A dose-response evaluation of a regional R&D subsidies policy

DOI: http://doi.org/10.1080/10438599.2020.1792604

Cerulli, G., Corsino, M., Gabriele, R., & Giunta, A. (2022). A dose–response evaluation of a regional R&D subsidies policy. *Economics of Innovation and New Technology*, *31*(3), 173-190.

https://doi.org/10.1080/10438599.2020.1792604

A dose-response evaluation of a regional R&D subsidies policy

This paper evaluates the effects of a regional R&D policy in the Italian province of Trento from 2002 to 2007, an ideal testing ground for the role of local government and the effectiveness of an R&D place-based policy. Exploiting a unique database and using a counterfactual dose-response regression model, we perform an evaluation exercise of policy targets concerning employment, fixed and intangible assets.

We find that two years after the award date, there exists a range of subsidy doses that is effective in stimulating employment and intangible assets growth. Instead, we do not find any additionality of the policy on fixed assets. At longer time span, i.e. four years after the award, the effect on employment growth persists and we do observe a mild effect on labor quality for intermediate grants spending. Moreover, the effect on intangible assets spending growth is also persistent for a similar interval of R&D subsidies amounts. We discuss the impact with respect to the aims of the policy maker, suggesting that policy makers should fine tune the intensity of the subsidy to maximize the overall policy impact.

Keywords: Regional Innovation Policy, Place-Based Public Programs, Ex Post Evaluation, Subsidies, Research and Development, Dose-Response Model

JEL codes: O25, O31, O38, C14

1 Introduction

The governance of R&D policies has changed significantly over the past fifteen years. Apart from the involvement of the European Union (first through the Seventh Framework Program and now the Horizon 2020 agenda), intensive academic and political discussion has increasingly designated the regional government as the most appropriate locus for R&D policy.

The devolution of power to regional governments is justified on several grounds. Institutionally, the 'principle of subsidiarity' established in Europe by the Treaty of Maastricht (1992) gives lower levels of government a major role in devising and administering policies that need to be tailored to the local context.

Theoretically, the literature on Regional Systems of Innovation (Malerba 2002; Edquist 2005) portrays innovation as a set of systemic and spatially bounded processes that can be successfully enacted at sub-national level insofar as they are ‘crucially regulated and enabled by the governance structures in which they are embedded’ (Koschatzky and Kroll 2007: 1116). In a similar vein, an OECD report observes that ‘regions matter’ and calls for transcending the ‘one size fits all’ policy approach usually implemented at national level (OECD 1999). An authoritative call for place-based regional policy is made also in the Barca report (2009), which significantly enriches the category ‘place-based’ to encompass social, institutional and cultural characteristics and the interaction of local stakeholders and policy makers. To be effective, it is argued, policies should be both place-based and people-based (Barca et al. 2012).

This paper evaluates the effectiveness of an R&D place-based policy carried out in the northern Italian province of Trento in the past decade. The analysis concentrates on the role played by differential subsidization, i.e. the “dose” as the amount of funds granted to each project. We aim to go beyond the traditional analyses focusing on average treatment effects of the policy as the latter does not take into consideration that the treatment is not equal for all the firms. In this respect, it is worth noting that while a growing literature has explored the effect of regional policies (Dimos and Pugh 2016; Caloffi et al., 2016; García-Quevedo 2004), only a handful of studies (Marino et al. 2016; Dai and Cheng 2015) have tried to cope with a more fined grained analysis of the effects of regional R&D programs. Therefore, the evidence about the effect of an additional euro on R&D additionality is scant and the quest to expand our understanding of this theme is mounting.

The paper is original in three ways.

First, the autonomous Province of Trento constitutes an ideal testing ground for the role of local government and the effectiveness of an R&D place-based policy, in that it has all the necessary institutional ingredients for being ‘a showcase example of regional governance and policy implementation’ (Koshatzky 2005, 696). Policy makers enjoy broad regional autonomy and have considerable financial resources to design and implement tailored R&D policies, which is a pre-condition for sound regional policy (Cooke et al., 2000; Cooke and Memedovic 2003; Todtling and Tripple 2005).

Second, the provincial policy evaluated here was the subject of a substantial financial commitment: average yearly funding of €22.7 millions equal to 33% of total expenses in subsidies in the period 2002-2007 is a high percentage considering that at national level the percentage is around 17.7% (MET 2009). Nevertheless, to the best of our knowledge, no systematic assessment has been so far carried out of the effectiveness of R&D grants to firms operating in the region.

Third, our econometric approach permits a thorough evaluation of the policy's effectiveness via a counterfactual dose-response approach, allowing to determine if and to what extent each additional euro of R&D subsidy bears an effect on the firm's investment decision.

Such approach enables us to address the issue of the effect of different doses of euros spent in subsidies by the policy maker. Indeed, knowledge about the amount of money granted with subsidies together with the information about employment figures, labor costs, fixed assets and intangible assets spending, allow us to investigate if and how one additional euros of subsidy expenses increases the magnitude of the effect, thus going beyond the traditional exploration of potential crowding-out phenomenon (González, and Pazó 2008).

Exploiting a unique database that covers the population of companies that received at least one R&D grant between 2002 and 2007, we rely on the dose-response treatment model proposed by Cerulli (2015), which builds on the regression adjustment model of Wooldridge (2010). Our model exploits data on the intensity of R&D grants to investigate the effect of increasing the R&D subsidy. The model compares each level of the treatment – calibrated by the amount of euros of the R&D grant – with the performance of non-treated firms. Hence, the reliability of the estimation depends on the comparability of the subsamples of treated and control firms: the higher the similarity between the two groups, the higher the precision of the estimation.

The local nature of the program (only firms that are located and carry out the investment in the province of Trento were eligible) significantly reduces the degree of heterogeneity. Thus, by focusing on a single province, our approach:

i) ensures greater similarity between treatment and control firms than is typically found in comparisons carried out at national level;
ii) reduces the heterogeneity that could undermine the robustness of counterfactual methods;
iii) neutralizes the potential confounding effects of multiple subsidies from different sources, by restricting the analysis to firms that received only R&D and no other subsidies.

Going to our results: we find that two years after the award date, there exists a range of subsidy doses that is effective in stimulating employment and intangible assets growth. Instead, we do not find any additionality of the policy on fixed assets. At longer time span –i.e. 4 year after– the effect on employment growth persists and we do observe a mild effect on labor quality for intermediate grants spending. Moreover, the effect on intangible assets spending growth is also persistent for a similar interval of R&D subsidies amounts.

The paper is organized as follows. Section 2 reviews the literature as background to our empirical evaluation; Section 3 describes the relevant legislation, Trento Provincial Law 6/1999. Section 4 details the estimation method, and Section 5 presents the data and the variables. The econometric results are presented in Section 6; Section 7 concludes and outlines some policy implications together with the agenda for future research.

2 The literature

From a theoretical point of view, the economic rationale for R&D subsidies lies on market failures ground (Nelson 1959; Arrow 1962). Such failures are due to the public good nature of knowledge that does not allow firms to fully appropriate the returns of R&D activity. It follows that private R&D investments are below the optimal social level. Another rationale for R&D subsidies is related to the presence of capital market imperfections that make costly for firms, especially new ventures and small ones, to secure the financing needed to support innovative endeavors.

The empirical literature relevant as background to our analysis is divided into two streams: one deals with the regionalization of R&D policy and the second concerns the impact evaluation of R&D subsidies.

Throughout Europe the role of regions in designing, implementing and evaluating innovation policies, especially those targeted to SMEs (small and medium size enterprises), increased enormously in importance after the turn of the century (European Commission 2004). This reflected recognition of the systemic nature of innovation, initially advanced by the 'National System of Innovation' school in the 1990's (Malerba 2002; Edquist 2005). Subsequently, increasing interest in Regional Systems of Innovation gained ground, providing a strong rationale for sub-national policy measures in this field.[1] Ribas (2009) emphasizes two factors that justify departure from national policy guidance: 'systemness', whereby regional and local governments may have a better grasp of the formal and informal institutions that shape behavioral patterns and social interactions in the territory; and heterogeneity, which signals that local governments may have better knowledge of local agents and the socio-economic structure, and hence superior capacity to tailor policy to conditions on the ground. This deeper knowledge of potential awardees and the specific local context should enable the

[1] The literature on Regional Systems of Innovation is vast. For a review of its origins, see Cooke, 1998, 2001. See also Fritsch and Stephan, 2005, and the special issue of *Research Policy* dedicated to the regionalization of innovation policy. On the distortion that might be caused by the capture of local policy makers by interest groups, see Lerner (2002).

host region to retain a share of the social benefit arising out of the projects funded (Roper et al., 2004) and so to select the marginal projects that are most likely to generate knowledge spillovers (Feldman and Kelley 2006).

As it is emphasized by Bronzini and Piselli (2009, 188), the application of the regional lens is not merely a change of geographical scale. 'By testing if regional R&D is important to explain regional growth, it is implicitly assuming that technological knowledge has a localized scope'. Indeed, several of the arguments for a regional role in formulating and implementing R&D policies relate to the importance of geographical proximity and its nexus with innovation (Audretsch and Feldman 1996): knowledge spillovers are often spatially bounded (Bottazzi and Peri 2003); the spread of tacit knowledge is facilitated by face-to-face contacts (Storper 1997; Morgan 2004); getting partners to work together requires a degree of common identity (Lundvall 1992; Braczyk, Cooke and Heidenreich 1998); innovation activities are frequently conducted in industrial clusters, by means of collaboration between firms and academic institutions, or through trust-based networks, all of which are highly region-specific (Paci and Usai 2000). This wide-angle background has shaped policy making, becoming the main toolkit in designing R&D policy in a variety of regional contexts (OECD 2010).

As for the effectiveness of public subsidies on private R&D spending, the number of scientific contributions has been growing in the last decades thanks to the development and refinement of methods for program evaluation in econometrics (Imbens and Wooldridge 2009; Imbens and Rubin 2015). This strand of research (David, Hall and Toole 2000; Garcia-Quevedo 2004; Caloffi et al., 2016; Dimos and Pugh 2016) seeks to determine whether subsidies prompt additional firms' investments in R&D, or they only substitute for investments that firms would have made anyway (infra-marginal projects).

As highlighted by some recent surveys (Zúñiga-Vicente et al. 2014), the bulk of the empirical evidence favors the thesis that public support does not crowd out private R&D

investment (Almus and Czarnitzki 2003; Hyytinen and Toivanen 2005; Czarnitzki and Toole 2007; Czarnitzki et al., 2007; Hussinger 2008; Aerts and Schmidt 2008; Bellucci et al. 2018; Vanino et al., 2019). Other scholars have instead found contrasting results (Busom 2000; Lach 2002; Duguet 2004; González Jaumandreu and Pazó 2005; Görg and Strobl 2007; Potì and Cerulli 2010; Bronzini and Iachin, 2014; Aristei et al., 2016; Mariani and Mealli 2018).

Within this stream of literature, it is worth noticing that only two studies have sought to determine whether different amounts of subsidy produce differential impacts on private R&D investment, and by what mechanisms. Marino et al. (2016) examine the effect of R&D subsidies on a sample of French firms during the period 1993-2009, finding evidence of crowding-out, i.e. substitution effects, by public R&D provision, for doses below €10 million, and additionality effects for larger doses. Furthermore, the authors find that significant substitution of public for private R&D resources is more likely among low and medium-sized classes (€20,000 to €55,000) for subsidy-only recipients, and among medium-sized and high classes (€145,000 to €1.8 million) for companies that are 'fully supported', i.e. via both grants and tax credits.

Dai and Cheng (2015), on a sample of Chinese manufacturing companies in 2005-2007, find a saturation point beyond which a further increment in public subsidies does not increase the firm's total R&D investment. In addition, they find that there is a minimum threshold value of public subsidies for inducing private R&D spending by a firm.

3 The context of analysis: Province of Trento and Provincial Law 6/1999

Trento is an Alpine province in the Northeast of Italy with nearly 500,000 inhabitants and gross domestic product per inhabitant of €30,400 in 2007, making it one of the 50 richest NUTS2 regions in Europe. A distinguishing feature of the institutional setting is that firms operating in the province of Trento can apply only for subsidies awarded by the local government[2].

The local financial commitment to R&D has been indeed very strong by comparison with other Italian regions: in 2007 the share of R&D subsidies in overall financial subsidies was 33.1%, against a national average 17.7% (MET, 2009). Nevertheless, a review of science and technology indicators (Eurostat 2009) of the EU-27 reveals some weaknesses that might well be redressed by policy intervention. These indicators show that total R&D expenditure amounted to 1.11% of provincial GDP in 2005, higher than the Italian average of 0.89% but below the EU-27 average of 1.28% and significantly short of the target – 3% –set in the Lisbon strategy for the EU as a whole. Similarly, the percentage of researchers in total employment was 0.65%, better than the average of Italian regions (0.5%) but worse than the EU-27 average (0.9%).

Provincial Law 6/1999 (PL6/1999) lays down the guidelines for grants to firms operating in the province. The objectives of the law are quite broadly stated: for example, the R&D policy, the PL6/1999, is meant to support the "quality" of local firms and investments, stimulate and sustain the growth of local economic activities (Capo 1 Art.1, PL6/99). In line with the Oslo Manual (OECD, 2005), PL6/1999 identifies two types of commercial research activities eligible for funding: industrial research and experimental development.

All firms operating in the province of Trento can apply for grants within the PL6/1999 framework, by submitting a project to the local authority. There is no deadline for presenting a project within any given calendar year, but since funds are allocated on a first-in-first-out basis (provided that a panel of experts issues a positive assessment on the project), some firms'

[2] In this section, we take into consideration data referred to the period under our scrutiny.

research projects may be refused once the year's budget for R&D funding is exhausted.[3] When a firm applies, its research project is examined and evaluated by a technical committee. If the project is judged acceptable, its economic viability and financial sustainability are then examined in a second stage. Only projects that are positively assessed at both stages are eligible for funding.

Firms can apply for co-financing of projects of different amounts, ranging from €25,000 to €3 million. Projects can entail spending during a period stretching for three years from the date of the grant. The expenditures fall into four categories: (1) employment costs; (2) patenting costs and contractual costs of license acquisition; (3) general additional costs related to the project (overhead up to 60% of costs declared under point 1); (4) costs related to the use of tools and machines for the project.

When a firm is awarded a grant, it must satisfy two further conditions for funding: (a) the results of the research have to be used/exploited in the province of Trento; and (b) for subsidies greater than € 500,000, or when the firm applies for additional funding beyond the original amount, a certain level of employment declared in the projects must be guaranteed for at least three years after the award date. If this latter condition is not met, the grant can be recalled for the full amount or else for a percentage based on the extent of the employment shortfall. Note that the employment constraint requested by the Trento Province makes this policy measure quite hybrid. To put it another way, the program cannot be considered a "true" R&D policy program. This have also implications in terms of the choice of objective variables chosen to investigate the "success" of the law (see below).

Firms started to apply for subsidies since 2001. At the beginning local firms were quite cautionary in applying for the law in the period under scrutiny (2002-2007) due to a number of

[3] This never actually happened during the period examined here (2002-2007): the take-up rate was low, although rising over time.

reasons: the uncertainty about the "new" procedure to get money and the rules to obey after having received the money (i.e. there was no experience of other firms to look at to have a better grasp of the procedure); the complexity of the procedure (firm had to prepare a report with technical and financial specification of the project); the need to avoid possible spillover of knowledge toward competitors (firms were afraid that supplying full disclosure of research projects to the financial and technical committees could let, even unintentionally, spillover some information to competitors).

4 The econometric model

We design our analysis to evaluate the impact of the intensity of R&D grants on several policy objective variables measured at the firm level. For this purpose, we set out by considering a continuous treatment (or dose-response) approach, as we observe firms receiving different amounts of R&D funding. In this way, we overcome the limitation of relying on just a binary (treated vs. untreated) treatment variable. Our reference model is the one proposed by Cerulli (2015), extending the regression–adjustment approach proposed in Wooldridge (2010) to a continuous treatment setting. This model is an alternative to the generalized propensity score of Hirano and Imbens (2004), as it can deal with situations in which also untreated units (units that did not received the subsidy) are available. Below a short account of the model.

The starting point is Rubin's potential outcome equation (Rubin 1977):

$$y_i = y_{0i} + w_i (y_{1i} - y_{0i}) \tag{1}$$

where y_{0i} denotes the potential outcome for firm i when it is not included in the treatment; y_{1i} denotes the potential outcome of unit *i* when it is treated; w_i is the dummy variable indicating the treatment status.

Substituting the proper expressions for potential outcomes, we can get the following baseline random-coefficient regression (Wooldridge 1997, 2003):

$$yi = \mu_0 + wi \text{ ATE} + \mathbf{x}i\delta_0 + wi\,(\mathbf{x}i - \mathbf{x})\delta + wi \cdot (h(li) - \bar{h})\eta i \tag{2}$$

where: $\eta_i = e_{0i} + w_i \cdot (e_{1i} - e_{0i})$; ATE is the unconditional average treatment effect; x_i is a set of control variables; $h(l_i)$ is the response function of y_i to the level of treatment l_i (equal to zero when $w_i=0$); μ_0, δ, and δ_0 are parameters; and the "bar" indicates average values.

For consistent estimation of the causal parameters, we need to make the usual additional assumption of unconfoundedness (Wooldridge 2010). Under this assumption, it can be proved that Ordinary Least Squares (OLS) provide consistent estimation of all the parameters of interest in (2). We can estimate ATE (Average Treatment Effect) directly from this regression, as well as ATET (Average Treatment Effect on Treated) and ATENT (Average Treatment Effect on Not Treated) indirectly. To complete parameters' identification we assume a parametric form of the dose-response function h(l):

$$h(l_i) = a \cdot l_i + b \cdot l_i^2 + c \cdot l_i^3 \tag{3}$$

where a, b, and c are parameters to be estimated in regression (2).

Once regression (2) is estimated, we can calculate the dose-response function as:

$$\widehat{\text{ATE}}(l_i) = w\left[\widehat{ATET(l_i)}_{l>0} + \hat{a}\left(l_i - \sum_{i=1}^{N} l_i\right) + \hat{b}\left(l_i^2 - \sum_{i=1}^{N} l_i^2\right) + \hat{c}\left(l_i^3 - \sum_{i=1}^{N} l_i^3\right)\right] +$$

$$+(1-w)\widehat{ATENT}(l_i) \tag{4}$$

Where $\widehat{ATE}(l_i) = \widehat{ATET}(l_i)\ for\ l_i > 0$.

Plotting the $\widehat{ATET}(l_i)_{l_i > 0}$ as a function of l_i allows for investigating the pattern of the average treatment effect over all the support of the treatment intensity. Furthermore, for every dose level (amount of funding for R&D investment granted to the firm), we can calculate the confidence interval around the dose-response function as:

$$\hat{\sigma}_{ATET(l_i)} = \left\{L_1^2\hat{\sigma}_{\hat{a}}^2 + L_1^2\hat{\sigma}_{\hat{b}}^2 + L_1^2\hat{\sigma}_{\hat{c}}^2 + 2\hat{\sigma}_{\hat{a},\hat{b}}^2 L_1 L_2 + 2\hat{\sigma}_{\hat{a},\hat{c}}^2 L_1 L_3 + 2\hat{\sigma}_{\hat{c},\hat{b}}^2 L_2 L_3\right\}^{1/2} \quad (5)$$

where, $L_1 = l - \mathrm{E}(\mathrm{l})$, $L_2 = l^2 - \mathrm{E}^2(l^2)$ and $L_3 = l^3 - \mathrm{E}^3(l^3)$. Therefore, the α-confidence interval for $\widehat{\mathrm{ATET}}(l_i)_{l>0}$ is:

$$\widehat{\mathrm{ATET}}(l_i) \mp Z_{\alpha/2}\hat{\sigma}_{\widehat{ATET}(l)} \quad (6)$$

This quantity can be used to check the significance of the effect of treatment as the dose varies.

In the empirical analysis, we propose a series of linear regression models based on Equation (2). In each model, the objective variable is chosen to capture a possible impact of the policy. We investigate the impacts of subsidies on:

i) employment, specifically on the rate of employment growth and average labor cost growth. The latter is regarded as a proxy of human capital, assuming that labor cost growth signals more skilled workers;

ii) rate of growth of both intangible and fixed assets investment of firm[4].

The different treatment doses are measured by a continuous treatment variable, the amount of euros granted as a subsidy to firm[5].

---

[4] All the objective variables are considered in terms of rate of growth to avoid "sheer size effect".

[5] One of the potential problems of considering the level of subsidy instead of subsidy percentage is related with possible scale effects. A potential solution to the problem could have been the inclusion of the "project size" as additional regressor. Nonetheless, it turns out that this variable was highly correlated with the size of firm and consequently cannot be both included in the regression models. Moreover, the inclusion of such variables on the right term side of regressions would imply that, for all the non-subsidized firms, the size of projects is set to zero and this could add noise to our estimations. Hence, we decided: i) to use the level of the subsidy as continuous treatment variable and to leave to the size of firms the role of correcting for the scale of the projects in the regressions; ii) to leave out the "project size".

Figure 1 shows the timeline for the variables used in implementing model (2). Denoting the treatment year (the year of the grant) as *t*, and the time window of validity of the employment constraint as *[t, t+3]*, we carry out two sets of evaluations. First, we analyze the dose-response function by considering the objective variables at time *t+2*, when the employment constraint is binding for those treated firms with a project beyond the threshold of €500,000 (i.e., 43 units out of 78 treated firms), and then taking the objective variables at *t+4*, after the expiration of the constraint, namely when these firms are free from such employment constraint and free to adjust their employment level as desired.

The model is implemented in the following way:

- The treatment group consists of firms that were awarded a public grant to co-finance an R&D project in any year in the period 2002-2007;
- The year of treatment is defined as that in which the firm received notification of the grant from the local government;
- Treatment intensity is the size of the grant in euros;
- The eligible control group consists of firms that did not receive any grant during the time window under scrutiny. Note that, given that the Province of Trento is the only possible source of funds for the group of firms under scrutiny, there is no bias due to policy overlapping; in other words, our firms cannot also be 'treated' by another law at a different level of government;
- Finally, we employ a pre-filtering procedure à la Ho et al. (2007), including in the eligible control group those firms that are active in the 5-digit Ateco 2002 sectors where we find at least one treated firm.

[insert Figure 1 around here.]

5 The data and the variables

5.1 The data

Local government administrative archives are our primary source of data on firms receiving R&D grants and firms receiving all types of grant.

The treatment group of firms is composed by those firms that, in the time window under scrutiny, received a grant specifically referring to Chapter n.5 of Provincial Law 6/99 that regulates the concession of R&D grants. In the years 2002-2007 under analysis, less than 100 firms applied for this particular kind of subsidy. The number of the treated firms used in the paper is 78 given that we operated a further selection in building the treatment group to ensure comparability with the group of control firms and exclude particular and 7 unique cases, i.e. companies that followed a slightly different procedure for reasons not related to economic context (e.g. they started a negotiation with Province of Trento on terms of the concession of the grant). Moreover, in some cases –less than 10– the subsidy was recalled because the firms that benefited from it did not obey to some of the regulations imposed by the law. For instance, they did not respect the employment constraint or they *de facto* moved the activity of the firm out of the province of Trento.

Once collected data about the subsidies for the treatment group, we also added accounting data retrieved from Bureau van Dijk's AIDA database and the Cerved Group's Pitagora database. We also drew data on firms' employees from Archivio Statistico delle Imprese Attive (ASIA), constructed and managed by ISTAT, the Italian National Statistical Institute. Then, we matched the treatment group with a control group of firms with similar observable characteristics, i.e. operate in the same sector at 5-digit Ateco level, have similar size and age. We excluded from the control group all the firms that received, in one of the years analyzed, other types of grants in order to avoid confounding effects. The final database comprises 78 subsidized firms and 2,107 untreated companies over the period 1998-2008[6].

The number of treated firms is limited but we should consider two methodological aspects: first, having a smaller number of treated compared to the number of untreated units is generally preferred compared to the opposite case (more treated than untreated units). Indeed, the main worry should be to build a soundly counterfactual sample and, in our estimation, we exploit the vast range of possibilities in choosing control firms.

Second, what really matters in interpreting the dose response model results are the confidence intervals and their significance along the dose values. In fact, the dose-response thus estimated uses interpolation as it is based on a 3-degree polynomial. Fitting a polynomial is a global estimation procedure. So that the values in sparse regions can be "filled-in" using the abundance of data in other part of the scatter cloud. This allows us to have acceptable results also in zones of the cloud characterized by fewer observations, which is probably our case in some zones.

5.2 The variables

The regression model (2) includes both a dummy variable (w) indicating the treatment –i.e. the concession of a R&D grant–, and a continuous variable representing the treatment intensity (*l*) as measured by the amount of money granted to the firm to co-finance its investment.

The decision about the objective variables to analyze was guided by the need to reconduct our results to literature streams about different kind of additionality. Hence, we

---

[6] The overall number of firms in Province of Trento in the time window under scrutiny was around 50,000. The number reduces to 10,000 excluding micro firms with less than 10 employees.

decided to break down the R&D policy aims of Trento Provincial Law 6/1999 into two sets of target variables related, respectively, with input additionality and quasi-output additionality. To investigate input additionality, we use:

the rate of growth of expenditure on tangible and fixed assets (*FA*);

the rate of growth of expenditure on intangible assets (*IA*)[7].

As measures of quasi-output additionality, we refer to:

the rate of growth of unit labor costs (*ULC*), namely the ratio of net labor costs to total number of employees, a proxy of the level of skill and/or labor quality;

the employment growth rate (*Growth*) that is also recalled in the law as one of the policy aims[8].

To construct our set of control variables, we first consider all factors that can be presumed to influence the participation decision and the outcome variables; in this way, we seek to satisfy the assumption of ignorable treatment assignment. The selection of factors is guided by economic theory, previous empirical findings, and information on the institutional setting (Rubin and Thomas 1996; Heckman et al., 1998; Glazerman et al., 2003; Caliendo and Kopeinig 2008; Stuart 2010).

Second, only variables that are not affected by participation in the treatment should be included in the model (Caliendo and Kopeinig 2008). In order to satisfy this condition, all time-variant control variables are lagged by one period (*t-1*) with respect to the year of treatment (t), thus making them predetermined vis-à-vis the treatment. As a result, the control variables – x exogenous confounders in model (2) –are all lagged by one year.

[7] See Bronzini and Piselli (2016) for a discussion of these two measures used as objective variables.
[8] Note that we do not have the opportunity to identify R&D employees. Hence, we have only indirect evidence of possible behavioral additionality as investigated in Afcha and García-Quevedo (2016). Moreover, if we consider the R&D and innovation policy evaluation literature, outcome additionality refers to the output of the R&D activity, such as product innovation. In our case, we extend the scope of the concept also to economic outcomes (see, for a similar analysis on economic outcome the paper by Wallsten, 2000). Consequently, we define quasi-output additionality this set of variables to distinguish our results from literature about output additionality. Indeed, in our case we do not have the availability of detailed laobr force employed in R&D that can be properly defined as a measure of output additionality. In a sense, finding a significant effect on overall employment is a prerequisite of having an effect on the subset of R&D workers.

They are:

firm size as measured by the number of employees ($Empl_{t-1}$);

per capita labor costs (ULC_{t-1});

rescaled cash flow ($Cashflow_{t-1}$), i.e. the ratio of cash flow to total sales, as a proxy for financial constraints (Hall et al.; 2016);

capital intensity ($Capint_{t-1}$), i.e. the ratio of fixed assets to total sales;

a control variable (*year*) to control for business cycle effects.

All the monetary variables are deflated by producer price indices.

Table 1 reports descriptive statistics for the variables, separately for treatment and control firms. The number of treated firms is 78; the number of research projects funded ranges from a low of 6 (in 2007) to a high of 20 (in 2006). The size of R&D projects ranges from €52.000 to around 9 million euros. The size of the R&D grants ranges from €26,000 to €3,000,000, with a mean of about €900,000 and a standard deviation of about €922,000. A fourth of the subsidized firms received grants smaller than €250,000 and half of them received a subsidy smaller than €600,000. Only a tenth of the firms received amounts greater than €2.4 million. In percentage terms, subsidies range from 28% to 75% of the overall amount of projects expenses. As it can be seen from Figure 2, the sample distribution[9] of grant intensities is right-skewed (Figure 2).

[insert Table 1 around here.]

[insert Figure 2 around here.]

[9] For year-by-year descriptive statistics, see Table A.1.

6. The impact of the policy

In this section we comment the estimated dose-response functions related to each model that provide information about the effect of an additional dose of treatment (an additional euro spent in subsidy by policy maker) on the outcome variable. Indeed, it should be stressed that there is no direct meaning to the estimated coefficients in the models (Hirano and Imbens 2004). We discuss the results of our econometric investigation by looking at each of the policy target variables, starting with our R&D input variables: employment growth and unit labour cost growth.

Employment growth

We start our analysis from the impact on employment growth rate of firms.

[insert Figure 3 around here.]

The dose-response functions for the models in Figure 3 map the subsidies level – horizontal axis – on conditional response on employment growth – vertical axis. The figures show average conditional effects (*ATET(l)*) – the continuous curve – and a 10% confidence interval of the estimation – the dotted line. Figure 3 shows that the employment effects are non-linear in treatment intensity both when the employment constraint is binding (Figure 3, panel a) and after its expiration (Figure 3, panel b).

In both cases, the relation between the amount of additional employment growth and the subsidy dose is non-linear. It is observed a S-shaped effect, i.e. different sensitivity of the objective variable to the cash-flow injection brought by the public support. In the two-years lag model the effect is increasing up to around 70% of the maximum dose (around €1,500 thousands) but it is significant only in the interval of around 33%-86% of the maximum dose (around €2,300-3,900 thousands). It follows that to achieve an impact on employment growth, policy makers have to co-finance at least 33% of the maximum amount but no more than 86%.

Subsidizing more than 86% of the maximum amount seems, in fact, not to have an additionality effects on employment[10]. Results indicate that "intermediate" doses intensities –compared to the maximum amount granted to firms– spur some effects, while spending too much is not beneficial to get an impact. Similarly, if the subsidy does not reach a given intensity, it will not induce any impact on subsidized firms. Moreover, the inverted u-shape of the dose-response function suggest that there exists an optimal level of subsidy that spurs the biggest effect.

The evaluation of the policy impact on employment growth, after the expiration of the constraint (four-years lag), shows that the award of an R&D grant has a persistent effect. Indeed, the shape of the dose-response curve is similar to the one discussed above for 2-years lag model. The interval of significance of the effect is similar, ranging from 30% to 90% of maximum dose.

Unit labor costs

As for the impact of the policy on the growth of per capita labor costs, it can be appreciated an increasing profile for both models –i.e. two and four years after the subsidy concession. Nonetheless, after 2 years we do not see any significant result (Figure 4, panel a). Instead, in the four years lag model, the range of subsidy intensities for which we find a significant result is from 38% to around 70% of maximum dose (Figure 4, panel b)[11].

[insert Figure 4 around here.]

Fixed assets

The results on fixed assets growth show that during and after the period of validity of the employment constraint, a quite flat S-shaped curves of dose-response emerge. Moreover, the impact is not significant on all the doses both in two- and four-years lag model (Figure 5)[12].

Intangible assets

[10] See Table A.2 for details about regression results.
[11] See Table A.3 for details about regression results.
[12] See Table A.4 for details about regression results.

Figure 6 panel (a) shows that after two years there is an effect on intangible assets growth for doses going from 45% to 85% of maximum dose. In Figure 7 panel (b), we see that such effect persists with a significant interval similar to the previous one: 48-82% of maximum dose. In both models. the inverted u-shape of the dose response function signals, as previously seen it, the existence of a subsidy intensity that maximizes the impact on intangible assets growth.

[insert Figure 5 around here.]

[insert Figure 6 around here.]

Table 2 summarizes the dose-response results by different dose levels. Considering all the results, we get a picture of the existence of a range of effectiveness of the law. Specifically, after 2 years employment growth and intangible asset growth are higher for treated firms in the dose interval going from around 50% to 80% of maximum dose granted. Instead, after 4 years, in the doses interval going from around 40% to 80% of maximum dose granted, the policy has an impact on employment and unit labor costs; while intangible assets growth shows an impact in the interval of doses going from around 50% to 80% of maximum dose granted.

[insert Table 2 around here.]

7 Conclusions and discussion

This paper evaluates the effects of a place-based R&D policy using a counterfactual dose-response regression model. In particular, the empirical inquiry deals with the evaluation of the impact of different intensities of a public R&D subsidy awarded in the Italian province of Trento over the period 2002-2007.

The results show: (a) an effect on employment dynamics, two years after the awarding of the subsidy and only if the subsidy ranges between 40-75% of the maximum amount of subsidy awarded to treated firms. Hence, beyond a certain threshold, larger doses of subsidy do not lead to any additionality. Such effect is persistent after four years;

(b) an effect on unit labor cost after four-years lag with an inverted u-shape profile. Small doses have small not significant effect; increasing the doses, the effect increases until we reach a threshold after which the impact decreases;

(c) no effects on fixed assets, whatever the amount of subsidy granted and the lag considered. Nonetheless, such result can be explained given the "nature" of the policy under scrutiny that does not explicitly mention the intent to foster investment in "new" machines to sustain the research project of firms. In a sense, policy makers seem to assume that the capital endowment of potential pool of recipient firms was already well suited to deal with R&D projects;

(d) an inverted u-shape effect on intangible assets with respect to doses of subsidies. There is an interval of doses intensity that seems to have an impact: subsidizing firms for given amounts has an effect on their investment, i.e. they invest more than non-treated firms in intangible assets (e.g. patents or licenses).

Putting all together the results, the use of subsidies in a given range of intensity –from 50% to 70% of maximum dose– induces some effects, that persist after 4 years. Such firms invested more than non-subsidized firms in employment, labor quality and intangible assets. Interestingly, after the expiration of the employment constraint –4 years lag– the impact on the growth of employees of doses in a specific range of intensity persists, and the unit cost of labor force is significantly higher, signaling that there is not only a scale effect on the employment but also an impact on the quality of human capital employed.

The results of our paper are in line with Marino et al. (2016). Indeed, in both evaluation exercises, it emerges an inverted u-shaped profile for the dose response function. Such results seem to be valuable especially when confronted with the scant literature on the topic (Marino et al. 2016; Dai and Cheng 2015), as they offer the opportunity to gather more evidence in order to better understand the *etiology* of the effect of the policies.

Some policy considerations can be derived. The R&D policy design of Law 6/1999 reveals that the policy maker intended to pursue two goals: stimulating R&D investments and sustaining local employment level. Such aims' mix produces an interesting outcome of the policy. Indeed, the employment constraints forces firms to keep the employment level for a given period after the concession of a R&D grant; yet, its effects persist when it expires. Moreover, our results on higher unit labor costs growth reveal that subsidized firms permanently alter their labor force composition towards workers of higher quality, a good achievement of the policy as human capital is a key determinant of firms' productivity and its competitive advantage. However, such "high quality labor" effect is not accompanied by changes in the firms' fixed assets capital endowment growth, but only by the growth of intangible assets.

Some corollary observations can be made to guide future evaluation exercises and ease the understanding of the policy effects.

First, it is advisable to look at disaggregated R&D expenses to disentangle the structure of the R&D investment additionality generated by different doses of subsidies.

Second, calibrating in the right way the subsidies can help in maximizing the effect per dose, in other words: it is crucial to rightly choose the projects that deserve more money.

In a sense, our results can be directly interpreted by the policy maker as the result of the euros spent on each project and can lead to the revision of the percentage of subsidization, in order to achieve the highest efficacy of the policy per euro spent.

Accordingly, the technique proposed in this paper could also function as a theoretical framework that suggests qualitative relationships between doses of subsidies and impacts on objective variables and provide some raw quantitative measures of the effects. A better understanding of the policy mechanisms could be used to modify the policy design to achieve larger effects by calibrating the different doses administered. Phrased differently, this means seeking to improve policy makers' ability to go more in depth in the evaluation of potential recipients and different projects to be able to better allocate the available amount of funds and to maximize additionality effects.

While we reach an overall positive evaluation of the effectiveness of Provincial Law 6/1999, we are also aware that several theoretical issues remain to be dealt to carry out a comprehensive investigation of this policy. First, complementarities between the acquisition of knowledge and organizational change deserve further inquiry. Second, localized spillovers may arise as an indirect effect of the regional policy. For example, some scholars (such as Roper et al., 2004) stress the importance of the nature of the R&D project and the surrounding innovation system as two major forces that make it more likely for the host region to appropriate the benefits of private R&D activities. These analyses are beyond the scope of the present paper, they can be the inspiration for future research on the topic.

References

Aerts, K., & Schmidt T. (2008). Two for the price of one?: Additionality effects of R&D subsidies: A comparison between Flanders and Germany. *Research Policy*, 37 (5), 806-822.

Afcha, S., & García-Quevedo, J. (2016). The impact of R&D subsidies on R&D employment composition. *Industrial and Corporate Change*, 25(6), 955-975.

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

Aristei, D., Sterlacchini, A., & Venturini, F. (2016). Effectiveness of R&D subsidies during the crisis: firm-level evidence across EU countries. *Economics of Innovation and New Technology*, 1-20.

Arrow, K.J. (1962) The economic implications of learning by doing, *The Review of Economic Studies*, 29(3): 155-173.

Audretsch, D., & Feldman M. (1996). Innovative clusters and the industry life cycle. *Review of Industrial Organisation* 11, 253–273.

Barca F. (2009). *An agenda for a reformed cohesion policy: A place-based approach to meeting European Union challenges and expectations*, Independent Report, Prepared at the Request of the European Commissioner for Regional Policy, Danuta Hubner, European Commission, Brussels.

Barca F., McCann P., & Rodriguez-Pose A. (2012). The case for regional development intervention: Place-Based versus place-neutral approaches. *Journal of Regional Science*, 52(1), 134–152.

Bellucci A., Pennacchio L., Zazzaro A. (2018). Public R&D subsidies: collaborative versus individual place-based programs for SMEs, *Small Business Economics*, https://doi.org/10.1007/s11187-018-0017-5

Bottazzi, L., & Peri, G. (2003). Innovation and Spillovers in Regions: Evidence from European patent Data. *European Economic Review*, 47, 687–710.

Braczyk H.-J., Cooke P., & Heidenreich, M. (1998). (Eds.), *Regional innovation systems*. UCL Press: London.

Bronzini, R., & Iachini, E. (2014). Are incentives for R&D effective? Evidence from a regression discontinuity approach. *American Economic Journal: Economic Policy*, 6(4), 100-134.

Bronzini R., & Piselli P. (2009). Determinants of long-run regional productivity with geographical spillovers: The role of R&D, human capital and public infrastructure. *Regional Science and Urban Economics* 39, 187–199.

Bronzini, R., & Piselli, P. (2016). The impact of R&D subsidies on firm innovation. *Research Policy*, 45(2), 442-457.

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

Caliendo, M., & Kopeinig, S. (2008) Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, 22(1), 31-72

Caloffi A., Mariani M., & Sterlacchini A. (2016) Evaluating public supports to the investment activities of business firms: a meta-regression analysis of Italian studies. *CREI Working Paper* No.1/2016

Cerulli, G. (2015), ctreatreg: Command for fitting dose–response models under exogenous and endogenous treatment, *Stata Journal*, 15, issue 4, p. 1019-1045,

Cooke P., Boekholt P., & Todtling, F. (2000). *The governance of innovation in Europe*. Pinter: London.

Cooke, P., & Memedovic, O. (2003). Strategies for regional innovation systems: Learning ransfer and applications. *Policy Papers, UNIDO*, Vienna.

Czarnitzki, D., Ebersberger B., & Fier A. (2007). The relationship between R&D collaboration, subsidies and R&D performance: empirical evidence from Finland and Germany. *Journal of Applied Econometrics*, 22, 1347-1366.

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

Dai, X., & Cheng, L. (2015). The effect of public subsidies on corporate R&D investment: An application of the generalized propensity score. *Technological Forecasting and Social Change*, 90, 410-419.

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. *Research Policy*, 29(4-5), 497-529.

Dimos, C., & Pugh, G. (2016). The effectiveness of R&D subsidies: A meta-regression analysis of the evaluation literature. *Research Policy*, 45(4), 797-815.

Duguet, E. (2004). Are R&D subsidies a substitute or a complement to privately funded R&D*?*, *Revue d'Economie Politique*, 114(2), 245–274.

Edquist, C., (2005). Systems of innovation: Perspectives and challenges. In: Fagerberg, J., Mowery, D., Nelson, R. (Eds.), *The Oxford Handbook of Innovation*. Oxford University Press: Oxford, 181–208.

European Commission (2004). Innovation Policy in Europe 2004, *DG Enterprise and Industry*. European Commission: Bruxelles.

Feldman M.P., & Kelley M. R. (2006). The *ex-ante* assessment of knowledge spillovers: Government R&D policy, economic incentives and private firm behaviour. *Research Policy*, 35(10), 1509-1521.

Fritsch, M. and Stephan A. (2005) Regionalization of innovation policy. Introduction to the special issue, *Research Policy*, 34(8): 1123-1127.

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

Glazerman S., Levy D.M., & Myers D. (2003) Nonexperimental versus experimental estimates of earnings impacts. *The Annals of the American Academy of Political and Social Science September,* 589(1), 63-93.

González, X., & Pazó, C. (2008). Do public subsidies stimulate private R&D spending?. *Research Policy*, 37(3), 371-389.

González, X., Jaumandreu J. & Pazó C. (2005). Barriers to innovation and subsidy effectiveness, *The RAND Journal of Economics*, 36(4), 930-950.

Görg, H., & Strobl E. (2007) The effect of R&D subsidies on private R&D, *Economica*, 74, 215–234.

Hall, B. H., Moncada-Paternò-Castello P., Montresor S., and Vezzani A. (2016). "Financing Constraints, R&D Investments and Innovative Performances: New Empirical Evidence at the Firm Level in Europe." *Economics of Innovation and New Technology* 25 (3): 183–196.

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

Hirano, K., & Imbens, G. W. (2004). The propensity score with continuous treatments. *Applied Bayesian modeling and causal inference from incomplete-data perspectives*, 226164, 73-84.

Ho, D.E., Imai K., King G., & Stuart E.A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis*, 15, 199–236.

Hussinger, K. (2008). R&D and subsidies at the firm level: an application of parametric and semi-parametric two-step selection models. *Journal of Applied Econometrics,* 23, 729-747.

Imbens G.W., Wooldridge J.M. (2009) Recent developments in the econometrics of program evaluation. *Journal of Economic Literature*, 47 (1), 5-86

Imbens G,W., Rubin D.B., (2015*). Causal inference in statistics, social and biomedical sciences: An introduction*. Cambridge University Press, New York.

Hyytinen, A., & Toivanen, O. (2005). Do financial constraints hold back innovation and growth?: Evidence on the role of public policy. *Research Policy*, 34(9), 1385-1403.

Koschatzky K., & Kroll H. (2007). Which side of the coin? The regional governance of science and innovation. *Regional Studies*, 41(8), 1115–1127.

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

Lerner, J. (2002) When bureaucrats meet entrepreneurs: The design of effective ‘public venture capital’ programmes, *The Economic Journal*, 112: F73-F84.

Lundvall, B. A. (1992). *National innovation system: towards a theory of innovation and interactive learning*. Pinter: London.

Malerba F. (2002). Sectoral Systems of Innovation and Production. *Research Policy,* 31, 247–264.

Mariani M., Mealli F. (2018). The effects of R&D subsidies to small and medium-sized enterprises. Evidence from a regional program. *Italian Economic Journal*, vol. 4, n. 2, July, 249-282

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. *Research Policy*, 45(9), 1715-1730.

MET (2009). *Rapporto MET 2009: Imprese e politiche in Italia*, Monitoraggio Economia e Territorio, Roma.

Morgan K. (2004). The Exaggerated Death of Geography: Learning, Proximity and Territorial Innovation Systems. *Journal of Economic Geography,* 4, 3–21.

Nelson, R.R. (1959) The simple economics of basic science research, *Journal of Political Economy*, 67: 297-306.

OECD (1999). *Managing National Innovation Systems*. OECD: Paris.

OECD (2005). *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, (third ed.). OECD: Paris.

OECD (2010) *The OECD innovation strategy: getting a head start on tomorrow*. OECD: Paris

Paci R., & Usai S. (2000). Technological enclaves and industrial districts: An analysis of the regional distribution of innovative activity in Europe. *Regional Studies* 34, 97–114.

Potì, B., & Cerulli G. (2010). La valutazione *ex-post* di uno strumento di politica della ricerca industriale: modello analitico, processo di realizzazione, eterogeneità degli effetti, *L'Industria*, 31, 307-333.

Ribas, A. F.-R. (2009). Public support to private innovation in multi-level governance systems: An empirical investigation. *Science and Public Policy*, 36(6), 457–467.

Roper, S., Hewitt-Dundas N. & Love J.H. (2004). An ex ante evaluation framework for the regional benefits of publicly supported R&D projects. *Research Policy*, 33, 487-509.

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

Rubin, D.B. & Thomas N. (1996). Matching using estimated propensity scores: Relating theory to practice. *Biometrics*, 2, 254-268.

Storper M. (1997). *The regional world*. The Guilford Press: New York.

Stuart, E.A. (2010). Matching methods for causal inference: A review and a look forward. *Statistical Science*, 25(1), 1-21.

Tödtling, F., & Trippl M. (2005). One size fits all? Towards a differentiated regional innovation policy approach. *Research Policy*, 34(8), 1203-1219.

Vanino, E., Roper, S., & Becker, B. (2019). Knowledge to money: Assessing the business performance effects of publicly-funded R&D grants. *Research Policy* (forthcoming).

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

Wooldridge, J. M. (1997). On two stage least squares estimation of the average treatment effect in a random coefficient model. *Economics Letters* 56: 129–133.

Wooldridge, J. M. (2003). Further results on instrumental variables estimation of average treatment effects in the correlated random coefficient model. *Economics Letters* 79: 185–191.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press: London.

Zúñiga-Vicente, J. Á., Alonso-Borrego, C., Forcadell, F. J., & Galán, J. I. (2014). Assessing the effect of public subsidies on firm R&D investment: a survey. *Journal of Economic Surveys*, 28(1), 36-67.

Letter to editor

Dear Editor,
we wish to thank you very much for the opportunity you gave us to improve our work on the basis of the referee reports. Their comments were extremely valuable for us in reviewing the manuscript in many key aspects. We did our best in answering to all the concerns raised by the referees and, hopefully, we enhanced the overall quality of the paper.
We revised all the aspects of the manuscript going from the quality and readability of tables and figures to the flow of English language.
Following the referee's advices, we also better focus some sections, i.e. Data and Method, Results and Conclusions. We also addressed all the minor remarks raised.
We would be pleased if you could consider this new version of the paper and we hope you appreciate our effort.
Thanks again for this opportunity.

Best regards,
Anna Giunta

Answers of the Authors to referees comments

Letter to referees:
Referee1
Dear Referee,
We wish to thank you for your valuable comments. In the following, we tried to address all your concerns. Based on your comments, we completely revised all the estimations and the comments. In doing so, some results slightly changed. We tried to discuss these new set of results based on your comments. The main structure of the paper and the main findings of the paper remain valid: we propose a dose-response approach to evaluate the effect of a R&D policy suggesting to try to disentangle different dimensions on which the effects may unfold. It emerges that there exists a range of subsidy intensities that is effective. In the conclusion section we discussed possible implications of the results.
Moreover, we also considered all your minor remarks and checked again the bibliography as suggested.
Thanks again for your comments.

Referee: 1

Comments to the Author
Using micro-data for firms located in the Italian Province of Trento the authors perform a counterfactual evaluation of a local R&D policy measure. The analysis is based upon a dose-response model able to account for the fact that the effectiveness of the policy could be different according to the amount of public subsidies received by the beneficiary firms.

Comment 1.1) *The paper is interesting, well written and particularly valuable from a methodological point of view (see, in particular, the section titled "The econometric model"). However, I have several doubts and remarks about the implementation of the empirical analysis, the interpretation of results, and the derived policy implications.*

REPLY:

Thanks for the appreciation of the paper. In the following we did our best to solve all the doubts the referee raises.

Comment* 1.*2) *The first remark refers to the very low number of treated firms: only 78 in a time span of 6 years (2002-2007; see Table A.1) which are opposed to more than 2,000 (or more than 1,700) untreated firms. This is quite surprising, especially in the light of what the authors write on page 14: "The eligible control group consists of firms that did not receive any grant during the time window under scrutiny. Note that, given that the Province of Trento is the only possible source of funds for the group of firms under scrutiny, there is no bias due to policy overlapping; that is, firms can be subsidized under the provincial law or not, and they cannot also be 'treated' by another law at a different level of government." Accordingly, its seems that the policy measure under investigation was far for being successful. The authors should address this remark in depth. Was the selection procedure too restrictive or the budget too low? It does not seem to be so since no application was refused (see page 10, footnote 3). So, how only about 4% of potential beneficiaries have applied for the incentive?*

REPLY:
The referee correctly underlines a key point. This remark gives us the opportunity to clarify some aspects of the framework so that a potential reader of the paper can better understand the results of the policy and the implications.
First, a clarification about the numbers and the law: we are referring to the chapter n.5 of Provincial Law 6/99 that regulates the concession of R&D grants. In the years under analysis less than 100 firms applied for this particular kind of subsidy. The number of the treated used in the paper is 78, given that we operated a further selection of treated firms in order to ensure full comparability with the group of control firms and exclude particular and unique cases, i.e. companies that followed a slightly different procedure for reasons not related to economic context (e.g. they started a negotiation with Province of Trento on terms of the concession of the grant).
Moreover, in some cases –less than 10– the subsidy was recalled because the firms that benefited from it did not obey to some of the strict regulations imposed by the law. For instance, they did not respect the employment constraint or they *de facto* moved the activity of the firm out of the province of Trento.
The number of firms that asked for a grant in the Province of Trento was higher than around 100 if we consider other kind of subsidies (i.e. investment grants, environmental investment grants, etc.).
We exclude from the control group all the firms that beneficiated from other kind of grants in order to avoid confounding effects.
Second, the doubts about the success of the law. The starting year of the law was 2001 and in the period under scrutiny firms were quite cautionary in applying for the law because of at least three factors: i) the uncertainty about the "new" procedure to get money and the rules to obey after having received the money (i.e. there was no experience of other firm to look at to "extract information"); ii) the complexity of the procedure (firm had to prepare a "dossier" with technical and financial specification of the project); iii) the need to avoid possible spillover of knowledge toward competitors (firms were afraid that full disclosure of research projects to the financial and technical committees could let, even unintentionally, spillover some information to competitors).
We changed the paragraphs of the paper according to the previous comments. See p. 14-16.

Comment* 1.*3) *Another connected question is whether the dose-response model is appropriate in presence of such a low number of treated firms. Indeed, the maximum amount of subsidy awarded to treated firms is 5201 thousands (K) euros (see table A.1). Looking at Figure 3, panel (a), it appears that 77 out of 78 firms received less than 3,750 K euros; 72 firms received less than 2,900 K euros. Thus, the distribution of grants is extremely skewed. I wonder if, in this case, the dose-response* *approach is a reliable tool to provide precise indications to policy makers, such as that specified by the authors on page 18: "It follows that to achieve an impact on employment, policy makers have to co-finance at least €2,354 thousands (45% of the overall amount of the project) but no more than €3,907 thousand.". If one applies these figures to the real sample, only 5 out the 78 treated firms should have been financed by the Trento Province! As a consequence, I strongly recommend to refrain from deriving punctual suggestions from the estimations.*

REPLY:
The observation points to a key potential critical aspect. First a reaction to the low number of treated firms. We should note that having a smaller number of treated compared to the number of untreated units is generally preferred compared to the opposite case (more treated than untreated units). This is because with a high number of control units available is possible to find better matches and consequently a sounder counterfactual sample.
Second, in interpreting the dose response model results, what really matters are the confidence intervals significance along the dose values. In fact, the dose-response thus estimated uses interpolation as it is based on a 3-degree polynomial. Fitting a polynomial is a global estimation procedure so that the values in sparse regions can be "filled-in" using the abundance of data in other part of the scatter cloud. This allows one to have acceptable results also in zones of the scatter characterized by fewer observations, which is probably our case in some zones.
Third, we agree with the observation about the use of precise figures to draw policy implications. The referee is absolutely right: it could be dangerous to use these numbers to give precise indications about optimal amounts. In the end they depend also on the model chosen. Nonetheless, it could be extremely interesting for the policy maker to know better the "shape" of the dose-response function. In our case the inverted u-shape emerges, suggesting that: i) it is better to use intermediate doses (compared to the ones administered in the past); ii) if the subsidy is too small, it does not spur any effect. Finally, if it is too big its impact is null, as well.
In the paper, following the referees' piece of advice, we removed the references to amounts of money. See p.19-20

Comment* 1.*4) *On page 8, as an original contribution of their study, the authors mention the use of disaggregated R&D expenses (see also pages 10 and 22). However, in the regression analyses (cf. Tables A2-A4) I do not find that these disaggregated expenses are taken into account. The authors should add an explanation or eliminate this specification.*

REPLY:
First, let us thank the referee for this observation that will hopefully help to clarify the point raised also in the paper. We refer to the ISTAT classification of R&D expenses. In particular, given data availability, we consider labor costs, fixed assets investments and intangible assets investments.
Moreover, we consider the number of employees and the unit labor cost. These variables represent good proxy of different R&D expenses, once we assume that we were able to clean out other differences between matched firms. In other words, the matching procedure behind the model should ensure that, for example, if there are differences in the total labor cost of a treated firms and of a matched control firm, this is due only to differences in R&D personnel costs.
In the manuscript, we added a discussion related to the choice of each of our objective variable.

Comment* 1.*5) *Another purported original contribution (emphasized both on page 8 and subsequent pages) is the consideration of the project size. Here, I found a very confused picture. The continuous variable for treatment is not the share of subsidies over project costs but their amount rescaled for*

the maximum amount of subsidies allowed by the program. This variable is clearly correlated with the size of the project so that to include the latter as explanatory variable is redundant. Indeed, in all the regressions but one (Table A.3, model 2) the size of the project is never statistically significant. The project size had to be included among regressors if the treatment dose was the percentage of subsidies over project costs. I really wonder why the authors did not use this variable for the subsidy doses. The justification included in footnote 4, page 15 is not convincing at all: for untreated firms this percentage is simply zero because they did not receive any subsidy; it is not true that for these firms also the project size is zero because the authors do not know if they have undertaken R&D projects without applying for the subsidy.
In any case, if the authors insist in employing the doses of subsidies rescaled for the maximum amount, they should not include the project size among regressors and avoid using the terms "grant intensity", "treatment intensity" or "subsidy percentage" in different parts of the paper.

REPLY:
This a key point of the implementation of the method and we thank the referee for drawing our attention on it. In the paper we described and discussed more deeply the choices made for treatment intensity and for control variables.
The referee is right on some points: the size of the project is correlated with the amount of subsidy; the project size for some untreated firms could be not zero. Nonetheless, some observations are needed to explain our choice. First, we do not know the project size of untreated firms. Our solution to include the project size on the right term side of the regression equation could lead to bias coming from the implicit assumption we made about zero value of the project size for untreated firms. We decided to use the level of the subsidy as treatment variable and to leave to the size of firm to play the role of controlling for the bias arising from different project size (the two are highly correlated and cannot be included both in the regression). In other words, we followed the last suggestion of the referee correcting accordingly the wording in the manuscript.

Comment* 1*.6.1) *Other drawbacks refer to the outcome variables of the evaluation exercise. First, it is not clear whether all the objective variables are in levels or growth rates. The authors should specify once for all this point and avoid the current confusion. On page 13 it is said that "the objective variables are considered in terms of rate of growth". However, in subsequent pages they talk about the level of employment, the level of intangible assets, etc.. Clarify the point***:**

REPLY:
The variables are considered in terms of rates of growth. Thanks for noting this incongruence. We clarify the point throughout the paper.

Comment* 1*.6.2) *Second, the total employment is not a proper outcome of an R&D policy measure. The appropriate indicator should be based on R&D employees. The employment constraint requested by the Trento Province makes this policy measure quite hybrid. To put it another way, is the program considered a "true" R&D policy program?*

REPLY:
We are aware of this point. Indeed, this had a paramount importance in terms of the choice of objective variables chosen to investigate the success of the law. We decided to include and discuss results about employment because the law put so much emphasis on employment and, specifically, on employment constraint. The referee is right: the law is a "hybrid" one. In any case the policy makers needed knowledge about the effectiveness of their policy design also to be oriented for future

re-designs of the law. In other words, the exercises we propose could also be interpreted as a guide for future fine tuning of the policy.

Comment* 1.*6.3) *Third, because among the outcome variables there are both the employment and the unit labour cost, the use of total labour costs is redundant*.

REPLY:
Thanks for this observation. We thought a lot about this point and finally we decided to include all the results for completeness. Nonetheless, we agree with the observation and we decided to remove the results about total labor costs. As the referee correctly noted the overall conclusions and results are not affected by this cut.

Comment* 1.*6.4) *Fourth, the authors conclude that there are no effects on intangible assets. On page 21, they write "Subsidized firms do not seem to invest more than non-treated firms in any intangible assets like patents or licenses". I found this conclusion misleading since the ATE for intangible assets is statistically significant (especially in model 1 of Table A.4). The fact that intangibles do not rise with the subsidy dose does not mean that the policy was ineffective.*

REPLY:
Thanks for raising this point that helped us in clarifying this technical aspect otherwise potentially mis understandable by a reader if not properly explained. We added results about ATETs and their standard errors calculated using the bootstrap method. We changed the comments to the results accordingly.

Comment* 1.*7) *Finally, the authors should check for some typos, double-check the references and improve the editing by numbering the sections and employing the same characters in footnotes.*

REPLY:
We corrected some typos, double checked the references and worked on the sections format. Moreover, we made uniform the format throughout the paper. We also double checked the references.

Referee 2

Comment 2.1) *Comments to the Author*
Matching estimators for treatment variables where it is not binary, i.e. where we only have information whether a firm received public support or not, and where the main contribution of the study is to have information about the amount of subsidy and in this case, "dose response"; continuous treatments effects need to be estimated it interesting and has novelty, and "Unconfoundedeness"; is just the assumption of any matching estimator (whether the treatment is binary or continuous).

REPLY:
Thanks for the appreciation of the work. We believe that one of missing pieces in the literature is indeed the analysis of dose-response function of the policies. In the manuscript, we tried also to reword some passages to put more emphasis on this "novelty" of the paper.

Comment 2.2)
However, the ATENT is not estimated. More problematic is that the author(s) estimated ATE, instead

of ATET, yet they interpreted their results as if they estimated ATET. For instance, in the conclusion is stated: "Subsidized firms increased both the number of workers and their quality…" However, when the ATE is reported (not ATET), then the results cannot be interpreted like that. The definition of ATE is a sample estimate of the effect of public support on employment (or other outcome variables) of a firm randomly selected from the population. Marino et al. (2016), one of two studies discussed in the literature review, explicitly discussed and reported the ATET. Moreover, both empirical studies in the literature review (Marino et al., 2016; Dai and Cheng, 2015) investigate input additionality, i.e. impact of public support on R&D investment, while the current study investigates some quasi output additionality (employment, labour costs etc.). See below comment on why quasi output additionality.

REPLY:

Thanks to the referee for drawing our attention on this crucial aspect. Hopefully, thanks to the changes introduced we improved the readability of the paper and let a potential reader be more confident about our results.

With regard to the fact of focusing on quasi-output additionality, this was strictly required by the fact that the policy in question was and R&D promoting policy with a constraint on hiring new employees. Therefore, it seemed to us correct to also evaluate the impact of this policy on the firm employment performance.

Furthermore, we did the following changes in the new version of the paper:

1) we slightly changed the method section explaining that ATE(l)=ATET(l) for l>0. We changed accordingly also the figures and the tables;
2) we used the bootstrap method to calculate ATET and its significance. Once obtained this measure for all objective variables used we commented them accordingly;
3) All the dose response figures report results for ATET(l).

We hope this could make our results clear and comparable with other studies.

Comment 2.2) *The paper's focus on Human Capital, and, Fixed and Intangible Assets, both appear feasible...the findings and discussion leave too much undiscussed and unestablished. HC appears to establish treatment effects additionality (at 2 years) but not thereafter, but not really further discussed, i.e. for how long thereafter? The F & I are never really well focused on and certainly not discussed and effects established in the latter part of the paper...F & I appear to be an add-on that attempts to give weight to the paper but lacks a part.*

REPLY:

The research design aimed at evaluating effect after a minimum reasonable lag (we identified this time span in two years) and at longer time span of 4 years (when even the formal requirements of the law were not binding) . To look at longer time spans can be problematic because the noise in the estimations increases a lot over time as a result of events that happen to firms and alter the dynamic path of some of the objective variables. On the other hand, to use longer span was impossible given the lack of availability of full information about firms changes that could prevent us to build a reasonable identification strategy.

We did our best in the paper to discuss more deeply the results and potential implications. This is even more important, once we note that the changes to estimations induced by the comments of both referees slightly changed the results and forced us to rethink about the full picture provided from our results.

Comment 2.3) *As the authors will know, there are three types of additionality investigated in this stream of research (input, output and behavioural), and this paper does not fit into any of these categories. For instance, Afcha and García-Quevedo (2016) (the reference is below) look at the impact of public support on R&D employment, while the current study looks at the impact on overall*

employment. No references to any papers are provided that look at the impact of innovation policy on total (not R&D employment) and on other outcome variables (labour costs, investment in tangible and intangible assets).
Afcha, S. and García-Quevedo, J. (2016) The impact of R&D subsidies on R&D employment composition. Industrial and Corporate Change 25 (6), 955–975.

REPLY:
Thanks to the referee for raising this point. We realized that in the previous version of the manuscript this point was not satisfactorily addressed. In the new version we discuss the point referring to the concept of input additionality and quasi-output additionality.
In particular, as a measure of quasi-output additionality we look at overall employment because the policy puts a particular attention to this objective. We define quasi-output additionality this variable to distinguish our results from literature about output additionality. Indeed, in our case we do not have the availability of detailed labor force employed in R&D that can be properly defined as a measure of output additionality. In a sense, finding a significant effect on overall employment is a prerequisite of having an effect on the subset of R&D workers.
We are aware that employment and employment unit costs could be considered a bit far from the objectives of an innovation policy, but this was one of the main dimensions along which policy makers evaluate the policy. Indeed, policy makers' aim was to induce the firms to hire more skilled workers.
For other measures, once controlled for observable characteristics and considering the local scope of the analysis (i.e. all the firms in the sample are active in Trentino), we take into consideration: i) fixed capital investment as a proxy of firms' physical capital; ii) intangible assets as a proxy of all the other investments that have non-physical nature (e.g. licenses, patents, etc.).
Fixed and intangible assets are a measure of input additionality because they represent percentages of R&D spending of firm.

Table 1: Descriptive statistics of the sample of firms.

	N	*mean*	*sd*	*min*	*max*
		untreated firms			
age	2029	24.59	17.39	0.00	98.00
intangibles	2029	193.42	2428.02	0.00	80754.00
fixed assets	2029	971.01	4371.92	0.00	98587.30
labor cost	2029	667.62	1729.21	0.00	20169.89
per capita labor cost	2029	24.07	11.23	0.00	84.77
number of employees	2029	20.09	42.25	1.00	479.00
cash flow rescaled	2029	10.52	39.48	-237.97	1401.33
capint	2029	0.3516	1.2069	-0.1190	27.7505
		treated firms			
Subsidy percentage	78	56.08	12.07	28.22	75
*Project size**	78	1711.62	1712.78	52.13	8967.76
age	78	25.71	17.79	0.00	42.00
intangibles	78	1577.17	4042.90	0.00	23389.00
fixed assets	78	6641.26	18890.69	0.00	121941.00
labor cost	78	5225.14	13073.65	0.00	75322.36
per capita labor cost	78	28.78	13.35	0.00	51.98
number of employees	78	127.69	324.30	1.00	1849.00
cash flow rescaled	78	12.61	16.61	-57.90	72.73
capint	78	0.2369	0.2900	0.0000	1.4462
		all firms			
age	2107	24.63	17.40	0.00	98.00
intangibles	2107	244.65	2518.50	0.00	80754.00
fixed assets	2107	1180.92	5709.64	0.00	121941.00
labor cost	2107	836.34	3141.57	0.00	75322.36
per capita labor cost	2107	24.24	11.35	0.00	84.77
number of employees	2107	24.07	77.31	1.00	1849.00
cash flow rescaled	2107	10.60	38.88	-237.97	1401.33
capint	2107	0.3474	1.1858	-0.1190	27.7505

*Notes: *thousands euros.*

Table 2: A summary of the results.

2 years
Intensity of the treatment

	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Employment growth	no	no	no	no	+	+	+	+	no	no
Unit labor costs growth	no	no	no	no	no	no	no	no	no	no
Fixed assets growth	no	no	no	no	no	no	no	no	no	no
Intangible assets growth	no	no	no	no	+	+	+	+	no	no

4 years
Intensity of the treatment

	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Employment growth	no	no	no	+	+	+	+	+	no	no
Unit labor costs growth	no	no	no	+	+	+	+	no	no	no
Fixed assets growth	no	no	no	no	no	no	no	no	no	no
Intangible assets growth	no	no	no	no	+	+	+	+	no	no

+ : positive and significant effect
no : no effect for the dose

Figure 1: Timeline of the econometric models.

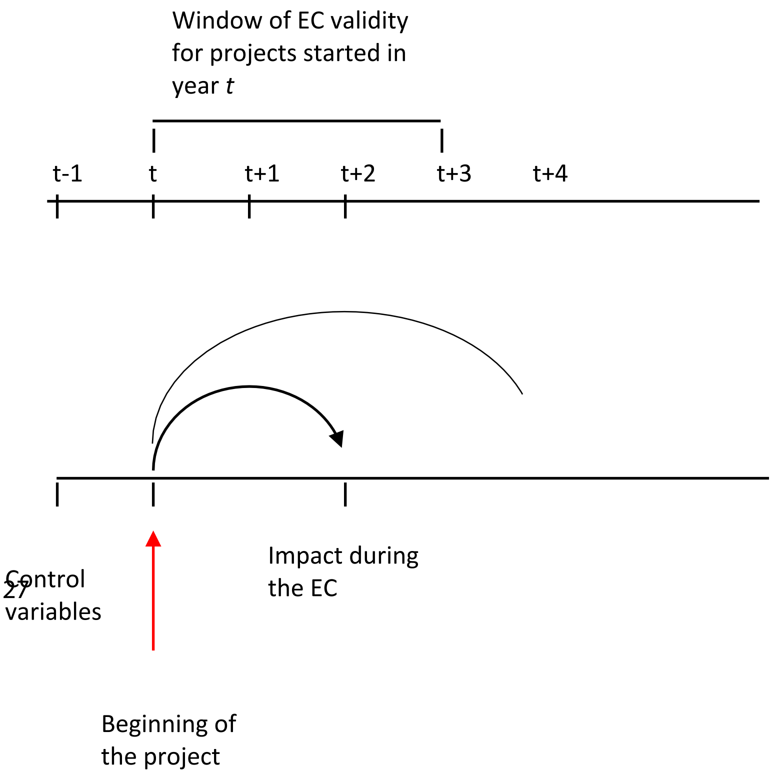

Figure 2: The distribution of R&D grant amounts.

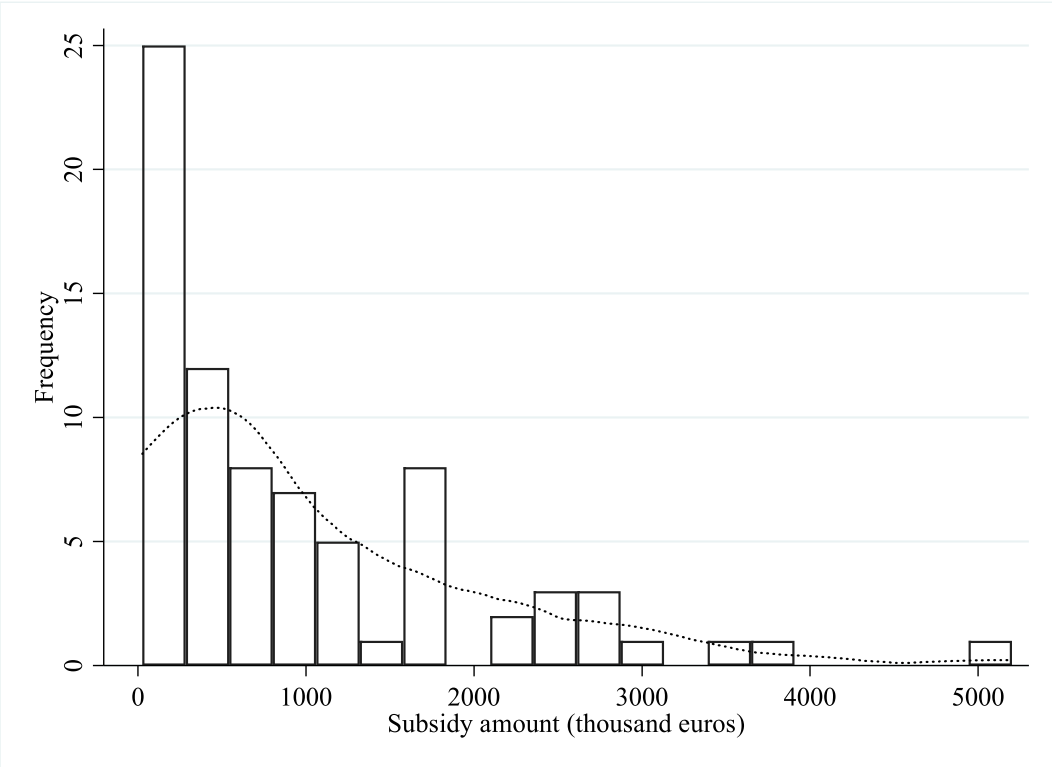

Figure 3: Dose-response function for the objective variable: Employment growth. Results for model during EC (panel a) and after EC expiration (panel b).

(a) **(b)**

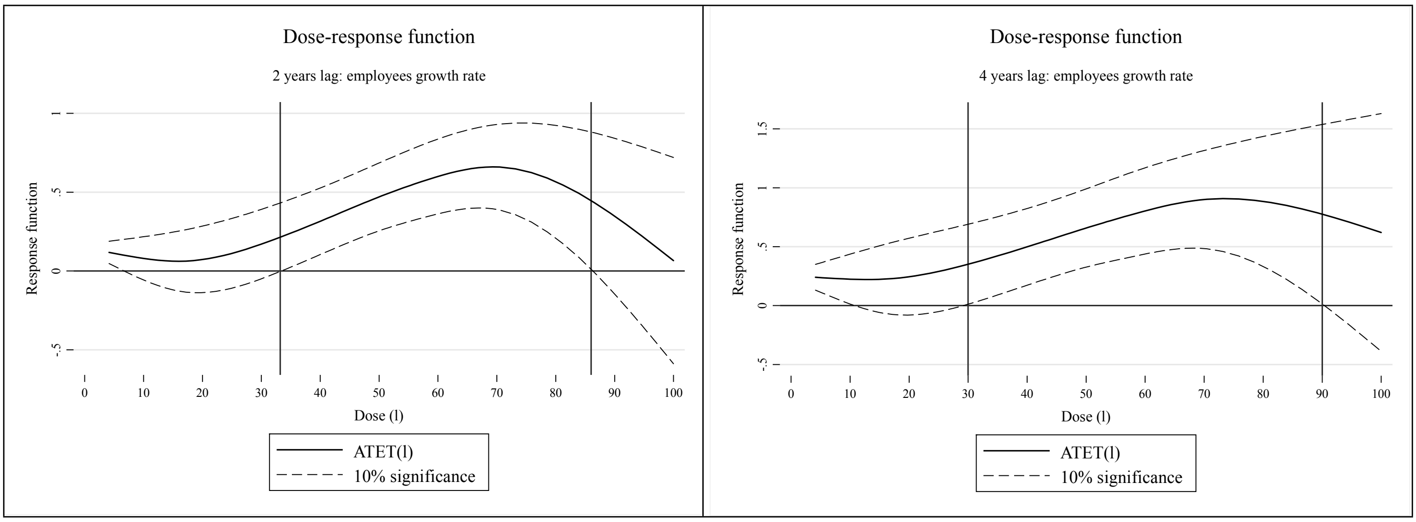

Figure 4: Dose-response function for the objective variable: unit labour cost. Results for model during EC (panel a) and after EC expiration (panel b).

(a) **(b)**

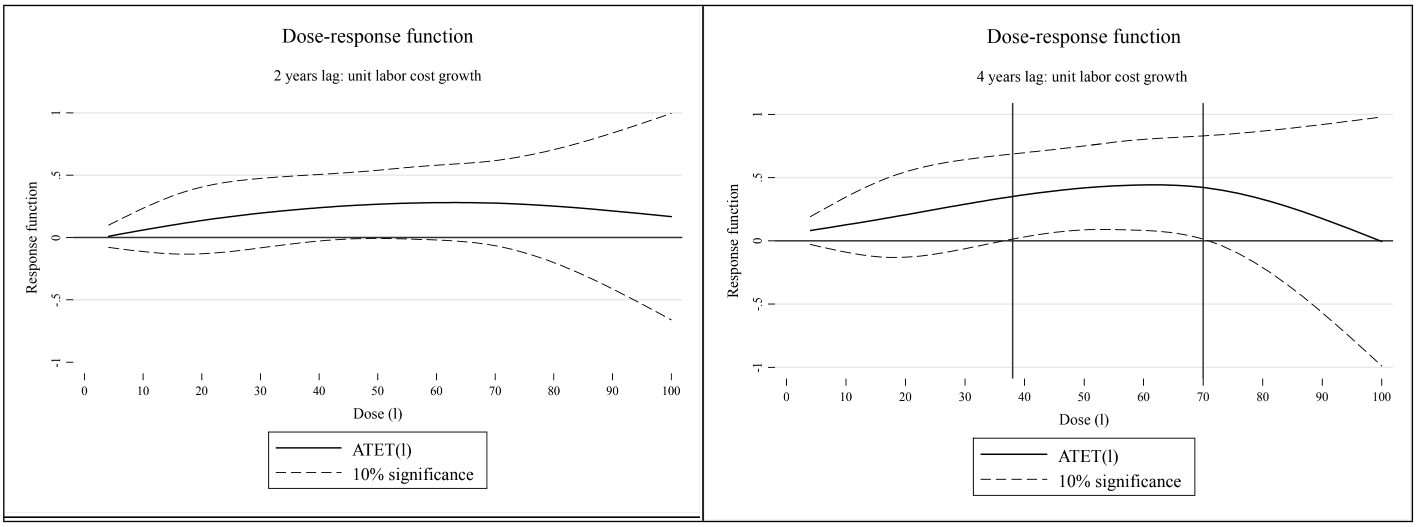

Figure 5: Dose-response function for the objective variable: fixed asset investment. Results for model during EC (panel a) and after EC expiration (panel b).

(a) (b)

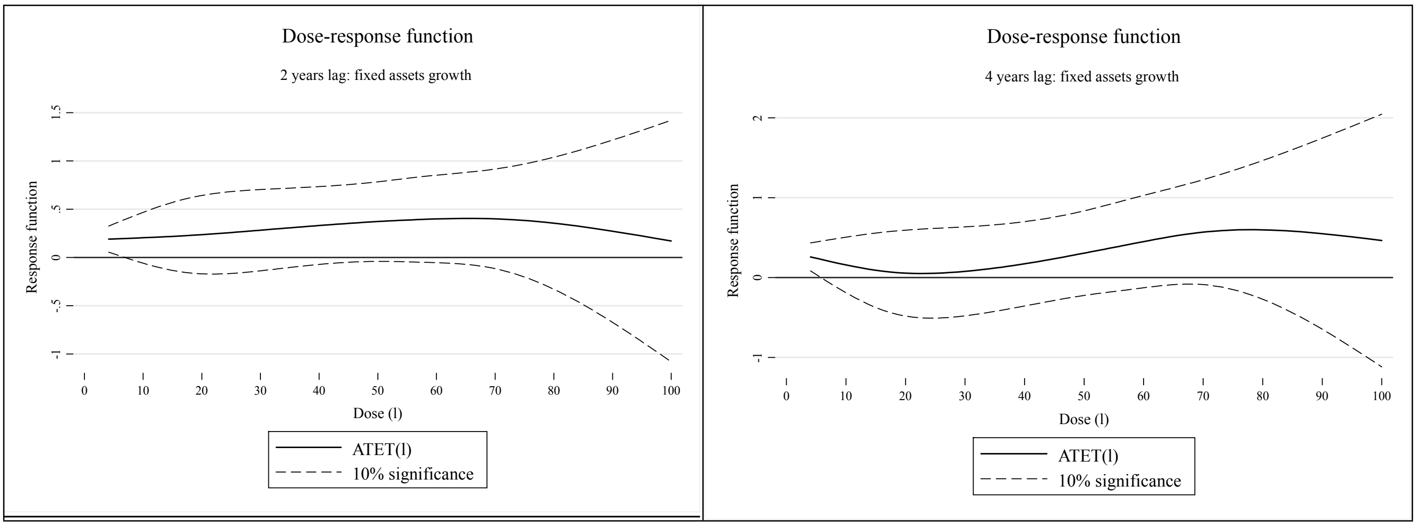

Figure 6: Dose-response function for the objective variable: intangible asset investment. Results for model during EC (panel a) and after EC expiration (panel b).

(a) (b)

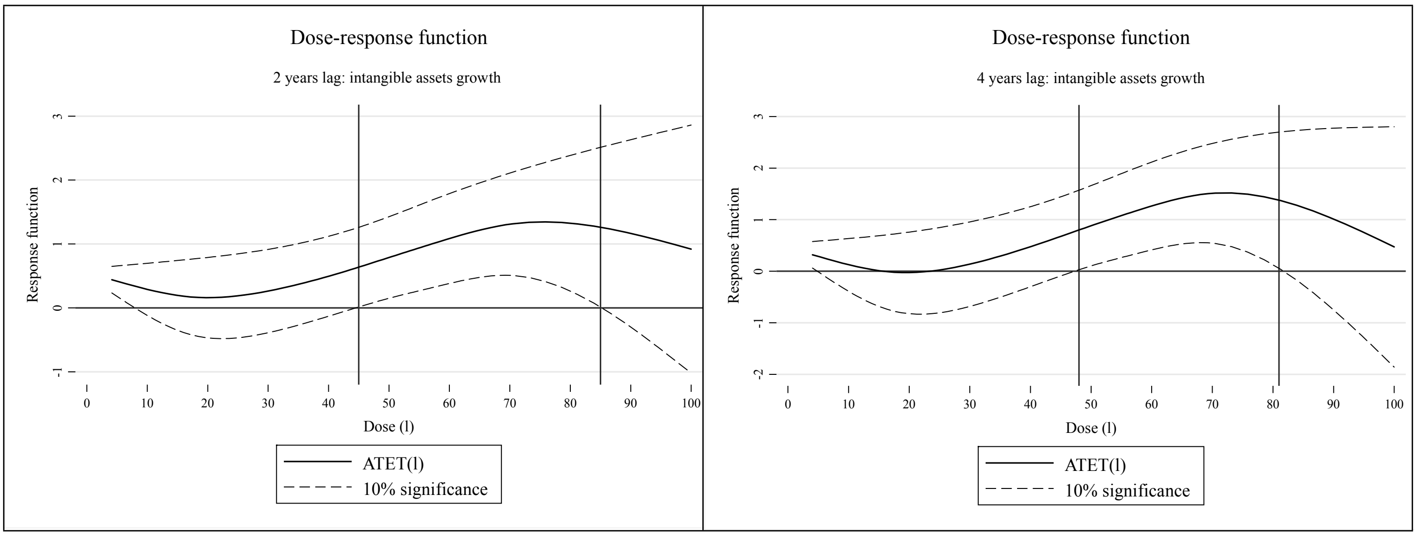

Table A.1. Treated firms by year (inclusion in the LP6 program in the years 2002-2007) - amount of subsidy per year.

	number of firms	Co-financed amount of subsidy (current values thousands of €)			
		average	std. dev.	min	max
2002	16	924.0795	1396.778	26.0626	5201.298
2003	9	709.3832	581.3392	126.016	1619.2
2004	10	701.7267	614.5744	56.95723	1673.21
2005	17	977.1796	837.7759	170.2219	2702.685
2006	20	1169.957	1186.525	47.79945	3702.087
2007	6	1461.198	1072.873	176.4045	2982.722
Total	78				

Table A.2: Ctreatreg estimations of the models using as objective variables: Employment growth. Columns (1) model during employment constraint; (2) after expiration of employment constraint

Models:	(1) *Growth(t+2)*	(2) *Growth(t+4)*
	Average effect of treatment	
ATE	0.1838**	0.2882**
	(0.087)	(0.125)
	Non-linear effect of doses	
L_1	-0.0192	-0.0259
	(0.012)	(0.018)
L_2	0.0008**	0.0010*
	(0.000)	(0.001)
L_3	-0.0000**	-0.0000*
	(0.000)	(0.000)
	Controls	
Age	-0.0027***	-0.0041***
	(0.001)	(0.001)
Per capita labor cost	-0.0027***	-0.0027**
	(0.001)	(0.001)
Employment level	0.0001	-0.0002
	(0.000)	(0.000)
Employment level^2	-0.0000	-0.0000
	(0.000)	(0.000)
Cash flow (rescaled)	0.0003*	0.0016**
	(0.000)	(0.001)
Capital intensity	-0.0075	-0.0352***
	(0.007)	(0.008)
Constant	0.1709***	-0.0041***
	(0.029)	(0.001)
Year dummies	yes	yes
Observations	2,103	1,856
N_treated used	78	72
N_untreated used	2025	1784
F	5.798	7.924
R-squared	0.040	0.061

Table 3: Ctreatreg estimations of the models using as objective variable the cost of labour per employee. Column (1): model during employment constraint; (2) after expiration of employment constraint

Models:	(1) ULC(t+2)	(2) UCL(t+4)
	Average effect of treatment	
ATE	-0.0245	0.0611
	(0.110)	(0.136)
	Non-linear effect of doses	
L_1	0.0098	0.0058
	(0.016)	(0.020)
L_2	-0.0001	0.0001
	(0.000)	(0.001)
L_3	-0.0000	-0.0000
	(0.000)	(0.000)
	Controls	
Age	-0.0015**	-0.0025***
	(0.001)	(0.001)
Per capita labour cost	-0.0030***	-0.0047***
	(0.001)	(0.001)
Employment level	0.0005	0.0006
	(0.000)	(0.000)
Employment level^2	-0.0000	-0.0000
	(0.000)	(0.000)
Cash flow (rescaled)	0.0003	0.0028***
	(0.000)	(0.001)
Capital intensity	-0.0077	-0.0347***
	(0.008)	(0.010)
Constant	0.0843**	0.1282***
	(0.037)	(0.047)
Year dummies	yes	yes
Observations	2,101	1,833
N_treated used	78	71
N_untreated used	2023	1762
F	2.346	3.943
R-squared	0.017	0.031

Note: All dependent variables are lagged by one year with respect to the year of the grant.

Table 4: Ctreatreg estimations of the models using as objective variables Fixed asset expenditure and Intangible assets. Columns (1) and (3): model during employment constraint; (2) and (4) after expiration of employment constraint

Dep. variable:	*Fixed Assets*		*Intangible Assets*	
Models:	(1) *FA(t+2)*	(2) *FA(t+4)*	(3) *IA(t+2)*	(4) *IA(t+4)*
Average effect of treatment				
ATE	0.1890	0.3625*	0.6204**	0.5566*
	(0.167)	(0.214)	(0.259)	(0.315)
Non-linear effect of doses				
L_1	0.0002	-0.0304	-0.0517	-0.0702
	(0.024)	(0.031)	(0.037)	(0.046)
L_2	0.0001	0.0009	0.0016	0.0024*
	(0.001)	(0.001)	(0.001)	(0.001)
L_3	-0.0000	-0.0000	-0.0000	-0.0000*
	(0.000)	(0.000)	(0.000)	(0.000)
Controls				
Age	-0.0004	0.0002	0.0027*	0.0033
	(0.001)	(0.001)	(0.002)	(0.002)
Per capita labour cost	-0.0019	-0.0033	0.0006	-0.0012
	(0.002)	(0.002)	(0.002)	(0.003)
Employment level	-0.0001	0.0004	-0.0013*	-0.0014
	(0.000)	(0.001)	(0.001)	(0.001)
Employment level^2	0.0000	-0.0000	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)
Cash flow (rescaled)	0.0003	0.0020*	-0.0002	-0.0013
	(0.000)	(0.001)	(0.001)	(0.002)
Capital intensity	-0.0346***	-0.0323**	0.0144	0.0099
	(0.013)	(0.015)	(0.024)	(0.025)
Constant	0.0209	0.0611	-0.2463***	-0.1293
	(0.056)	(0.076)	(0.093)	(0.116)
Year dummies	yes	yes	yes	yes
Observations	2,082	1,847	1,895	1,701
N_treated used	78	72	78	72
N_untreated used	2004	1775	1817	1629
F	2.448	1.121	2.294	2.040
R-squared	0.011	0.019	0.009	0.018

Note: All dependent variables are lagged by one year with respect to the year of subsidization.