sciences, doctor degree in (veterinary) medicine or a civil engineering degree (as of 1 January 2006: labelled as List 1 throughout the rest of the text);
- For R & D personnel with a master's degree, with the exception of masters in social and human sciences (as of 1 January 2007: labelled as List 2 throughout the rest of the text).

For the first two measures the exemption originally amounted to 50% and for the last two to 25%. The exemption, for all four measures, was raised to 65% in July 2008, to 75% in January 2009 and as of 2013 the exemption amounts to 80%.

Starting in tax year 2008, the federal government grants a deduction of 80% of qualifying gross patent income − for example from licensing to third parties − from the taxable basis. With a statutory corporate income tax rate of 33.99%, this implies effective taxation of 6.8% on patent income

As of tax year 2007, Belgian companies can choose between a tax deduction or a tax credit for investment in R & D (tangible and intangible fixed assets and patents). The tax deduction provides a deduction of the taxable base whereas the tax credit is a reduction of the tax due. The advantage of the tax credit is that if companies cannot use the entire tax credit against taxable income, the part that has not been used within five years, is refunded. For this reason the majority of firms prefer the tax credit over the tax deduction.

In contrast with most other countries with tax incentives for R & D, which restrict themselves to a single tax benefit (most often a tax credit for R & D investment), Belgium has opted for several distinct schemes of tax support for R & D. The four schemes of partial exemption from advance payment of the withholding tax, are provided apart from corporate income taxation. Firms that are eligible for partial exemption do not have to pay 80% of the withholding tax that is normally deducted from salaries. These schemes therefore provide immediate financial support, also to firms without any profit (for example, biotech start-ups). In addition to the partial exemption, the more traditional tax deduction/credit for R & D investment and the tax deduction of 80% of qualifying gross patent income are implemented through corporate income taxation and therefore only apply to firms that make profit, except for the tax deduction that can be carried forward for an unlimited period in case of insufficient profits and the part of the tax credit that is not used after 5 years, which is refunded. Firms can combine subsidies with tax benefits but can also combine different tax benefits. Table 1 shows the extent to which firms combined, over the period 2007–2011, the different available schemes of support to R & D, in effect, direct support (subsidies) provided by regional authorities, the four schemes of partial exemption as well as the two tax benefits through corporate income taxation provided by the federal government. For each policy instrument, the shares in each column sum to 1. Taking the example of firms that benefit from regional subsidies, 54% benefit only from subsidies in a given year, 5% combine subsidies support with a partial exemption for research cooperation and so on until 19% that combine subsidies with at least two different tax benefits.

Of those firms that benefit from a regional subsidy or a partial exemption from advance payment of the withholding tax for R & D personnel of Young Innovative Companies, 54% did not receive any other public support in Belgium. For firms that benefit from a tax credit for R & D investment this share is only 23%. Almost half (47%) of firms that benefit from the R & D tax credit, combine this with at least two other support schemes. Except for YIC and regional subsidies and for List 1 and List 2 which are often combined without any other support scheme, if firms combine individual schemes they at least benefit from three different schemes. Table 1 clearly shows that firms that receive public support for R & D in Belgium pervasively benefit from several support schemes. This indicates the need to control for all available instruments in estimating the impact of each individual instrument but also that an assessment of the extent to which the combination of different schemes affects the effectiveness of public support is warranted.

3. Methodology

The evaluation of the impact of public support on the R & D activities of private companies is hampered by the limitations of econometric methods to establish causal links. Regression provides indications of association (correlation) between variables but does not permit to prove indisputably any causal link. It is necessary to realize that a private company decides autonomously how much it invests in R & D. Availability of direct support or tax benefits is only one factor that companies take into consideration (see Becker, 2013 for a recent survey on the determinants of R & D investment by private companies). It is also the company that decides to apply for a subsidy or a tax benefit. This complicates the assessment of the effects of introducing a support scheme or changing the conditions of public support. Moreover, public agencies follow explicit rules to grant subsidies. For example, most regional agencies in Belgium have programmes that specifically target SMEs or technology fields. Subsidies are granted, based on the quality of the project proposal which may reflect firm-specific characteristics known to the agency or the reviewers but most of the times not to the evaluator. More implicitly, agencies may favour a strategy of “picking the winner”. The granting of subsidies or tax benefits is clearly subject to selection by agencies and self-selection by companies which implies that companies that receive public support for their R & D activities cannot be considered as a random sample of the population of companies (Lichtenberg, 1984; Busom, 2000; David et al., 2000; Klette et al., 2000; Wallsten, 2000; Jaffe, 2002; Cerulli, 2010; Cantner and Kösters, 2012).[5] If the selection by agencies that provide direct support and the self-selection and autonomy of firms to decide how much to invest in R & D are not accounted for, regression may result in a biased (optimistic) estimate of the causal impact of public support. Different estimation procedures exist to address the selection bias of public support. All procedures have known advantages as well as several limitations. Unfortunately, no single method that is based on observational data can be considered to provide undisputed evidence on the causal effect of public support. Angrist and Pischke (2009, 2015) consider four alternative methods to account for selection and endogeneity in a context in which random assignment of treatment (in this case, receiving a subsidy or tax benefit for R & D) is not applicable and assessment is based on observational (post-treatment) data: Regression, instrumental variables, regression discontinuity and differences-in-

[4] A Young Innovative Company is defined (see Belgian Science Policy, 2006) as a company which: carries out research projects; has been set up for less than 10 years before January 1 of the year during which the advance payment exemption is granted; is not set up within the framework of concentration, a restructuration, an extension of a pre-existing activity or resumption of such activities; has made expenditures on R & D representing at least 15% of the total costs in the foregoing taxable period.

[5] Antonelli and Crespi (2013) distinguish between vicious Matthew effects and virtuous Matthew effects of R & D subsidies. They present evidence for Italy that suggests the picking-the-winner strategy adopted by authorities positively contributed to the effectiveness of the subsidies.

Table 1
Policy mix: combinations of public support to Business R & D in Belgium (2007–2011).

		Partial exemption from payment of withholding tax on wages R & D personnel				Corporate income taxation	
	Regional subsidy	Research cooperation	YIC	List1	List 2	Tax credit R & D	Tax deduction 80% patent income
Single use	0.54	0.38	0.54	0.38	0.39	0.23	0.34
Combined with:							
Regional subsidy		0.20	0.26	0.08	0.08	0.06	0.07
Research cooperation	0.05		0.01	0.03	0.01	0.01	0.00
Young Innovative Company (YIC)	0.08	0.01		0.01	0.00	0.10	0.02
List 1	0.06	0.08	0.02		0.27	0.08	0.06
List 2	0.06	0.03	0.00	0.26		0.05	0.08
Tax credit R & D	0.01	0.01	0.04	0.01	0.01		0.00
Tax deduction 80% patent income	0.00	0.00	0.00	0.01	0.01	0.00	
Combined with at least two other support schemes	0.19	0.29	0.12	0.23	0.23	0.47	0.42

Note: The table shows the share of firms that received, in a given year over the period 2007–2011, only one of the given forms of public support (single use), combine it with one of the other benefits (second up to seventh line) or combine it with at least two other benefits (last line), so that columns sum to 1 (except for rounding error).

differences. Causal inference of these methods relies on the conditional independence assumption or the selection on observables assumption which implies that all potential covariates that may affect (self-) selection are known and observed. If the assumption holds, the selection bias can be removed by controlling for observed covariates and a causal interpretation can be justified. Angrist and Pishke argue that including covariates as control variable increases the plausibility of the conditional independence assumption.

The approach used in this paper is a fixed effects panel regression with known determinants of R & D expenditures as covariates, in addition to variables of the amount of public support received by firms. Selection is accounted for through the prior estimation of a selection specification (Heckman selection model). Instrumental variable estimation is considered, in this paper, in the Generalized Method of Moments estimation of a dynamic panel specification that accounts for the substantial persistence in R & D expenditures as reported by Arqué-Castells (2013), Arqué-Castells and Mohnen (2015) and Huergo et al. (2016). Regression discontinuity is not considered as this approach requires some threshold or unexpected discontinuity in the public support variables (see for example de Blasio et al., 2015; Dechezleprêtre et al., 2016) that is not available in the Belgian data. Differences-in-differences is mostly applied when data over a long period of time are not available (mostly one observation before and one observation after a firm receives support). The fixed effects regression, as discussed in the next section, can be considered as a generalization of differences-in-differences in a panel context (Heckman et al., 1998; Angrist and Pischke, 2009; Klette et al., 2000). Klette and Møen (2012) argue that when data for more than two years are available, and the amount of support is known, a fixed effects specification is to be preferred to a differences-in-differences estimator. Fixed effects permit to account for time-invariant firm heterogeneity. If firm-specific effects related to the selection process of public support change only little over the considered period, fixed effects can be useful in addressing the endogeneity problem.[6]

In this study detailed firm-level data on the amount of public support granted to individual firms in all available schemes are used to construct a panel covering the period 2003–2011 with a continuous rather than a binary or categorical treatment variable as in most studies. The panel estimation permits to control for observed as well as unobserved (time-invariant) firm heterogeneity, which Dimos and Pugh (2016) point out as an issue that can explain the diverging results in the literature on the effectiveness of public support to business R & D. The panel considers the cross-section as well as the time dimension of R & D expenditures and public support. The period that is covered moreover contains a number of years prior to the introduction of the federal tax benefits (starting in 2005 as listed in the previous section).

The panel specification estimates the impact of each support scheme conditionally on the other support schemes, avoiding the possible bias due to omitting available information on other forms of public support. Moreover, the specification contains variables on the amount received by firms that combine two schemes as well as a variable with the total amount of public support received by firms that combine subsidies with at least two tax benefits and a variable with the total amount of public support for firms that combine at least three different tax benefits but receive no subsidies, in a given year. These variables are constructed such that they only differ from zero when firms actually use a specific combination of support measures. The variables thereby permit to assess whether the combination of different measures of public support increases or decreases the effectiveness of support relative to the effectiveness of individual measures. Given seven different schemes (subsidies and six tax benefits), 21 combinations exist, although some combinations are not possible by definition or not considered due to a lack of sufficient observations that differ from zero. The coefficients of the combination variables should be interpreted as additional effects of combining two schemes relative to the individual schemes. A statistically significant positive coefficient implies that combining the two schemes provides a complementary impact and a negative coefficient would indicate that the combination results in some crowding out of R & D expenditures.

Given the assumption, explicit in most estimation procedures, that errors are normally distributed, a log–log specification is preferred (see for example Clausen, 2008)[7]:

[6] I would like to thank an anonymous referee for pointing out this advantage of fixed effects.

[7] The estimates of a linear specification would provide a direct estimate of the Bang for the Buck (see end of Section 5), in effect, how much one euro in public support gives rise to how much additional own R & D expenditures by companies. However, the distribution of R & D expenditures, as well as the distribution of public support for R & D, is extremely skewed and far from normal. The logarithm of R & D expenditures is relatively normally distributed. As only firms with support in all schemes would be considered in a log–log specification, 1 euro is added to all support variables. This also permits to consider the control group of R & D firms that do not receive any public support in a given year. The log transformation may pose a problem under heteroscedasticity as discussed in the text.

$$\ln(RD_{it}) = \alpha_0 + \beta^{reg}\ln(X_{it}^{reg}) + \beta^{coop}\ln(X_{it}^{coop}) + \beta^{YIC}\ln(X_{it}^{YIC}) + \beta^{List\,1}\ln(X_{it}^{List\,1}) + \beta^{List\,2}\ln(X_{it}^{List\,2}) + \beta^{Credit}\ln\left(X_{it}^{Credit}\right) + \beta^{Patent}\ln(X_{it}^{Patent}) + \sum_{j=1}^{N}\sum_{k=2}^{N}\beta^{j+k}\ln\left(X_{it}^{j} + X_{it}^{k}\right) + \beta^{3\,or\,more}\ln(X_{it}^{3\,or\,more}) + \beta^{CF}\ln(CF_{it}) + \beta^{E}\ln(Employees_{it}) + \beta^{A}\text{Age} + \beta^{KL}\ln(K_{it}/L_{it}) + \varepsilon_{it} \quad (1)$$

Dependent variable:

RD_{it}: Internal R & D expenditures (excluding the amount of public support) of company *i* in year *t*

Explanatory variables (public support for R & D):

X_{it}^{reg}: Total amount of regional subsidies received by company i in year *t*

X_{it}^{coop}: Total amount saved through partial exemption of the withholding tax on the wages

of researchers cooperating with a university, college or a scientific institution

X_{it}^{YIC}: Total amount saved through partial exemption of the withholding tax on the wages

of R & D personnel in Young Innovative Companies (YIC)

X_{it}^{List1}: Total amount saved through partial exemption of the withholding tax on the wages

of researchers with a List 1 degree (PhD in exact or applied sciences, doctor degree in (veterinary) medicine or a civil engineering degree)

$X_{it}^{List\,2}$: Total amount saved through partial exemption of the withholding tax on the wages

of researchers with a List 2 degree (Master's degree except for master in social or human sciences)

X_{it}^{Credit}: Total amount saved through the tax credit for R & D investment

X_{it}^{Patent}: Total amount saved through the tax deduction of 80% of qualifying gross patent income

$X_{it}^{j} + X_{it}^{k}$: Total amount of support received by firm *i* that combines support scheme *j* and *k* if $X_{it}^{j} > 0$ and $X_{it}^{k} > 0$

$X_{it}^{3\,or\,more}$: Total amount of support received by firm *i* that combines at least three different types of public support. If a firm does not combine three different types (or more) of support the variable equals zero. In the estimation this group is split between firms that combine a subsidy with at least two different tax benefits and firms that do not receive a subsidy but combine at least three different tax benefits.

Control variables:

CF: Cash flow

Employees: Number of full time equivalent (FTE) employees

Age: Number of years since the company was incorporated

K/L: Capital intensity (tangible fixed assets per employee)

ε_{it}: error term (assumed to be randomly distributed with an expected value of 0 and a constant variance).

The dependent variable is total R & D expenditures reported by a firm minus the total amount of public support for R & D received by that firm. As pointed out by Cerulli (2010), if the amount of public support is known, 'own R & D' (total R & D minus public support) should be the target variable for the estimation of the input additionality of public support. If 'total R & D' (R & D expenditures including support) is used − which is the case in many empirical studies as data on the amount of support is not available- the fact that support is included in the target variable is a confounding element in assessing the effectiveness of public support (Cerulli, 2010, p. 427; see also among others David et al., 2000; Clausen, 2008; Zúñiga-Vicente et al., 2014).

Estimation of Eq. (1) includes year dummies to account for year-specific shocks and industry-year dummies to control for time-varying industry-specific characteristics, following Aghion et al. (2012) and Einiö (2014). Industry is considered at the two-digit NACE level.

In the interpretation of the estimates of the direct support variable it should be kept in mind that, as the total amount of all regional subsidies received by companies is considered, the variable on direct support does not account for the potential different effects of specific programmes and possible differences across regions. Given the plenitude of subsidy programmes, an evaluation of the complementarity between different types of subsidies is beyond the scope of this paper.

As pointed out before, if the selection criterions of agencies that provide direct support and the self-selection and autonomy of firms to decide how much to invest in R & D and whether or not to apply for public support are not accounted for, regression may result in a biased estimate of the impact of public support. Henningsen et al. (2015) considered the evaluation grades of applications by firms, for R & D subsidies granted by the Research Council of Norway. Evaluation grades appear to predict, to a large extent, R & D investment of firms. However, the grades do not change much over time such that, at least in the sample of Henningsen et al. (2015), unobserved project quality can be absorbed by firm fixed effects. However, not all factors that can induce a selection bias can be expected to be fixed over time. A possible way to take into account the selection mechanism involved in public support for R & D is a so-called selection model, which consists in the estimation of two specifications, a selection specification and the actual (structural) regression. The selection specification assesses which factors can explain why a firm receives support in a given year or not. The estimation of this model provides variables (inverse Mills ratios) that can be included in the specification of interest, the regression of private R & D expenditures on public support. The statistical significance of these variables will provide an indication on the relevance of the selection bias. The original selection model, proposed by Heckman (1979) considered a bivariate choice variable (for example, support or not), which would reflect the possible outcome for a single instrument. Busom (2000), Hussinger (2008) and Huergo and Moreno (2014) have applied the two-step selection model in the context of evaluation of public support for R & D. In our case, in a given year a firm can receive direct support (subsidies) as well as one of six tax benefits. The selection and self-selection involved in regional subsidies and federal tax incentives is likely to be explained by different firm and industry characteristics. Rather than using a bivariate selection, four possible categories of public support are considered[8]:

- Firm receives no support for R & D
- Firm receives a subsidy but no tax benefit
- Firm receives a tax benefit but no subsidy
- Firm receives a subsidy as well as a tax benefit

A multinomial logit estimation provides estimates of the extent to which right-hand side variables explain the probability of a given company to receive public support (X denotes the vector of potential explanatory variables and β the vector of corresponding coefficients). The probability to belong to category *i* is given by:

$$\Pr(y = i) = \frac{e^{X\beta^{i}}}{\sum_{j=1}^{N} e^{X\beta^{j}}} \quad (2)$$

In a review of studies that estimate the probability of receiving public support for R & D, da Silva (2014) enlists factors that are commonly considered. Firm size is often found to be a significant determinant. Usually, larger firms are more likely to receive a subsidy except for countries where agencies explicitly favour smaller firms. Past experience in R & D as well as past participations in R & D programmes

[8] In principle each individual tax support scheme can be considered as a separate category but, probably due to the small number of firms that benefit from some specific schemes, such a specification provides poor results. Attempts with more categories result in a failure to converge of the multinomial logit estimation.

Table 2
Descriptive statistics by support scheme and combinations of schemes (2011).

	No support (# firms: 754)		Subsidy (# firms: 89)		R & D cooperation (# firms: 41)		Young Innovative Companies (# firms: 37)	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
R & D expenditures	472	126	1689	200	459	190	654	366
Total public support	0	0	123	84	29	19	65	40
Support rate	0	0	0.50	0.52	0.14	0.09	0.17	0.10
# employees (FTE)	71	24	96	16	54	19	20	6
Firm age	24	21	17	16	25	21	6	6
Cash flow	2611	317	5054	229	1632	762	−144	84
Capital/employee	68	32	64	26	103	31	30	7

	List 1 (# firms: 73)		List 2 (# firms: 115)		Tax credit R & D investment (# firms: 7)		Tax deduction 80% patent income (# firms: 6)	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
R & D expenditures	1093	400	1180	278	606	354	524	230
Total public support	104	35	61	25	22	12	38	29
Support rate	0.13	0.10	0.13	0.09	0.03	0.01	0.23	0.15
# employees (FTE)	101	40	142	55	153	27	82	38
Firm age	22	19	24	21	17	9	29	29
Cash flow	3767	345	5473	644	5861	283	6450	3620
Capital/employee	60	31	62	28	60	43	117	74

	Combination of two schemes (# firms: 59)		Combination of subsidy and at least two tax benefits (# firms: 186)		Combination of more than two tax benefits but no subsidy (# firms: 114)	
	Mean	Median	Mean	Mean	Mean	Mean
R & D expenditures	2521	87	10,100	1415	11,600	1378
Total public support	226	125	1886	365	1422	1799
Support rate	0.22	0.12	0.35	0.25	0.15	0.10
# employees (FTE)	170	67	263	55	347	120
Firm age	24	20	25	18	27	22
Cash flow	6439	1286	26,700	940	30,600	2465
Capital/employee	50	28	51	28	116	29

Note: For individual policy instruments the statistics apply to those firms that only benefit from that specific support scheme. All amounts are denoted in 1000 euro.

are also known to raise the probability of receiving a subsidy. Other factors that have been considered are the patent stock of companies (number of patents raises probability of support) and firm age, for which results are mixed. Human capital, as for example measured by the share of qualified personnel, also seems to increase the probability of receiving support. Foreign ownership, on the other hand, is in some studies found to negatively affect the probability of support, which may be due to a preference of agencies for domestic firms or research centres of foreign companies being located abroad (da Silva, 2014, p. 10). The variables included in the selection model are based on the determinants listed by Takalo et al. (2013), da Silva (2014) and Huergo et al. (2016), conditional on data availability. Lagged values of R & D expenditures and public support are included in the first-step estimation of the selection equation. Cash flow is included as a proxy for the extent to which companies can finance R & D activities out of own funds. As the regional agencies that grant subsidies in Belgium have specific programmes for SMEs, a dummy variable denoting whether a company is a SME (less than 250 employees) or not is included as the exclusion criterion in the first-step selection specification, following Takalo et al. (2013) who use this dummy as exclusion variable in their estimation of the returns to R & D subsidies, provided by the Finnish Funding Agency for Technology and Innovation (TEKES). In addition, the variables denoting the amount of subsidies and the amount of tax benefits received in the previous year are also considered in the estimation of the selection model but not in the second-step estimation.

To assess whether (self-) selection affects the results of the actual regression, Heckman (1979) computes the inverse Mills ratio from the first-step selection specification. This ratio is then introduced in the second-step estimation of the actual effects. Statistical significance of the coefficient of the inverse Mills ratio indicates that ignoring (self-) selection of firms is likely to result in biased estimates. The original bivariate Heckman model provides one inverse Mills ratio. In a multivariate context, (number of categories − 1) inverse Mills ratios need to be computed (Dubin and McFadden, 1984), so in the case of four categories three ratios need to be computed. The estimation of this study therefore consists in two steps, first the estimation of selection specification (2) and consequently the estimation of specification (1) including three inverse Mills ratio variables computed based on the first-step estimation results. Industry-year dummies cannot be included in the multinomial logit estimation. For this estimation only year, region and industry dummies are considered.

4. Data and descriptive statistics

The R & D Policy Mix database was created by the Belgian Federal Public Service Finance. In the database, information from the Belgian biennial R & D survey, carried out by the Federal Science Policy Office, is linked to data on the direct support to business R & D by the regions and data on the tax incentives for private R & D activities provided by the federal government. The database also contains firm-level annual account and balance sheet information from Belfirst (Bureau van Dijk). The data cover the period 2003–2011.

Table 2 provides descriptive statistics, for 2011, of the main variables in the dataset for those firms that responded to the R & D survey. The table shows the mean and the median of own R & D expenditures (net of public support); R & D intensity (R & D expenditures/value added); the total amount of public support (subsidies and tax benefits) received by companies; the support rate (total amount of support/R & D expenditures); the total full-time equivalent number of employees; firm age; cash flow and capital intensity (tangible assets per employee).

Table 3
Descriptive statistics of variation over time (within) and over firms (between).

Variable		Mean	Standard Deviation	
R & D expenditures	total	2983	20,000	Observations = 9146
	between		11,600	Number distinct firms = 3109
	within		5857	Average number of years = 2.94
Total amount subsidies (regional)	total	68	425	Observations = 9146
	between		230	Number distinct firms = 3109
	within		224	Average number of years = 2.94
Total amount i.s.o. Amount tax support (federal)	total	167	3409	Observations = 9146
	between		1151	Number distinct firms = 3109
	within		2776	Average number of years 2.94
Number of employees	total	160	501	Observations = 8925
	between		444	Number distinct firms = 3056
	within		78	Average number of years = 2.92
Age	total	23	19	Observations = 9136
	between		18	Number distinct firms = 3105
	within		2	Average number of years 2.94
Cash flow	total	10,400	93,300	Observations = 8875
	between		72,700	Number distinct firms = 3037
	within		49,100	Average number of years = 2.92
Capital per employee	total	84	1274	Observations = 8550
	between		1506	Number distinct firms = 2906
	within		277	Average number of years = 2.94

Time pattern	% of observations
000000011	23.32
000001100	16.48
000110000	11.76
100000000	9.17
011000000	7.06
000001111	4.83
000111100	3.08
000110011	2.05
000111111	2.04
011110000	1.49

Note: The table shows, for each variable, the total standard deviation around the mean, the standard deviation over firms (between) and the standard deviation over time (within). All amounts are denoted in 1000 euro. The time pattern shows the share of observations for which R & D expenditures are available (denoted by 1) or not (denoted by 0) for each year in the period of nine years.

Descriptive statistics are shown for firms that received no public support for their R & D activities in 2011 as well as for firms that received support in only one specific scheme, firms that combined two support schemes, firms that benefited from subsidies and at least two different tax benefits and firms without subsidies that combined at least three tax benefits.

The substantial difference between the average and the median reveals that the skewness of public support parallels the skewness of most firm characteristics. Most variables are skewed to the right, with the mean exceeding the median. This reflects the fact that output and R & D is concentrated in a small group of large firms in most industries. The concentration is even more pronounced in R & D than in cash flow or employment. A notable exception is the cash flow of Young Innovative Companies. The average cash flow of firms that received support in 2011 under this scheme is actually negative whereas the median is slightly positive.

Young Innovative Companies − by definition- spend much on R & D but often do not have much sales or even no sales at all. The negative average cash flow reflects a group of Young Innovative Companies known for their high cash burn rate, namely companies active *in research and experimental development on biotechnology*. For this group of firms wage-based tax benefits, such as the partial exemption from payment of the withholding tax, are appropriate as these firms cannot benefit from benefits provided through corporate income taxation.

From Table 2 it is clear that firms that do receive public support are, on average, larger and older than firms that do not receive support except for firms that receive a subsidy which tend to be larger but younger than firms that do not receive support and Young Innovative Companies, which − not surprisingly- are younger and smaller than non-supported firms or firms receiving other benefits.

Firms that benefit from two or more different support schemes are by far much larger than all other firms, in terms of R & D expenditures, public support, number of employees and cash flow. The support rate is highest for firms that only receive direct support (funding rate is often 50% for research activities), not surprisingly followed by firms that combine different support schemes.

Table 3 provides some indications of the variation in the panel, over firms (between dimension) and over time by firm (within dimension). For a meaningful fixed effects estimation (benchmark specification) there should be sufficiently variation over time in the variables. There is substantial between as well as within variation. Between variation tends to dominate within variation except for the total amount of tax support received by firms, for which the within variation is 2.4 times as large as between variation. The table indicates that both dimensions of the panel (cross-section and time) can offer valuable information and that a fixed effects estimation is warranted. As suggested by the average number of years for which data are available, around 2.9 for a possible maximum of 9 available years, the panel is unbalanced. The bottom of Table 3 shows the 10 most occurring time patterns of available data for R & D expenditures with 0 denoting absence of reported R & D and 1 denoting that the data are available for the given year. For 23.32% of observations, reported R & D expenditures is only available for the last two years. The time pattern of availability for all years only comes in 11th position, covering 1.37% of observations. The time pattern could

Table 4
Number of observations by group of firms in the selection model.

Group of firms	Number of observations	%
No support	3843	68.19
Only direct support	449	7.97
Only tax benefit	862	15.30
Direct support and tax benefit	481	8.54
Total	5634	

reflect the distinction between stable R & D performers and occasional R & D performers.

Arqué-Castells and Mohnen (2015) found, for Spanish manufacturing firms, that stable R & D performers are mainly large firms and rarely small firms whereas occasional R & D performers are most common among medium-sized firms. As the data on R & D expenditures used in this paper are based on the responses of firms to the biennial R & D survey, missing observations do not necessarily imply that a firm did not perform R & D in the years covered by the survey but only that they did not respond.

5. Estimation results

The first step of the estimation consists in estimating the determinants of the probability that a firm will benefit from public support in a given year. As pointed out in Section 3, four categories of firms are considered. The group of R & D active firms that receive no support is the benchmark group. The other three groups consist in, respectively, firms that only receive direct support, firms that only benefit from a tax benefit and firms that benefit from direct support as well as tax benefits. As mentioned before, considering more categories of public support to R & D (for example, by individual instrument) results in non-convergence of the multinomial logit estimation, which is an iterative Maximum Likelihood procedure. The non-convergence is probably due to collinearity of categories with only a small number of non-zero observations. Table 4 shows that firms that receive no support form by far the largest group. This is explained by the fact that a substantial share of R & D active firms indeed do not apply for any public support but also by the fact that federal tax benefits where only gradually introduced over the period under consideration (starting in 2005). The years 2003 and 2004 are included in the sample to account for R & D activities in the years before introduction of the tax benefits. For these years data on subsidies provided by regional authorities are available and included in the estimation.

Table 5 shows the results of the multinomial logistic regression of the selection model specification (2). The dependent variable is a category variable reflecting four possible situations in terms of public support for R & D in a given year: 1 (firm receives no support for R & D); 2 (firm receives a subsidy but no tax benefit); 3 (firm receives a tax benefit but no subsidy) and 4 (firm receives a subsidy as well as a tax benefit). The table shows the results for the latter three categories relative to the benchmark group of firms without public support. The SME dummy equals 1 for SMEs (employees < =250) and 0 for large firms. The estimation considers region, industry and year dummies (not reported). When industry-year dummies are included, the estimation procedure does not converge.

The coefficients denote the relative risk ratio which reflects the change in probability to belong to a group, relative to the benchmark group, for a unit change in the explanatory variable, with the other variables held constant. A coefficient above (below) one indicates that the higher the given variable the higher the odds to belong to a given group of public support relative to receiving no support. Taking, for example, the statistically significant coefficient of 1.30 for the lagged amount of direct support (regional subsidy) for the group of firms that only receive direct support, it implies that a positive unit change in

Table 5
Determinants of receiving public support for R & D (2003–2011).

	Subsidy − no tax benefit	Tax benefit − no subsidy	Subsidy and tax benefit
Explanatory variables:			
Lag R & D expenditures	1.00 (2.95)***	1.00 (3.25)***	1.00 (4.12)***
Lag regional subsidy	1.30 (21.45)***	1.06 (3.10)***	1.31 (14.57)***
Lag tax support	1.12 (2.50)**	1.80 (24.22)***	1.87 (21.32)***
Cash flow	0.96 (−0.62)***	1.26 (3.88)***	1.19 (2.19)**
SME (0/1)	0.66 (−1.85)*	0.91 (−0.42)	0.84 (−0.63)
Number of employees	1.00 (0.01)	0.99 (−0.05)	1.11 (−0.91)
Age	0.99 (−1.42)	0.99 (−1.62)*	0.98 (−2.19)**
Age^2	1.00 (1.07)	1.00 (0.62)	1.00 (1.98)**
Capital intensity	1.13 (2.08)**	0.96 (−0.75)	1.01 (0.13)
Mc Fadden pseudo R-squared: 0.54			
Number of observations: 5634			

Note: The table shows the results of multinomial logistic regression. The dependent variable is a category variable reflecting four possible situations in terms of public support for R & D in a given year: 1 (firm receives no support for R & D); 2 (firm receives a subsidy but no tax benefit); 3 (firm receives a tax benefit but no subsidy) and 4 (firm receives a subsidy as well as a tax benefit). The table shows the results for the latter three categories relative to the benchmark group of no support. The coefficients denote the relative risk ratio which reflects the change in probability to belong to a group, relative to the benchmark group, for a unit change in the explanatory variable, with the other variables held constant. The SME dummy equals 1 for SMEs (employees < =250) and 0 for large firms. The estimation considers region, industry and year dummies (not reported). *, ** and *** denotes that the coefficient estimate differs from zero at a statistical significance level of respectively 10%, 5% and 1%. As the coefficients are relative risk ratios, a ratio below 1 implies a negative t-value (reported in brackets).

lagged direct support increases the odds that a firm will receive a subsidy but no tax benefit by 1.30 relative to the odds to receive no support. The table clearly indicates the persistence in receiving public support, for direct support as well as for tax benefits. Somewhat surprisingly, SMEs have a lower probability to belong to the group of R & D active firms that receive subsidies than to the group of R & D active firms that receive no public support, although the effect is only statistically significant at 10%. Despite some programmes that specifically subsidise SMEs, this result suggests that SMEs with R & D activities are inhibited to apply for subsidies or are selected less by funding agencies in those programmes for which firm size is not a criterion. Given the surprising result for subsidies and the fact that the SME criterion is not relevant for tax benefits, this variable does not appear to be a good exclusion variable. Dropping the variable does not change very much the first-step or the second-step estimates. However, the two variables denoting direct support and tax benefits received by firms in the previous year are statistically significant for all categories in the first-step estimation. When these variables are also included in the second-step estimation the coefficients are not statistically significant. This indicates that they can be excluded from the second step and that these variables are more acceptable as exclusion variables.

The coefficient for cash flow in the group of firms with only direct support (0.96) seems to suggest that credit-constrained firms are more likely to apply for and receive a subsidy whereas high cash flow increases the probability of firms to receive tax benefits. All other things equal, younger firms are more likely to receive a tax benefit than not, explained by the specific scheme for Young Innovative Companies.

The results of the estimation of the selection model reveal that a number of firm characteristics can explain the fact that a firm will receive a given type of support or combine support schemes. Although the tax benefits provided by the federal government are not subject to specific firm characteristics, except for the Young Innovative Companies scheme, firm characteristics such as past experience and support but also cash flow and firm age significantly explain whether firms apply for and receive tax benefits for their R & D activities or not.

Table 6
Results of the estimation of the policy mix of public support for R & D (2003–2011).

Dependent variable (R & D expenditures net of public support)	Fixed effects Static panel	Fixed effects (weighed) Static panel	System GMM Dynamic panel
Explanatory variables:			
R & D expenditures net of public support (t-1)	–	–	0.92 (53.76)***
R & D expenditures net of public support (t-2)	–	–	−0.19 (−4.81)***
R & D expenditures net of public support (t-3)	–	–	0.14 (4.09)***
Individual support scheme:			
Regional subsidy	0.06 (2.97)***	0.13 (1.77)*	0.00 (0.06) – [0.01]
Research cooperation	0.08 (2.16)**	0.20 (1.56)	0.01 (1.11) – [0.11]
Young Innovative Company	0.05 (0.68)	0.05 (0.28)	0.02 (0.64) – [0.18]
List 1	0.03 (1.46)	−0.05 (−0.55)	0.02 (1.91)* – [0.18]**
List 2	0.09 (3.53)***	0.35 (2.95)***	0.04 (2.99)*** – [0.28]**
Tax credit R & D	0.02 (0.82)	−0.10 (−0.88)	0.02 (1.46) – [0.16]
Tax deduction 80% patent income	0.02 (0.67)	0.30 (1.96)**	0.03 (2.09)** – [0.27]**
Combination of support schemes:			
Regional subsidy + List 2	−0.11 (−1.20)	−0.87 (−3.12)***	−0.06 (−1.11) – [0.45]
Regional subsidy + Tax credit R & D	−0.04 (−1.53)	−0.22 (−1.48)	−0.06 (−1.69)* – [−0.42]
Research cooperation + List 1	−0.11 (−2.12)**	−0.51 (−2.77)***	−0.01 (−0.47) – [−0.06]
List 2 + Tax deduction 80% patent income	0.00 (0.02)	−0.28 (−1.88)*	0.10 (0.90) – [0.75]
Combination of subsidy with at least two different tax benefits	−0.06 (−2.75)***	−0.25 (−2.76)***	−0.04 (−1.90)* – [−0.31]*
Combination of more than two tax benefits (no subsidy)	−0.06 (−2.57)***	−0.33 (−3.00)***	−0.02 (−1.22) – [−0.13]
Number of observations	5634	5634	2115
R-squared (within)	0.13	0.52	

Note: The table shows the results of an estimation of specification (1). The second column shows the results of a fixed effect (within) estimation of a log–log specification (logs of all non-categorical variables). Four control variables (lag of cash flow, lag of number of employees, lag of capital per employee and firm age), year and industry-year dummies (except in the dynamic panel specification) are included in the estimation but not reported. Also included but not reported are the three Mills variables resulting from prior estimation of a selection model with four possibilities of public support (see text for details). The third column reports results of a panel estimation in which observations have been weighed by the inverse of R & D expenditures (variance appears to be inversely correlated with the level of R & D expenditures). The last column shows the results of a two-step System GMM estimation of a dynamic panel specification with three lags of the dependent variable included (as the panel is unbalanced orthogonal deviations are used to maximize sample size, see Roodman, 2009, p. 104). A two-step GMM estimation is more efficient than a one-step estimation and should not be confounded with the two-step estimation that consists in the multinomial logit estimation of the selection model in the first step and the actual estimation of the impact of public support in a second step, as reported in this table. The long-run coefficients computed from the system GMM estimation are reported in square brackets in the last column. *, ** and *** denotes that the coefficient estimate differs from zero at a statistical significance level of respectively 10%, 5% and 1%. The t-values, shown in round brackets, are robust to heteroscedasticity and serial correlation (clustered by firm) and have been corrected for additional variance due to the inclusion of the Mills variables, generated from the first step estimation, in the second step estimation (following Dumont et al., 2005).

From the selection model, three inverse Mills ratios can be computed which are used in the estimation of specification (1) to account for the selection mechanism in public support. Table 6 reports the results of the estimation of specification (1). Column II shows the results of the estimation of specification (1) including the three Mills variables resulting from the prior estimation of the selection specification. The coefficients of the first and third Mills variable are statistically significant in the second-step estimation. The selection bias thus seems to apply especially to firms that benefit from direct support (only subsidies or in combination with tax benefits), as compared to firms that receive no support. This results indicates the need to account for the selection of firms that receive subsidies, in the evaluation of the impact of public support on business R & D.

Only variables of combinations of two support schemes are shown for which the coefficient is at least statistically significant in one of the three specifications. Given the highly skewed distribution of R & D expenditures, specification (1) is log-log, in effect, all continuous variables are considered in log. Standard errors reported in Table 6 are clustered (by firm) and therefore robust to heteroscedasticity and autocorrelation. This does however not ensure consistency of the coefficient estimates under heteroscedasticity and autocorrelation. Specification tests clearly indicate the presence of heteroscedasticity and autocorrelation in the panel.[9]

In the context of the estimation of gravity models of international trade, Santos Silva and Tenreyro (2006) pointed out the potential bias due to heteroscedasticity in a log–log specification.

They show that the bias may be exacerbated if an arbitrary integer is added to zero values in order to preserve these observations, as is the case in the log–log specification.[10]

For this reason, column III shows the results of a weighed panel estimation. As the variance of residuals is clearly inversely correlated with the level of R & D expenditures, observations are weighed by the inverse of average R & D expenditures.[11]

The autocorrelation that is clearly present in the panel reflects the persistence in R & D expenditures due to sunk costs and learning-by-doing in R & D activities. Following Arqué-Castells (2013), Arqué-Castells and Mohnen (2015) and Huergo et al. (2016), Table 6 also reports the results of the estimation of a dynamic panel specification (including lag(s) of the dependent variable).

Column IV reports the results of a two-step system GMM estimation of a panel with three lags of R & D expenditures included, as Arellano-Bond tests of autocorrelation indicate that at least three lags of R & D expenditures need to be included to ensure that residuals are not serially correlated and that the instruments are

[9] Panel tests clearly reject the null hypothesis of homoscedasticity (xttest3) and no serial correlation (xtserial).

[10] As only firms with reported R & D expenditures are included, given the focus on input additionality of public support to R & D, taking logs does not pose any problem for the dependent variable. However, as firms without support are included as the control group, 1 euro is added to the amount of support received by firms (zero for firms without support).

[11] A panel Generalized Least Squares estimation (STATA procedure xtgls) provides similar results but almost all coefficients are statistically significant in this estimation. Poisson Quasi-Maximum-Likelihood estimation, as Santos Silva and Tenreyro (2006) propose for the estimation of gravity models, does not converge, even when rescaling the continuous variables. In contrast with gravity models there are no zero values for the dependent variable as only firms with reported R & D expenditures are considered. In a linear specification, with all variables expressed in levels, only the positive coefficient for regional subsidies and for the tax benefit for R & D personnel with a list 1 degree and the negative coefficient of the combination of subsidies with at least two different tax benefits is statistically significant (both only at 10%). The coefficients do not appear to be very reliable and residuals diverge substantially from a normal distribution.

Table 7
Bang for the Buck (BFTB) of public support for R & D (2003–2011).

	Fixed effects Static panel	Fixed effects Static panel (Weighted)	System GMM Dynamic panel (Short-run) [Long-run]
Individual support scheme:			
Regional subsidy	0.45	0.93	–
Research cooperation	1.89	–	–
Young Innovative Company	–	–	–
List 1	–	–	(0.23) [2.12]
List 2	1.06	4.34	(0.65) [4.65]
Tax credit R & D	–	–	–
Tax deduction 80% patent income	–	0.18	(0.02) [0.19]
Combination of support schemes:			
Regional subsidy + List 2	–	−7.77	–
Regional subsidy + Tax credit R & D	–	–	(−0.05) [−]
Research cooperation + List 1	−1.57	−8.61	–
List 2 + Tax deduction 80% patent income	–	−47.82	–
Subsidy with at least two different tax benefits	−0.11	−0.43	(−0.09) [−0.72]
More than two tax benefits (no subsidy)	−0.07	−0.40	–

Note: The table shows the Bang for the Buck (BFTB), an estimate of how much additional R & D expenditures result from one euro in foregone tax receipts due to public support received by companies. The BFTB is calculated at the mean of net R & D expenditures and support for non-missing observations in the given specification. Only estimates of elasticity (from Table 6) that are statistically significant (at least at 10%) are considered. In the last column the BFTB based on the short-run estimates from the system GMM estimation are reported in round brackets, the BFTB computed with the derived long-run coefficients are reported in square brackets.

valid.[12] The long-run coefficients of the public support variables, which can be derived from the system GMM estimation (see, for example Bun and Sarafidis 2015) are reported in square brackets in the last column.

All three specifications in Table 6 provide robust indications of the effectiveness of the partial exemption from advance payment of the withholding tax for researchers with a master's degree (List 2). The statistical significance of the positive coefficient for regional subsidies and the partial exemption from advance payment of the withholding tax is not confirmed in the dynamic panel specification. The significantly positive coefficient for the partial exemption from advance payment of the withholding tax for researchers with a List 1 degree in the static panel is confirmed in the dynamic panel but not in the weighed estimation. The long-run coefficients of the dynamic panel estimation exceed the short-run coefficients. The long-run coefficient for the combination of regional subsidies and the R & D tax credit is not statistically significant whereas the short-run coefficient is, although only at the 10% significance level.[13]

Due to the required inclusion of three lags of R & D expenditures in the dynamic panel specification, the number of observations drops substantially, from 5346 in the static panel to 2115 i.s.o. 1944 in the dynamic panel. This is explained by the relatively small number of firms with consecutive responses to the R & D survey, as clearly reflected in the time pattern of available observations reported in Table 3. Only firms that report R & D expenditures in consecutive biennial R & D surveys will be included in the dynamic panel. Comparing the average of variables for the group of firms that are included in the static panel but not in the dynamic panel to the average for firms that are included in both panels reveals statistically significant and very substantial differences.[14] Firms included in both panels are on average much larger than firms that are only included in the static panel. The first group of firms on average spend 5.9 million euro on R & D whereas the latter group only spend 1.7 million on R & D. The statistical significance and the magnitude of the lags of R & D expenditures clearly confirm the persistence in R & D activities and calls into question the conditional independence assumption of estimation procedures that fail to account for past R & D activities. However, the difference in results between the static and the dynamic panel specification seem to be not only explained by the acknowledgement of the persistence of R & D activities but also by differences between firms that consistently respond to the R & D survey and firms that only respond occasionally. The differences seem to hint at the possible distinctive impact of public support on the intensive margin (R & D active firms extending their R & D activities) and on the extensive margin (non-R & D active firms that start performing R & D) and the possible different impact between firms that perform R & D on a permanent basis and firms that perform R & D occasionally. Unfortunately, the data at hand do not enable a reliable assessment of these distinctions.

Most coefficients of the variables reflecting the additional impact of public support when firms benefit from two support schemes are negative but the statistical significance is not very robust over the three different specifications. The only coefficient that is robust across all three specifications is the negative coefficient for firms that combine a subsidy with at least two different tax benefits.

Input additionality of public support for R & D is often measured by the Bang for the Buck (BFTB), which denotes by how much private R & D increases per monetary unit (for example, 1 euro) of tax receipts foregone through public support (see, for example, Hægeland and Møen, 2007b; Lokshin and Mohnen, 2007; Ientile and Mairesse, 2009). To provide a quantitative indication of the extent to which the individual support schemes and the combination of different support measures affects business R & D, Table 7 shows the BFTB based on the estimates in Table 6.

The BFTB is only computed for the coefficients that are statistically significant, using the average of R & D expenditures and the average amount of public support. As R & D expenditures are considered net of public support, the reported BFTB are net measures. For example, the

[12] The STATA procedure xtabond2 which is used for the estimation of the dynamic panel specification reports tests of autocorrelation and test of the validity of instruments (instruments uncorrelated with errors). Roodman (2009) provides more details on the xtabond2 procedure. For the Sargan test of over-identifying restrictions the null hypothesis that the instruments are uncorrelated with errors is rejected but this test is not robust. For all other tests the null hypothesis of valid instruments is not rejected. Tests indicate autocorrelation of order 1, as expected in system GMM, but no autocorrelation of higher order. One-step estimation (results not reported but available upon request) provide similar results. There are 412 instruments in the GMM estimation. Using the command "collapse" to reduce the number of instruments results in the rejection of most null hypotheses of instrument validity.

[13] The long-run coefficients, which are non-linear combinations of estimates, are computed using the nlcom command in STATA. Statistical significance of short-run coefficients therefore does not imply statistical significance of long-run coefficients.

[14] Applying a *t*-test to the mean of the group of firms that are only included in the static panel and the mean of the group of firms that are included in both panels, allowing for unequal variance between the two groups.

BFTB of 0.45 for regional subsidies in the fixed effects static panel estimation indicates that a 1 euro subsidy results in 1.45 euro additional R & D expenditures or 0.45 euro additional R & D, net of the 1 euro public support.

Most computed BFTB estimates fall within the range reported in previous studies, except for some estimates from the weighted fixed effects estimation. Especially for the variables reflecting the combination of support measures, the BFTB is too high to be credible. This casts some doubt on the reliability of the weighted estimation results. The results suggest that, at least for those individual support measures for which input additionality is statistically significant, the combination of different measures reduces the positive impact of public support but only to some extent. Even when accounting for the negative impact of the combination of support measures, the BFTB of individual support measures remains positive. The most robust result is the decrease in BFTB when firms combine direct support with tax benefits.

6. Summary and conclusions

There is a broad consensus on the importance of business R & D for innovation, technological progress and economic growth and public support is generally considered as necessary to optimize the level of private R & D activities. Consequently, public support to business R & D increased in most OECD countries over the past decade. Countries however differ substantially in the extent of public support as well as in their mix of support measures.

Recent review studies point at the effectiveness of individual measures of public support to business R & D but the impact appears to be limited. Although most countries provide different support measures (mostly at least direct as well as indirect support), surprisingly few studies investigate the effectiveness of the combination of different measures. Estimates of the impact of a single policy instrument may be biased when other instruments are not considered in the estimation. The availability of different support measures also raises the question whether the combination of measures increases or decreases their effectiveness relative to their single use.

This study considers a panel of R & D active firms in Belgium, over the period 2003–2011, to investigate the policy mix of available R & D support schemes. Following the introduction of several tax benefits − in addition to the substantial direct support provided by regional authorities − Belgium has become the most generous OECD country in terms of public support to business R & D relative to GDP. With regional subsidies as well as several federal tax benefits, Belgium seems an appropriate country to investigate the multi-level policy mix of public support to business R & D. In contrast with most of the small number of previous policy mix studies, this study uses a continuous variable for all support measures, as information on the amount received by individual firms is available. Dimos and Pugh (2016) point out that a binary treatment variable, as used in most studies due to the lack of information on the amount of support, precludes a full assessment of the additionality of support. This may explain the mixed indications − even for the same country − on the effectiveness of the policy mix in previous studies.

Estimates of the impact of public support appear to be sensitive to the econometric specification that is considered, for example whether past R & D expenditures are accounted for (dynamic panel) or not (static panel). In line with previous studies, there is clear evidence of strong persistence in R & D activities which need to be accounted for in the estimation of the effects of public support to R & D.

This study provides robust indications that the combination of different measures decreases the effectiveness of public support in Belgium. This result seems in line with the recent study for France by Marino et al. (2016). If confirmed by other studies, this may go some way to explaining the limited impact of direct as well as indirect support in raising business R & D, as found in recent review studies.

Guellec and van Pottelsberghe de La Potterie (2003) argued that a lack of coordination, between the administrative departments or agencies that provide public support, may explain why direct support and tax incentives appear to be substitutes for a panel of 17 OECD countries. The fact that the most robust evidence of diminished effectiveness of support in Belgium is found for firms that combine direct support with several tax benefits, seems to provide indications of a lack of coordination between the regional and federal authorities. Guellec and van Pottelsberghe de La Potterie (2003) also point out evidence that above a support rate of 20%, additional public support seems to substitute for private funding of R & D. That the results in this paper suggest that the effectiveness of public support in Belgium diminishes for firms that combine several support schemes, could indicate that by combining several incentives, these firms achieve a support rate above the optimum. A qualified answer to this research question, for the Belgian policy context, is however beyond the scope of this paper.

Of the six specific tax benefits for R & D that currently exist in Belgium, robust evidence of effectiveness is only found for the partial exemption from advance payment of the withholding tax on the wages of R & D employees with a master's degree. There are hardly any indications that the two more traditional tax benefits that operate through corporate income taxation (tax credit for R & D investment and tax deduction of 80% of patent income) succeed in stimulating additional business R & D. These results corroborate the conclusion, of a recent assessment of tax incentives for R & D, that tax benefits based on the wages of researchers (as, for example, the partial exemption from advance payment of the withholding tax) can be considered best practice as they are likely to generate higher knowledge spillovers and administration and compliance costs are lower than for other measures of public support (European Commission, 2015: p. 7). Another advantage of wage-based tax benefits over more traditional benefits through corporate income taxation is that R & D intensive firms that do not have any profits (for example biotech start-ups) can also receive tax benefits. This prevents a bias of public support, in favour of incumbents, which may deter the entry of new innovative firms as pointed out by Acemoglu et al. (2013).

Some limitations of this paper however caution for overhasty conclusions. The criterion to assess public support considered in this study is input additionality, in effect, the extent to which public support succeeds in raising R & D efforts of private firms. Potential effects on the R & D behaviour of firms (for example, a shift from development towards riskier research activities) or on the output of R & D activities (innovation or increased efficiency), which rightly receive increasing attention from scholars, is beyond the scope of this paper. Moreover, as the period covered is relatively short, the results are likely more informative of short-term than of long-term effects. Data over a longer period would not only permit to assess the issue of the stationarity of the time series and to distinguish between short-term and long-term effects but also to evaluate possible differences in the impact of public support between firms that raise their R & D efforts and firms that start doing R & D or between firms that perform R & D on a permanent basis and firms with only occasional R & D activities.

Public support is only one of the factors that firms consider in deciding on their medium- and long-term R & D programmes and on the location of their R & D activities. A stable policy framework is known to be of crucial importance in these decisions so changes in public support ought to be well-thought-out. The introduction of different tax benefits may have been instrumental in the relatively strong increase in R & D intensity in Belgium after 2006, even during the Great Recession However, the fact that Belgium has become the most generous OECD country in terms of public support to business R & D and the indications of decreased effectiveness due to the combination of several support schemes seem to suggest that some rebalancing may be warranted between the incentive for companies to apply for public support and the budgetary cost and effectiveness of that support.

Borrás and Edquist (2013) discern three categories of policy instruments: regulatory instruments (for example intellectual property rights and competition policy); economic and financial instruments and soft instruments (for example recommendations or voluntary technical standards). With regard to innovation policy, they list four categories of activities that instruments can target: the provision of knowledge inputs to the innovation process; demand-side activities (for example, creating new product markets); the provision of constituents for innovation systems (for example, creation of innovation networks) and support services for innovating firms (for example, incubator activities). This paper considers a limited mix of policy instruments, namely the different forms of financial public support to business R & D in Belgium. As such the paper only evaluates the extent of complementarity between financial instruments (second category of instruments) that aim at increasing the provision of knowledge inputs (first set of innovation activities). A comprehensive evaluation of the policy mix for innovation clearly requires a more systemic assessment of the complementarity between all existing policy instruments that aim to reinforce the innovativeness of a country. The idiosyncratic characteristics of national and regional innovation systems warn against generalizations based on analysis for a single country.

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References

Acemoglu, D., Akcigit, U., Bloom, N., Kerr, W.R., 2013. Innovation, Reallocation and Growth. NBER Working Paper 18993. National Bureau of Economic Research.
Aghion, P., Askenazy, P., Berman, N., Cette, G., Eymard, L., 2012. Credit constraints and the cyclicality of R & D investment: evidence from France. J. Eur. Econ. Assoc. 10 (5), 1001–1024.
Angrist, J.D., Pischke, J.-S., 2009. Mostly Harmless Econometrics: An Empiricist's Companion. Princeton University Press.
Angrist, J.D., Pischke, J.-S., 2015. Mastering' Metrics: The Path from Cause to Effect. Princeton University Press.
Antonelli, C., Crespi, F., 2013. The matthew effect in R & D public subsidies: the italian evidence. Technol. Forecasting Social Change 80 (8), 1523–1534.
Arqué-Castells, P., Mohnen, P., 2015. Sunk costs, extensive R & D subsidies and permanent inducement effects. J. Ind. Econ. 63 (3), 458–494.
Arqué-Castells, P., 2013. Persistence in R & D performance and its implications for the granting of subsidies. Rev. Ind. Organ. 43 (3), 193–220.
Becker, B., 2013. The Determinants of R & D Investment: A Survey of the Empirical Research. Discussion Paper Series 2013_09. Department of Economics, Loughborough University (revised Sep 2013).
Borrás, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecasting Social Change 80 (8), 1513–1522.
Bun, M.J.G., Sarafidis, V., 2015. Dynamic panel data models. In: Baltagi, B.H. (Ed.), The Oxford Handbook of Panel Data. Oxford University Press, New York N.Y, pp. 76–110.
Busom, I., Corchuelo, B., Martínez-Ros, E., 2015. Dynamics of Firm Participation in R & D Tax Credit and Subsidy Programs, Working Paper 15.03. Department of Applied Economics at Universitat Autonoma of Barcelona.
Busom, I., 2000. An empirical evaluation of the effects of R & D subsidies. Econ. Innov. New Technol. 9 (2), 111–148.
Cantner, U., Kösters, S., 2012. Picking the winner? Empirical evidence on the targeting of R & D subsidies to start-ups. Small Bus. Econ. 39 (4), 921–936.
Castellacci, F., Lie, C., 2015. Do the effects of R & D tax credits vary across industries? A meta- regression analysis. Res. Policy 44 (4), 819–832.
Cerulli, G., 2010. Modelling and measuring the effect of public subsidies on business R & D: a critical review of the econometric literature. Econ. Rec. 86 (274), 421–449.
Clausen, T., 2008. Do Subsidies Have Positive Impacts on R & D and Innovation Activities at the Firm Level? Working Paper on Innovation Studies 20070615, Centre for Technology, Innovation and Culture. University of Oslo.
Czarnitzki, D., Lopes-Bento, C., 2014. Innovation subsidies: does the funding source matter for innovation intensity and performance? Empirical evidence from Germany. Ind. Innov. 21 (5), 380–409.
David, P.A., Hall, B.H., Toole, A.A., 2000. Is public R & D a complement or substitute for private R & D? A review of the econometric evidence. Res. Policy 29 (4-5), 497–529.
Dechezleprêtre, A., Einiö, E., Martin, R., Nguyen, K.-T., Van Reenen, J., 2016. Do Tax Incentives for Research Increase Firm Innovation? An RD Design for R & D. NBER Working Papers 22405. National Bureau of Economic Research.
Dimos, C., Pugh, G., 2016. The effectiveness of R & D subsidies: a meta-regression analysis of the evaluation literature. Res. Policy 45 (4), 797–815.
Dubin, J.A., McFadden, D.L., 1984. An econometric analysis of residential electric appliance holdings and consumption. Econometrica 52 (2), 345–362.
Dumont, M., Rayp, G., Thas, O., Willemé, P., 2005. Correcting standard errors in two-stage estimation procedures with generated regressands. Oxford Bull. Econ. Stat. 67 (3), 421–433.
Einiö, E., 2014. R & D subsidies and company performance: evidence from geographic variation in government funding based on the ERDF population- density rule. Rev. Econ. Stat. 96 (4), 710–728.
European Commission, 2015. A Study on R & D Tax Incentives—Final Report, Taxation Paper No. 52. Directorate General Taxation and Customs Union.
Gaillard-Ladinska, E., Non, M., Straathof, B., 2015. More R & D with Tax Incentives? A Meta-analysis, CPB Discussion Paper 309. CPB Netherlands Bureau for Economic Policy Analysis.
Guellec, D., van Pottelsberghe de La Potterie, B., 2003. The impact of public R & D expenditure on business R & D. Econ. Innov. New Technol. 12 (3), 225–243.
Guerzoni, M., Raiteri, E., 2015. Demand-side vs. supply-side technology policies: hidden treatment and new empirical evidence on the policy mix. Res. Policy 44 (3), 726–747.
Hægeland, T., Møen, J., 2007a. The Relationship Between the Norwegian R & D Tax Credit Scheme and Other Innovation Policy Instruments, Statistics Norway Reports 2007/45.
Hægeland, T., Møen, J., 2007b. Input Additionality in the Norwegian R & D Tax Credit Scheme, Statistics Norway Reports 2007/47.
Heckman, J., Ichimura, H., Smith, J., Todd, P., 1998. Characterizing selection bias using experimental data. Econometrica 66 (5), 1017–1098.
Heckman, J.J., 1979. Sample selection bias as a specification error. Econometrica 47 (1), 153–161.
Henningsen, M., Hægeland, T., Møen, J., 2015. Estimating the additionality of R & D subsidies using proposal evaluation data to control for research intentions. J. Technol. Transf. 40 (2), 227–251.
Huergo, E., Moreno, L., 2014. National or International Public Funding? Subsidies or Loans? Evaluating the Innovation Impact of R & D Support Programmes, MPRA Paper 54218. University Library of Munich, Germany.
Huergo, E., Trenado, M., Ubierna, A., 2016. The impact of public support on firm propensity to engage in R & D: Spanish experience. Technol. Forecasting Social Change 113 (PB), 206–219.
Hussinger, K., 2008. R & D and subsidies at the firm level: an application of parametric and semipara- metric two-step selection models. J. Appl. Econometr. 23 (6), 729–747.
Ientile, D., Mairesse, J., 2009. A policy to boost R & D: Does the R & D tax credit work? EIB Pap. 14 (1), 144–169.
Jaffe, A., 2002. Building programme evaluation into the design of public research-support programmes. Oxford Rev. Econ. Policy 18 (1), 22–34.
Klette, T.J., Møen, J., 2012. R & D investment responses to R & D subsidies: a theoretical analysis and a microeconometric study. World Rev. Scie. Technol. Sustain. Dev. 09 (2/3/4), 169–203.
Klette, T.J., Møen, J., Griliches, Z., 2000. Do subsidies to commercial R & D reduce market failures? Microeconometric evaluation studies. Res. Policy 29, 471–495.
Lichtenberg, F.R., 1984. The relationship between federal contract R & D and company R & D. Am. Econ. Rev. 74 (2), 73–78.
Lokshin, B., Mohnen, P., 2007. Measuring the Effectiveness of R & D Tax Credits in the Netherlands, MERIT Working Paper 025. United Nations University − Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT).
Marino, M., Lhuillery, S., Parrotta, P., Sala, D., 2016. Additionality or crowding-out? An overall evaluation of public R & D subsidy on private R & D expenditure. Res. Policy 45 (9), 1715–1730.
OECD, 2016. OECD Science, Technology and Innovation Outlook 2016. OECD Publishing, Paris. http://dx.doi.org/10.1787/sti_in_outlook-2016-en.
Roodman, D., 2009. How to do xtabond2: An introduction to difference and system GMM in Stata. Stata Journal 9 (1), 86–136.
Santos Silva, J.M.C., Tenreyro, S., 2006. The log of gravity. Rev. Econ. Stat. 88 (4), 641–658.
Takalo, T., Tanayama, T., Toivanen, O., 2013. Estimating the benefits of targeted R & D subsidies. Rev. Econ. Stat. 95 (1), 255–272.
Van Pottelsberghe, B., Nysten, S., Megally, E., 2003. Evaluation of Current Fiscal Incentives for Business R & D in Belgium, Working Paper CEB 03-011. RS, Universite Libre de Bruxelles (ULB).
Wallsten, S., 2000. The effects of government-Industry R & D programs on private R & D: the case of the small business innovation research program. Rand J. Econ. 31 (1), 82–100.
Zúñiga-Vicente, J.A., Alonso-Borrego, C., Forcadell, F.J., Galán, J.I., 2014. Assessing the effect of public subsidies on firm R & D investment: a survey. J. Econ. Surv. 28 (1), 36–67.
da Silva, A.M.N.M., 2014. The determinants of participation in R & D subsidy programmes: evidence from firms and S & T organisations in Portugal. Innovation Economics and Management. Faculdade de Economia da Universidade do Porto (Master Dissertation).
de Blasio, G., Fantino, D., Pellegrini, G., 2015. Evaluating the impact of innovation incentives: evidence from an unexpected shortage of funds. Ind. Corp. Change 24 (6), 1285–1314.