The impact of R&D subsidies on R&D employment composition

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Abstract

In this paper we examine the impact of subsidies granted at national and regional levels on a set of R&D employment variables and we specifically seek to identify the existence of additional effects of these public subsidies on the R&D human resources of firms. We begin by assessing the effects of public funds on private R&D expenditure and on the number of R&D employees, and then focus on the impact of these funds on the composition of human resources engaged in R&D classified by occupation and level of education.

The data used are from the Spanish Technological Innovation Panel for the period 2006-2011. To control for selection bias and endogeneity, a combination of non-parametric matching techniques are used. Our results show that R&D subsidies increase the number of R&D employees but no contemporaneous increase is found in the average level of qualification of R&D staff members in subsidized firms. Nevertheless, in the subsequent years there is a positive effect on the recruitment of PhD holders. The effects of public support are heterogeneous and are dependent on the source of the subsidy and the firms' characteristics.

Keywords: R&D subsidies, R&D employment, matching estimators, technology policy.
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1. Introduction

Governments use a broad mix of innovation policy tools to correct market failures. This public intervention is justified from a social point of view as a means of preventing underinvestment in R&D activities. However, the ultimate goal of this policy is concerned not simply with increasing private R&D expenditure, but rather with boosting productivity, economic growth, employment and welfare.

R&D subsidies, together with tax incentives, have been broadly used as technology policy tools to correct market failures. Their implementation implies the use of public funds and consequently their impact has been assessed from various perspectives. Until recently, these evaluations have focused primarily on two criteria: the ability of subsidies to induce greater R&D expenditure (input additionality) and their ability to generate more innovative outputs (output additionality).

This paper aims to analyse the effects of public R&D subsidies to business R&D on the level of qualification of R&D employees. The human capital in firms' R&D employees affects the capacity of the firms to generate new knowledge and to innovate. Public support may favour changes in the human resources of subsidized firms. It can strengthen human capital and technological know-how or enhance technology management through the recruitment of personnel with specific skills and knowledge important for R&D projects. Georghiou and Clarysse (2006) argue that rather than simply increasing the number of employees, public funds should serve as an incentive to increase the level of qualification of R&D staff members, enabling firms to attract the skills that allow them to acquire competitive advantages.

Nevertheless, to the best of our knowledge, there are no evaluation studies of R&D subsidies that have assessed the effects of public support on the level of qualification of R&D employees. The lack of information regarding the skills of individual R&D workers (Thomson and Jensen, 2013) has prevented this kind of analysis being carried out.

After assessing the effect of R&D subsidies granted in Spain on the number of R&D employees, we analyse the impact of subsidies on the behaviour of firms in terms of the recruitment of highly qualified human resources. To detect these effects we examine the way in which R&D subsidies can affect the composition of human resources engaged in R&D. First, we analyse occupation type and the responsibilities of R&D personnel, distinguishing between researchers, technicians and auxiliary staff. Second, we consider their level of education, separating PhD holders, graduates and engineers, those with short-cycle tertiary education and personnel with other non-tertiary education. This analysis affords us a better understanding of the impact of these subsidies on the quantity and quality of R&D employees. It reveals the way in which subsidized firms allocate their additional funds to R&D projects as far as their human resources are concerned.

R&D subsidies are granted by public agencies operating at different levels of government and these may have different policy objectives (Afcha, 2011; Blanes and Busom, 2004). Consequently, it is important to distinguish between levels of government (Zúñiga-Vicente et al., 2014), since these public agencies may influence firms' demands for specific types of R&D personnel to carry out their R&D projects, depending on the selection criteria of the agencies. We focus our analysis on national and regional R&D subsidies, which are the most important in Spain in terms of the number of recipient firms and budget. However, in the estimations, we control for other sources of public support including European R&D subsidies.

The database used in this paper is that of the Spanish Technological Innovation Panel (PITEC) for the period 2006-2011. This database, built with the Spanish version of the Community Innovation Survey (CIS), provides information on the occupation and educational level of R&D workers, data rarely available at firm-level. With these data we are able to overcome limitations caused by the lack of information about the skills of individual R&D workers. Our estimations of the impacts of subsidies are carried out by combining two non-parametric matching techniques – the coarsened exact matching method (CEM) and the propensity score matching method (PSM).

The rest of the paper is organised as follows. Section 2 presents the analytical framework and summarises the empirical evidence concerning R&D subsidies and their impact on R&D employment. Section 3 describes the dataset and the methodology used in the evaluation approach. In section 4 we discuss the main results of the estimations and present several robustness checks. Section 5 concludes.

2. Background

2.1. Public subsidies and R&D employment

In recent years the literature devoted to evaluating the impact of technology policy intervention has grown rapidly. This literature analyses the impact of policy tools on firms' innovative performance indicators. The empirical evidence (David et al., 2000; García-Quevedo, 2004; Cerulli, 2010; Zúñiga-Vicente et al., 2014) has focused primarily on evaluating the impact of public funding on R&D inputs measured through R&D spending and R&D effort, and on R&D outputs such as patents, sales of new products or the number of new products and processes.

Recent papers propose complementing measures of input and output additionality with analyses of changes in firms' behaviour attributable to public intervention. Falk (2007) finds that scope additionalities arise, in the form of more cooperation or more challenging R&D projects, when multiple policy interventions or continuous public support is provided. Autio et al. (2008) show that collaborative R&D programs, by enhancing the identification of subsidized firms with a community of practice, enhance learning outcomes in these firms. Similarly, Clarysse et al. (2009) shed some light on the organizational factors affecting input additionality. Specifically, their results point to the fact that companies reporting the highest learning outcomes also continue to invest in their absorptive capacity. Therefore they provide evidence of a strong correlation between input additionality and behavioural additionality.

Numerous studies evaluating public intervention in technology policy analyse the impact of subsidies on private R&D expenditures. Although some of them examine the effects of subsidies on employment as a complementary indicator (Eshima, 2003; Lerner, 1999; Link and Scott, 2013; Wallsten, 2000), the number of studies explicitly using R&D employment as the dependent variable is very limited.

Some studies (Goolsbee, 1998; Wolff and Reinthaler, 2008) use aggregate data to analyse the effect of subsidies on wages and on the number of employees. While Goolsbee's (1998) conclusions support a crowding out effect, showing that public financing increases the remuneration of the R&D personnel already engaged in R&D activities, Wolff and Reinthaler's (2008) findings show that R&D subsidies stimulate both variables positively although the effect is greater on R&D wage levels.

Other papers use microdata to examine the effects of public subsidies on R&D employment directly. Falk (2006) evaluates the impact of public subsidies in Austria using the number of R&D workers as the dependent variable. Her results indicate that R&D subsidies have a small but significant effect on R&D employment. A 1% increase in public funds generates a 0.04% rise in R&D personnel. Piekkola (2007) reports positive effects for Finland in the proportion of R&D employees as well as productivity growth improvements in subsidized firms. These results coincide with those obtained by Ali-Yrkkö (2005), also for Finland, when analysing the impact of R&D subsidies and distinguishing between domestic employees, those working in Finland, and non-domestic employees and R&D and non-R&D employees. His results show that subsidies have a positive impact only in the case of domestic employees engaged in R&D activities.

These studies capture the impact of subsidies on increases in the number of R&D employees. Yet the effect produced by subsidies on the composition of human resources engaged in these R&D activities has not, to date, been analysed in detail.

2.2. Public subsidies, R&D projects and human resources

Human resources are a key component in innovation and economic growth processes, as well as a priority objective for technology policy. For instance Griffith et al. (2004) stress the importance of human capital for technical change and innovation in OECD countries.

Lundvall (2008) reports that higher levels of education allow sufficient competence for the assimilation of technological change to be acquired. This therefore increases the importance of university graduates, since individuals with higher levels of education serve as a vehicle for the construction of innovative skills and learning capacity. These two elements are essential for taking advantage of technological opportunities. In addition the complexity and tacit nature of scientific knowledge implies high costs in terms of knowledge transfer and exploitation. The recruitment of PhDs may help to overcome these problems, providing better ties with universities and public research institutions (García-Quevedo et al., 2012) and act as a channel bringing the knowledge embodied in these graduates into industry (Stephan et al., 2004).

Empirical approaches have identified a positive link between human resources and R&D and innovation from a variety of perspectives. Leiponen (2005) shows that there are significant complementarities between technical skills and innovation and that human capital is positively associated with innovative performance. Innovation policies need to take these interactions into account. Piva and Vivarelli (2009) conclude that there is a positive link between ex-ante available skills and R&D investment and that improvements in a firm's manpower skills may be beneficial for its innovation strategies. D'Este et al. (2014) also report a positive relationship between human capital and innovation showing that a strong skill base has a significant impact by attenuating deterrents to innovation.

The concept of behavioural additionality emphasizes the role of human resources as a key component in any evaluation of the benefits derived from public policies. This perspective, grounded in resource-based theory, stresses the importance of unique, rare and hard to imitate resources for firms and hence the importance of taking policy impact into account in terms of quality improvements recorded among employees.

Georghiou and Clarysse (2006) describe various mechanisms of public intervention that may change firms' strategies. The effects of technology policy may result in the acquisition of higher levels of knowledge, the upgrading of skills and improvements in technology management, as well as changes in the scale and length of R&D projects. Clarysse et al. (2009) provide empirical evidence of the impact of subsidies on organizational learning and technology management. However, to the best of our knowledge, no previous study has examined the impact of subsidies on the composition of R&D staff.

R&D subsidies granted to promote the R&D projects of firms may have effects on the educational composition of their R&D staff and improve the quality of their human capital, even if they do not specifically have this aim. David et al. (2000) point out, following on from the work of Blank and Stigler (1957), that besides the direct effect on private R&D investment, there are other potential micro-level effects of publicly subsidized R&D activity such as possible learning and training improvements that acquaint the firm with the latest advances in scientific and technological knowledge.

In a model of firm-level investment in R&D (David et al., 2000), subsidies are expected to lower the marginal cost of R&D and stimulate current and even future R&D expenditure (Arqué-Castells, 2013; Lach, 2002; Takalo et al., 2013). A very important proportion of the cost of R&D projects is expenditure on R&D personnel (Goolsbee, 1998; Hall, 2002). Therefore firms that receive public support may increase their R&D expenditure on personnel and undertake new R&D projects. Nevertheless public support is not expected to have any effect on the educational qualifications of R&D staff if R&D projects are homogeneous and public subsidies are neutral in the sense that they are targeted towards supporting the same or very similar types of R&D projects that firms are already undertaking.

However, public agencies use specific eligibility criteria in selecting which R&D projects to grant subsidies to. This allocation of subsidies may have an upgrading effect on the educational level required of the R&D staff that will carry out the subsidized R&D projects. In principle, the policy prescription and objective of public agencies is to maximise social welfare and they should therefore direct their R&D subsidies towards projects that have greater social benefits, frequently in cooperation with public institutions (David et al., 2000; Jaffe, 2002).

In European Union countries, public programs supporting private R&D have to comply with the rules of the Community framework for state aid for research and development and innovation. This framework states that aid for R&D must lead to recipients changing their behaviour so that they increase their level of R&D activity and R&D projects take place that would not otherwise have been carried out. These rules also favour basic research and establish higher aid intensities for industrial research than for experimental development. In addition, they consider it to be an important criterion to demonstrate that public support has an incentive effect, increasing the scope of research so that more ambitious projects with a higher probability of achieving scientific or technological breakthroughs or projects that involve greater risk are undertaken.

From the perspective of behavioural additionality scope effects are also an important dimension of the impact of R&D subsidies (Falk, 2007). The existence of scope effects means that new objectives are added to projects, including new research areas that are beyond the key competences of firms and that involve greater difficulties and new technology or research fields (Falk, 2007; Georghiu et., al., 2004; Wanzenböck et al., 2013). If scope additionality takes place the search for knowledge leads to a firm enlarging its previous knowledge base, exploring new trajectories and different technology and research fields. In order to acquire this additional knowledge, firms may need to recruit R&D personnel with new skills. Firms conducting new R&D projects or interested in engaging in technology cooperation with other firms and research institutions, in fields of technology distant from their previous competence (Katila and Ahuja, 2002), may need to recruit new research personnel in order to gain expertise and enlarge their knowledge base.

Recent contributions (Huergo and Trenado, 2010; Takalo et al., 2013) show that the degree of technical challenge and potential of an R&D project positively influences the likelihood of receiving public support. In addition, fostering cooperation with research institutions is a very frequent objective of public policy and a relevant factor in the eligibility criteria for R&D projects, as has been shown by empirical analysis (Czarnitzki et al., 2007; Huergo and Trenado, 2010) and also by the results of this paper (see Table A.2 in the Appendix).

In synthesis, an important implication of the above discussion is that firms may need to increase their human capital and change the educational composition of their R&D staff to undertake publicly supported R&D projects that may have greater scientific and technological content and that need to be carried out in cooperation with research institutions. The hiring of PhDs by firms is positively related to the technological level of R&D projects and to the existence of R&D cooperation with universities and research institutions (García-Quevedo et al., 2012; Herrera and Nieto, 2015). Even in the event that there is some substitution between privately financed and government-funded R&D projects, an increase in the educational level of the R&D staff could occur if the projects that receive public subsidies require higher levels of human resource skills.

Nevertheless, in order for public support to R&D projects to achieve these effects it is required that it is effectively oriented to this type of project. It may be the case that public agencies are under strong pressures to provide support for projects with a high probability of success and private marginal rate of return (David et al., 2000; Lach, 2002). These projects could be financed by the firms themselves and do not require the educational level and qualifications of R&D staff to be upgraded. Furthermore, the magnitude of the additionality effect and the potential changes in the educational composition of the R&D staff are related to the elasticity of supply of research personnel. If the supply of qualified personnel is inelastic, public support to R&D may result in an increase in the cost of salaries (Goolsbee, 1998) and not in the number of employees or in changes in the R&D staff. In synthesis, although there are sufficient reasons to expect public subsidies to have a positive effect on the human capital level of R&D staff, empirical analyses are required to test this hypothesis and to estimate the magnitude of this potential effect.

2.3. Effects of R&D subsidies provided by different levels of government

Recent evaluations stress the importance of considering the different levels of government that intervene in technology policy, because they may well use R&D subsidies to target different policy goals (Afcha, 2011; Blanes and Busom, 2004; Czarnitzki and Lopes-Bento, 2014; Fernández-Ribas, 2009; García-Quevedo and Afcha, 2009).

At the country level, a distinction should be drawn between subsidies granted by central governments and those coming from regional governments. The rationale underpinning technology policy at the national level is the existence of market failures (OECD, 2008) and it therefore seeks to create incentives to enhance the level of investment in R&D. Various empirical studies (Antonelli and Crespi, 2013; Blanes and Busom, 2004; Hussinger, 2008) associate the objectives of national governments with the so-called "picking-the-winners" strategy which tends to focus its efforts on strengthening technological levels in medium-large firms that belong to high or medium-high technology sectors and that have projects requiring large amounts of private investment. For Spain, Blanes and Busom (2004) show that national and regional R&D subsidies seek to fulfil different objectives. Firm size and human capital intensity play an important role in their concession at the national level where subsidies are oriented, in the main, towards promoting high level, commercially viable, technological projects.

The participation of regional governments in innovation and technology policy has increased substantially over the last two decades. Initially, these interventions were also made with the aim of correcting market failures. More recently however regional interventions have been more closely concerned with correcting systemic failures. This perspective identifies other sources of failure that might hinder the smooth operation of innovation systems and constitute obstacles for the development and economic growth of a region. Indeed, institutions such as the OECD (2008) suggest that technology policy at the regional level could be more effective in solving problems associated with i) a lack of innovative capacity in regional firms, ii) rigidities that prevent the correct configuration of institutions; iii) network and coordination problems related to the interaction between agents in the innovation system; iv) a failure to adapt frameworks so as to regulate economic activities and; v) lock-in failures motivated by practices and behaviour inhibiting the adoption of new methods.

The objectives of regional technology policy may thus differ from those adopted by national governments. In most regions in Spain they tend to be more closely oriented towards developing technological clusters, broadening the base of small and medium-sized firms performing R&D activities and, more generally, towards reducing technological gaps between innovative and non-innovative firms.

These differences in the technology policy goals of the two levels of government suggest that there may well also be differences in the impact of their respective subsidies on business R&D expenditures and employment. In Spain, national and regional agencies do not have the same criteria for selecting the R&D projects that are to receive subsidies (García-Quevedo and Afcha, 2009). In addition, the sizes of the subsidies are significantly different. In the period of analysis of this paper, 2006-2011, the average national subsidy was 176,092 euros while the average regional subsidy was

130,312 euros. Marzucchi and Montresor (2015) also show, in their analysis for Italy and Spain, that the impacts of the subsidies from these two levels of government are different. Therefore differences in impacts can be expected that may be especially marked in the case of R&D employment, the main characteristics of which tend to be specifically related to the type of project proposed by the firms that apply for grants from public agencies.

3. Institutional framework, data and methodology

3.1. Institutional framework: R&D and innovation policy in Spain

Support to R&D projects in firms during the period of analysis 2006-2011 were, at a national level, carried out within the framework of the Spanish Plans for Scientific Research, Development and Technological Innovation for the periods 2004-2007 and 2008-2011. These Plans are the basic programming mechanism of the Spanish system of R&D and innovation. They establish priorities, policy objectives and design the instruments to achieve them. The main objectives of the Plans for these two periods were to significantly increase the scientific and technological level of Spain, to promote the technological and innovation potential and competitiveness of firms, to enhance the relation between the public research system and private agents, to reinforce cooperation between national and regional levels, to strengthen the international dimension of the Science and Technology (S&T) system, to provide a favourable climate for R&D investment and to provide favourable conditions for the promotion of scientific culture and the diffusion of S&T advances in society. These Plans had different programmes and instruments (European Commission, 2010). Although the Spanish government is the main actor in R&D policy, most regional governments have their own innovation policies. In these policies, they also grant R&D subsidies to firms as a part of a strategy of reinforcing their respective regional innovation systems.

In both the Spanish national and regional governments the promotion of R&D projects in firms through the granting of subsidies is mainly done through competitive calls and with an evaluation of the proposals of the firms. R&D subsidies are granted in these calls in a process similar to international procedures (Jaffe, 2002; Takalo et al., 2013). First, an overall budget is allocated to the call for R&D subsidies. Second, firms apply for subsidies by submitting a proposal for an R&D project. This application contains qualitative and quantitative information on both the firm and the R&D project itself. Third, in accordance with established and public criteria, experts evaluate the projects. The main criteria considered in the Spanish calls for this period that were the most important in quantitative terms (Herrera and Nieto, 2008) were the scientific and technological contribution of the R&D project, the socio-economic impact and cooperation with agents of the S&T system. Other criteria also considered were the feasibility of the project and the expected increase in R&D activities. Finally, a committee used this information to determine which projects would be granted a subsidy and the amount of that subsidy.

3.2. Data description

The data used in this study are taken from the Spanish Technological Innovation Panel (PITEC). This database is compiled for Spain by the National Statistics Institute (INE). This body is advised in this task by a group of university researchers and sponsored by the Spanish Foundation for Science and Technology (FECYT) and the COTEC Foundation. The panel database includes the annual Survey of Innovation in Companies, carried out annually by the INE following the guidelines of the OECD's Oslo Manual, which means it can be compared with similar European innovation surveys (Community Innovation Survey). The panel comprises 12,283 firms drawn from industrial and service sectors for the period 2003-2011. We limit our study to the period 2006-2011 given that some questions in the survey have changed over the years and some information is not available for the early years. The PITEC provides detailed information about R&D employment according to occupation and level of education or formal qualifications of R&D personnel. Its panel structure allows lagged variables to be included to control for previous performance and the granting of subsidies so that potential persistency in the allocation of public funds can be taken into account.

Occupation data are classified according to the criteria proposed by the OECD (2002) in the Frascatti Manual, distinguishing between researchers, technicians and other support staff employed in R&D activities measured in full-time equivalent (FTE). Education data also adhere to OECD guidelines and include the following categories: PhD holders (ISCED level 6), Graduates or Engineers (ISCED level 5a), Short-cycle tertiary (ISCED level 5b) and personnel with non-tertiary education (ISCED level 4 or below). Although a new version of the International Standard Classification of Education was published in 2011, we use the categories from the 1997 version as these are used in the PITEC in the period 2006-2011.

Table 1 shows the distribution of R&D personnel classified by occupation and level of education. By occupation, researchers constitute the main group followed by technicians and auxiliary staff in R&D. By level of education, graduates and engineers are the most numerous group followed by personnel with non-tertiary education, those with short-cycle tertiary and, finally, PhD holders. The number of PhD holders in firms in Spain is below the respective OECD and EU averages (Cruz-Castro and Sanz-Menéndez, 2005) but their number has tended to increase in recent years.

Table 1

3.3. Methodology

The evaluation of technology policy has evolved rapidly in recent years and traditional problems in the evaluation of R&D subsidies such as sample selection and endogeneity have been broadly analysed in the empirical literature (Cerulli, 2010). The first of these problems, sample selection, arises because it is only possible to observe the performance of those firms participating and obtaining public subsidies. The second problem is that the variables used to measure the effect of public intervention (e.g. private effort in R&D) could be endogenously determined if we assume that firms making a greater effort in R&D are more likely to be subsidized.

Most recent studies use non-parametric matching techniques to solve these problems. Propensity score matching (PSM), as a matching method for the estimation of the average treatment effect on the treated (ATT), has been used extensively in empirical studies of the effects of R&D subsidies (see, among others, Aerts and Schmidt; 2008; Almus and Czarnitzki, 2003; Carboni, 2011; Czarnitzki and Licht, 2006; Czarnitzki and Lopes Bento, 2013; Duch et al. 2009; Duguet, 2004; González and Pazó, 2008; Herrera and Nieto, 2008).

We also use non-parametric techniques. We combine two matching techniques in order to ensure the maximum degree of similarity between control and treated groups. The first technique is coarsened exact matching (CEM) as proposed by Blackwell et al. (2009) and the second is PSM as proposed initially by Rosenbaum and Rubin (1983). Using CEM before the implementation of the subsequent matching technique is suggested as an appropriate procedure that improves the quality of matching and the inferences drawn after PSM (Blackwell et al., 2009; Iacus et al., 2011).

Matching techniques allow the comparison of two potential results, W^1 for those firms receiving the subsidy, D=1, and W^0 for those firms not receiving any treatment (D=0). Matching is based on the conditional independence assumption (CIA), which states that, conditional on a vector of covariates, potential outcomes W^1 and W^0 are independent of D. In order to ensure the fulfilment of this assumption it is necessary to observe those variables that simultaneously affect the outcome and the reception of the treatment exhaustively.

The wealth of information provided by the PITEC allows an exhaustive set of variables to be selected and similar controls to be included as those used in previous evaluation studies (see, among others, Aerts and Schmidt, 2008; Almus and Czarnitzki, 2003; Antonelli and Crespi, 2013; Czarnitzki and Lopes-Bento, 2013; Czarnitzki and Lopes-Bento, 2014; González and Pazó, 2008; Hussinger, 2008).

We consider three different types of variables. First, we control for the experience of firms of obtaining subsidies in previous periods or from other levels of government. The experience gained in past and current applications seems to be valuable for subsequent applications, which underlines both the importance of the learning process and the persistence of R&D activities (Antonelli and Crespi, 2013; González and Pazó, 2008). Taking advantage of the panel data structure, we include a lagged variable to control for persistence in obtaining subsidies, as has been done in other papers that use the same methodology (Czarnitzki and Lopes-Bento, 2013; Duguet, 2004; González and Pazó, 2008). In addition, receiving subsidies from other agencies - regional, national or European - may also have influence on obtaining subsidies from a specific government level. We therefore control for subsidies granted by other levels of government when estimating the effects of one specific source of public financing.

Second, we include a large number of variables regarding the R&D activities of firms and their characteristics. Most of these variables are considered in the year previous to the granting of the subsidy to minimise possible endogeneity concerns and also to control for the path dependence associated with the innovation process. These variables are whether the firm performs internal R&D, the characteristics of the R&D staff according to their occupational level, and the number of patents applied for. All these variables control for the degree of engagement in R&D activities and for innovation potential. These may be important in making the firm eligible to receive subsidies. In this group of variables we also include whether the firm has engaged in R&D cooperation, a criterion that is usually taken into account in granting subsidies. R&D cooperation may increase the likelihood of receiving public support because of the importance that technology policy at different levels of government gives to reinforcing relationships between the different agents of the innovation system. As a proxy for the existence of financial constraints we also use, in a similar way to Aerts and Schmidt (2008), a four-point-Likert-scale reflecting whether the firm considers the lack of funds within the firm to be an important factor hampering innovation activities. Finally, we include a proxy for the training activities of the firms because of possible complementarities between human capital and innovation.

Third, we include a large number of variables related to the characteristics of firms that the literature shows may influence receiving a subsidy and the R&D activities and outcomes of firms. Specifically, we use the following characteristics. We include size measured in terms of employees. Because one of the main outcomes to estimate is the effect on R&D employment we have considered total employees less R&D employees. Size may affect the likelihood of receiving a subsidy although according to different criteria with central or regional governments. While being a large firm may increase the likelihood of receiving central government subsidies, regional subsidies may be more oriented towards small and medium-sized firms. Second, we include the age of the firm. Public policy may be more oriented towards supporting R&D projects in start-ups or young firms. Nevertheless, the expected result is inconclusive because older firms are more likely to have better knowledge about public support and about different funding alternatives (Huergo and Trenado, 2010). Third, we include exports to control for the possible relationship between innovative and exporting activities, and also because this can influence the decision of the agency, which may want to reinforce the competitive position of those firms that participate in international markets.

We also include some characteristics of the firm related to organisation and ownership. We control for whether the firm belongs to a group and if there is foreign capital participation. As Czarnitzki and Lopes-Bento (2014) point out, agencies may favour firms that are part of a group because they are more likely to benefit from potential spillovers. In addition, firms belonging to groups may have more information about public calls and better funding resources (Antonelli and Crespi, 2013). On the other hand foreign ownership might have a negative influence on the probability of receiving R&D subsidies because country level public support may be more directed towards promoting domestic investments in R&D. In addition we take sector heterogeneity into account with dummies to control for differences in technological content. Public support may favour, in a “picking-the-winners” strategy, high-tech manufacturing or services firms. However, regional subsidies may be more oriented towards traditional manufacturing activities in order to regenerate low and medium-low technology companies. Finally, we take the geographic location of the firm into account and we include, using all the information available in the PITEC, dummies for the three biggest Spanish regions (Andalusia, Catalonia and Madrid) to control for specific regional factors that may affect the likelihood of receiving a subsidy and the outcomes.

In order to guarantee the similarity between treated and control groups, the first method used is the CEM, which allows covariates to be matched exactly. The main advantage of CEM over other matching methods is that the maximum imbalance of the empirical distribution is bounded through an ex-ante user choice. By choosing this imbalance ex-ante, users can control the amount of imbalance in the matching solution. By so doing this method improves the estimation of causal effects and reduces differences between treated and control groups (Collins et al., 2011; Finseraas et al., 2011; Mason et al., 2011).

By combining CEM with other matching methods, it is possible to improve the estimates in several ways, such as reducing variance or removing heterogeneity. Furthermore, CEM has two main benefits. It meets the congruence principle and it restricts the matched data to areas of common empirical support (Iacus et al., 2011).

Finally, matching methods inherit many of the CEM properties when applied to further matching data pre-processed by the CEM method (Blackwell et al, 2009).

CEM generates intervals for each variable submitted for comparison, coarsening observations into different subgroups. After coarsening each variable into substantively meaningful groups, the exact matching algorithm is applied to the coarsened data, and the values of the matched data are retained uncoarsened.

The measure of imbalance in CEM is obtained using this formula:

$$\mathcal{L}_1(f, g) = \frac{1}{2} \sum_{\ell_1 \ldots \ell_k} \left| f_{\ell_1 \ldots \ell_k} - g_{\ell_1 \ldots \ell_k} \right| \quad (1)$$

where $f_{\ell_1 \ldots \ell_k}$ and $g_{\ell_1 \ldots \ell_k}$ are relative frequencies of the discretized variables $X_{1 \ldots} X_{k,}$ for the treated and control units respectively.

The data for the period 2006-2011 are treated as pooled data; thus observations for the same firm in different years are considered as independent observations. After discarding variables with missing values, CEM is run, providing a sample of treated and control firms, matched exactly for a set of variables. The next step involves the use of a second matching method, in this case propensity score matching (PSM), on the sample previously matched with CEM. Rosenbaum and Rubin (1983) define the PSM as the conditional probability of being treated given a vector of covariates X:

$$p(X) \equiv P(D=1|X) = E(D|X) \quad (2)$$

where D is a dummy variable indicating the exposure to the treatment that takes values D= (0,1). Then, ATT is formulated as follows:

$$\tau = p(x)\Big|D=1\left\{E\left[Y(1)|D=1, P(X)\right] - E\left[Y(0)|D=0, P(X)\right]\right\} \quad (3)$$

where:

Y(1) represents the expected outcome for subsidized firms.

Y(0) represents the outcome for non-subsidized firms.

The nearest neighbour matching (NNM) algorithm is used to construct the treatment and control groups. The two nearest neighbours for each subsidized firm, restricted to common support, are obtained. The set of variables used in the matching procedure, CEM and PSM, are described in Table A.1.

4. Results

4.1. Determinants of the probability of receiving an R&D subsidy

The results of the probit estimations, carried out after the CEM (Appendix, Table A.2), regarding the determinants of a firm receiving a subsidy are consistent with the literature. The results also show that there are some differences between the variables influencing the probability of receiving national or regional subsidies, although most results are similar for both subsidies. First, the variables corresponding to a firm's experience in obtaining subsidies in previous periods play a key role in obtaining public funds. To receive subsidies from other public agencies also has an important influence.

Second, the variables for the R&D activities category show that previous internal R&D has a positive influence on obtaining subsidies, a result confirming the persistency of R&D and that public support favours firms that already perform R&D. R&D cooperation significantly increases the likelihood of receiving public support in all the estimations. This result underlines the fact that the purpose of technology policy is to reinforce relationships between the agents of the innovation system. Public support is also more oriented towards firms with existing technology activities as is shown by the positive and statistically significant parameter corresponding to patents.

Finally, the variables related to the characteristics of firms show that size, age, to form part of a group and to be an exporter increase the likelihood of receiving a subsidy. However public support does not seem to particularly favour high-tech manufacturing firms. The results also reveal some differences between national and regional subsidies.

4.2. Validity of the matching

The validity of the matching is a crucial step in applying these techniques and the main objective is to determine the similarity of the joint distribution of the set of covariates corresponding to the control and treated groups (Stuart, 2010). A common procedure to confirm that both groups are properly balanced involves estimating the standardized bias or the difference in standardized means, before and after matching (LaLonde, 1986; Rosenbaum and Rubin, 1983).

$$\frac{\bar{x}^1-\bar{x}^0}{\sqrt{(Var(x^1)-Var(x^0))}}.100 \qquad (4)$$

Table A.3 in the appendix shows, for each variable, the reduction in bias achieved in the differences between treated and controls after the second matching procedure (PSM). The mean values for these variables do not present significant differences between controls and treated groups receiving national, regional or total public funding for R&D.

4.3. Impact of R&D subsidies

Table 2 shows the results corresponding to the effect of public subsidies for R&D activities, without distinguishing between the levels of government. These results correspond to different categories of R&D expenditures and number of R&D employees classified by type of occupation and level of education. In these estimations, the effects on the different outcomes are estimated for the same year as the granting of the subsidy.

In line with previous studies for Spain (Busom, 2000; González and Pazó, 2008; González et al., 2005; Herrera and Heijs, 2007), these results reveal the existence of financial additionality in private R&D expenditures. The estimations also show that public subsidies have a positive and significant effect on the number of R&D employees. Public subsidies afford firms the possibility of increasing their stock of human capital and of allocating it to R&D projects. This is something that, according to the empirical literature, will have positive effects on a firm’s productivity and innovative performance.

Our data allow us to examine not only the magnitude of the increase in the number of R&D employees but also to analyse the behaviour of subsidized firms taking certain characteristics of their R&D staff, such as occupation and educational level, into account. This level of observation enables us to examine changes in the internal structure of the firm and to analyse whether the subsidy induces changes in these two dimensions of R&D human resources.

By occupation, the increase in the overall size of R&D staff induced by subsidies leads to increases in each of the three categories (i.e., researchers, technicians and auxiliary personnel), although the greatest growth is recorded in the number of researchers. By level of education, the increase in R&D personnel is mainly in the number of graduates followed by personnel with other non-tertiary and short cycle tertiary studies and, finally, PhD holders.

Table 2

To examine whether these increases in the different categories of R&D employees lead to an improvement of the average level of human capital we compare the structure of the R&D staff in the treated and control firms by both occupation and qualification. The results (Appendix, Table A.4) do not reveal the existence of a greater proportion of highly qualified personnel in treated firms. Thus, for example, the percentages of researchers among R&D staff are 47.4% and 55.9% for treated and control firms respectively. Similarly, while 4.2% of the R&D staff hold PhDs in the treated firms, this percentage is 5.5% in the controls. These results show that subsidies generate an increase in R&D expenditures and an increase in R&D staff numbers, but that they do not bring about changes in the composition of R&D personnel in the same year as when the subsidy is received.

Nevertheless public subsidies may have long-term effects distributed over several years. It takes time to implement R&D activities and for their benefits to show. In addition R&D support programmes may be targeted more at medium and long-term objectives (Cerulli, 2010; Zúñiga-Vicente et al., 2014). To recruit but also to fire R&D personnel, particularly highly qualified personnel, may imply high adjustment costs for the firms. In addition, once a firm hires a PhD holder for a subsidized R&D project, it may retain the PhD for later years. After hiring a PhD, a firm will have better information on their contribution to its research activities (García-Quevedo et al., 2012) and these highly qualified personnel will also have acquired firm-specific knowledge. Therefore the short-term and long-term effects of public subsidies on R&D employment may differ.

To examine potential effects in the years after receiving a subsidy we took advantage of our longitudinal data and we estimated the impact of receiving a subsidy in the year t on the outcome variables for the next two years, t+1 and t+2. In these estimations we used the same control variables as previously but we also controlled for receiving a subsidy in t+1 and t+2. The purpose of this is to attribute to the treatment, receiving a subsidy in the year t, the effects for the two subsequent years, in the most precise way possible. Nevertheless, some caution is necessary because of the difficulties in controlling properly for all the variables that may affect the outcomes of t+1 and t+2. Although we were controlling for subsidies in t+1 and t+2, other variables may not have remained invariant throughout this period of time, and this would influence the outcome variables.

The results (Table 3) show that the effects of public subsidies go beyond the year of treatment. However these impacts diminish through time both in quantitative terms and in significance. The results regarding changes in the R&D staff provide evidence that the treatment in year t has a positive and significant effect on total personnel in R&D, on researchers and PhD holders in the next year, t+1, while for the year t+2 the only positive effect to be found is in the recruitment of PhD holders. These results suggest that public subsidies may have medium-term effects and help to improve the average level of qualification of R&D staff, particularly regarding the employment of PhD holders. The comparison of the structures of R&D staff by occupation and qualification in treated and control firms (Appendix, Table A.5) shows that for the subsequent years, t+1 and t+2, the proportion of PhD holders among R&D staff is notably greater in treated firms than in control firms. In the year t+1, 5.3% of the R&D staff in the treated firms holds a PhD, while in control firms the proportion is 3.1% (7.9% and 3.2% respectively in year t+2)

Table 3

As shown by recent empirical literature and its growing interest in analysing possible heterogeneous effects, the impact of public financing may differ depending on the firms' characteristics. This heterogeneity suggests that a firm's reaction to public intervention may be conditioned by specific characteristics that influence the innovation process. Several papers analyse the impact of R&D subsidies on firms according to their size (Falk, 2007; González and Pazó, 2008; Lach, 2002; Össçelik and Taymaz, 2008). In this paper, the possible existence of differences attributable to firm size is also analysed. Additionally, we take the type of R&D performed into account, whether it is continuous or occasional in nature.

R&D subsidies are mainly granted to solve market failures and financial market imperfections that hamper access to finance for R&D projects. These failures primarily affect those firms that face difficulties in meeting the financial costs of R&D projects. Therefore differences in the impacts of public subsidies on small and medium-sized firms, on the one hand, and on large firms, on the other, are to be expected, since the latter *a priori* face fewer financial restrictions and are less dependent on public funding. In order to test this hypothesis, ATT was estimated by splitting the sample into two groups, firms with 250 employees or less and firms with more than 250 employees (Table 2).

The results show, first, that there are financial additionality effects of R&D subsidies for both types of firm and for all categories of R&D expenditure. Second, R&D subsidies have a significant impact on the number of R&D employees. Third, there is an increase in all categories of R&D employees, by occupation and or level of education, in both types of firm. Therefore, even in small and medium-sized firms, the granting of R&D subsidies leads to the recruitment of graduates and PhD holders.

With the aim of analysing the impact of public financing on firms performing R&D on a regular basis compared with those firms performing occasional R&D, ATT was estimated considering the frequency of R&D activities. While firms that perform R&D on a regular basis have, in general, long-term R&D strategies and stable R&D staffs, occasional performers do not, in many cases, have a formal R&D organisation. Different effects of public financing are expected in relation to differences in the qualifications held by staff members in both types of firm and also to the characteristics of the subsidized projects.

The results show an additional effect of public subsidies on R&D expenditures and an increase in the number of R&D personnel in the two types of firm. The growth in the overall size of R&D staff attributable to a subsidy leads to an increase in each of the three categories of occupation in both cases. Nevertheless, by level of education, there is no statistically significant impact on the recruitment of PhD holders for firms performing R&D on a regular basis. In contrast, our results show that for firms performing occasional R&D, public subsidies have a positive effect on the level of education of their R&D staff with a rise in the number of PhDs recruited and significant differences in the participation of PhD holders in the structure of the R&D staffs of treated and control firms. This result suggests that occasional R&D performers face human capital shortcomings when seeking to carry out new R&D projects and that the subsidies granted to these firms have additional effects by increasing the average level of education.

4.4. Impact of subsidies according to different levels of government.

Previous analyses indicate, as discussed above, that technology policies implemented at different levels of government correspond to different motivations. Table 4 shows the impact according to national and regional levels of public financing. Calls for applications for public subsidies from a specific level of government do not exclude firms already being subsidized by other levels of government. Consequently in a given year a firm can receive public subsidies from more than one source. To take this into account, ATT was calculated for each level of government, controlling for the possibility that subsidies may have been obtained from other public agencies. In addition Table 4 also shows the ATT estimation for those firms receiving just one subsidy in a given year, i.e. only national or only regional.

The results show that public financing (both national and regional subsidies) has a positive effect on the number of employees; however, the magnitude of this effect is greater in the case of national subsidies. The respective quantitative impacts on the different categories of R&D staff by level of education in subsidized firms also differ significantly. National subsidies have a greater effect on the recruitment of employees holding PhDs than regional subsidies and for the firms that receive only regional support the effect is not significant.

These results are consistent with the different objectives targeted by national and regional agencies respectively. Spain's national government seems to adopt a "picking-the-winners" strategy, promoting R&D and high-technology projects that require qualified personnel. In contrast most regional governments show a greater concern for promoting innovation (but not exclusively R&D) and for improving the links between the agents in their regional systems. Nevertheless, the recruitment of PhD holders attributable to national subsidies and the relative R&D staff structures of treated and control firms do not present any significant differences in the short-term. These results therefore seem to confirm those obtained for total subsidies indicating that R&D subsidies do not generate additional effects in terms of the average level of qualification of R&D staff.

Table 4

4.5. Robustness checks

In order to verify the robustness of our estimations and results we have carried out two complementary analyses regarding estimation procedures and a "placebo" test with a different definition of the dependent variable.

The first robustness check concerns the matching procedure and the selection of the observations for the control group. In our analysis we have restricted the matching to firms in the same year. With this procedure we are able to control for annual changes in cyclical behaviour, financial conditions, and fiscal policies among other things. These are areas in which change was very intense in Spain during this period. In addition, it also allows possible changes in R&D subsidy policies during these years to be controlled for. All of these are non-observable factors that may affect the likelihood of being granted a subsidy and the outcome. However, with this procedure we missed the fact that in the matching estimations a firm in a different year acts as its own control observation if its support status has changed. For short periods of time, the same firm may behave as a proper control because it helps to consider non-observable factors such as management quality that may be similar when comparing near time spans. To take this possibility into account we have carried out the estimations without imposing the condition that the matching is restricted to firms in the same year. The results for total subsidies (Appendix, Table A.6) are, both in significance and in quantitative values, very similar to those of the main estimation and lead to the same conclusions regarding the additional effects of R&D subsidies and changes in human resources.

Second, in the main estimations we have considered non-parametric matching to be the most suitable approach due to the characteristics of our data. To guarantee the quality of the matching we have used CEM and PSM methods and a large number of relevant control variables to correct for selection bias. One general limitation of this method is that it only controls for the selection on observables. The availability of panel data offers, *a priori*, the possibility of using a diff-in-diff estimator. However the lack of information regarding the length of each project and the existence of multiple treatments with concessions that follow irregular trajectories over time hinders the establishment of a baseline year without loss of data and an appropriate application of a diff-in-diff estimator turns out to be very difficult (Czarnitzki et al., 2011). We also faced, like Czarnitzki and Lopes-Bento (2014), the limitation that quite a large percentage of the firms were only observed once in the sample or were not observed in two consecutive periods. In addition, those firms receiving public funds every year from either national or regional governments are discarded in diff-in-diff estimations. A necessary condition to be met in order to perform a diff-in-diff analysis is that the firms have not received a subsidy in at least one year. Considering their R&D performance, these discarded firms would be, presumably, one of the main targets of R&D policy. Therefore using a diff-in-diff estimator implies a considerable loss of observations, 30.8% of our sample, and of information in analysing the effects of R&D subsidies. Despite these limitations we carried out a diff-in-diff estimation, following the same procedure as Lach (2002) to pool the data. The results (Appendix, Table A.7) are consistent with our main results and again suggest that our findings are robust.

Finally, in the third robustness check we carried out a “placebo” test. Our hypothesis is that public subsidies addressed to promoting the R&D activities of firms should have an additional effect on R&D expenditure and on R&D employment but not on non-R&D employment, at least in the short-term. The results (Appendix, Table A.8) confirm this hypothesis and show that the effects of R&D subsidies on non-R&D employment are not significant. These results also reinforce the validity of our estimations and the conclusions regarding the causal relationship between public subsidies and R&D employment.

5. Conclusions

In this paper we have analysed the impact of public subsidies on the composition of R&D employment. Despite R&D employment being a priority objective in technology policy, few studies explicitly examine this relationship. After confirming that subsidies increase both total and private R&D expenditures, our estimations show that public support has a positive effect on the number of R&D employees. However, our results do not identify the existence of behavioural additionality effects in the short-term. The increase in the size of the R&D staffs of subsidized firms does not lead to an improvement in the average level of qualification of the staff members in the same year as the subsidy is received. Nevertheless, there are positive effects on the recruitment of PhD holders in the years after receiving the subsidy.

Our results show that when evaluating the impact of R&D subsidies it is necessary to consider the multilevel structure of governments involved in the granting of subsidies. Indeed, our findings point to differences depending on the level of government. At the two levels considered - national and regional - subsidies have a positive effect on the number of R&D employees but in the case of firms that only receive regional subsidies there is no significant effect on the recruitment of PhDs.

The analysis carried out is not free of limitations. First, as in most studies of this kind, information about the specific characteristics of the projects actually being funded is not available. Second, it is not possible to distinguish between subsidies granted by the various regional agencies that may have quite distinct innovation policy objectives. Third, the time period for which information is available is too short for a detailed examination of the potential long-term effects regarding changes in the wages and in the supply of highly qualified personnel such as PhD holders.

Despite these limitations, this analysis has provided information about the effects of technology policy. First, it confirms the existence of financial additionality as regards

R&D expenditures and employees. Second, the results do not show that R&D subsidies lead to significant changes in the composition of R&D staff in subsidized firms and they rule out the existence of additional effects on the level of education of R&D personnel in the same year as receiving the subsidy. Third, the analysis carried out shows the importance, as Cerulli (2010) and Zúñiga-Vicente et al., (2014) point out, of analysing the impact of public subsidies not only in the short-term but also in the medium and long-term. Our results for the educational composition of R&D personnel suggest that the subsidies have positive effects on the proportion of PhD holders in the R&D staff of a firm in the years after the granting of a subsidy. Finally, our results show that R&D subsidies have no effect on non-R&D employment, at least in the short-term. This result confirms, first, the effectiveness of R&D policy in fostering the recruitment of highly qualified employees devoted to R&D activities, and second allows us to rule out a substitution effect replacing non-R&D employees with R&D personnel.

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Table 1. R&D personnel by occupation and level of education (data in full-time equivalent, FTE)

	Occupation				Education				
Year	Researchers	Technicians	Auxiliary staff	Total	PhD	Graduates/ Engineers	Short cycle tertiary	Non-university degree	Total
2006 (10444)*	2.51	2.03	0.86	5.40	0.31	2.57	1.21	1.31	5.40
2007 (10479)*	2.56	2.10	0.83	5.50	0.36	2.62	1.17	1.35	5.50
2008 (10421)*	2.64	2.16	0.81	5.61	0.40	2.69	1.19	1.33	5.61
2009 (10427)*	2.74	2.20	0.78	5.71	0.39	2.80	1.20	1.32	5.71
2010 (10014)*	2.79	2.37	0.76	5.91	0.43	3.05	1.14	1.30	5.91
2011 (9619)*	2.74	2.27	0.76	5.77	0.44	2.87	1.17	1.28	5.77
Total (61404)*	2.66	2.19	0.80	5.65	0.39	2.76	1.18	1.32	5.65

Note: Mean values at firm-level. * Number of observations.

Table 2. Impact of R&D subsidies. Subsidies from any public administration.

	Total		250 employees or less		More than 250 employees		Continuous R&D performers		Occasional R&D performers	
Variable	**Difference**	**T-stat**	**Difference**	**T-stat**	**Difference**	**T-stat**	**Difference**	**T-stat**	**Difference**	**T-stat**
Total R&D expenditures	85088.77	12.23***	62422.49	7.86***	296172.73	5.30***	99420.38	5.74***	83328.21	6.86***
Private R&D expenditures	69691.25	8.42***	53454.74	6.05***	247372.25	4.01***	29715.48	1.60	67307.30	5.21***
Internal R&D expenditures	60981.80	12.17***	44027.77	8.62***	224180.51	5.40***	77303.47	4.72***	56804.77	6.74***
Total personnel in R&D	0.81	14.23***	0.63	8.97***	3.78	4.79***	1.18	6.65***	0.83	8.28***
Research personnel	0.32	10.63***	0.27	7.23***	1.71	4.76***	0.54	5.28***	0.40	7.27***
Technicians	0.31	10.79***	0.23	6.61***	1.72	3.46***	0.42	4.54***	0.27	6.36***
Auxiliary staff	0.16	9.43***	0.12	6.08***	0.34	2.98***	0.22	3.53***	0.15	5.63***
PhDs	0.02	3.09***	0.02	2.47***	0.10	3.28***	0.03	1.06	0.02	2.44***
Graduates	0.44	2.83***	0.29	7.79***	2.21	4.69***	0.64	6.22***	0.44	6.55***
Short cycle tertiary	0.15	8.22***	0.12	5.26***	0.95	3.13***	0.27	3.91***	0.16	6.09***
Non-university degree	0.19	7.92***	0.18	5.43***	0.50	3.34***	0.22	2.57***	0.20	6.21***

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively. R&D expenditures are expressed in Euros and personnel in FTE.

Table 3. Impact of R&D subsidies in the years t+1 and t+2. Subsidies from any public administration

	Total. Year t+1		**Total. Year t+2**	
Variable	**Difference**	**T-stat**	**Difference**	**T-stat**
Total R&D expenditures	45076.26	1.90*	35081.05	1.77*
Private R&D expenditures	40374.51	1.79*	29901.54	1.55
Internal R&D expenditures	19721.46	1.10	12763.71	1.20
Total personnel in R&D	0.24	2.37***	0.07	0.52
Research personnel	0.12	1.97**	-0.01	0.13
Technicians	0.07	1.53	0.04	0.47
Auxiliary staff	0.04	1.53	0.04	1.11
PhDs	0.03	2.47***	0.04	2.34**
Graduates	0.12	2.15**	0.00	0.00
Short cycle tertiary	0.05	1.62	0.00	0.03
Non-university degree	0.04	0.92	0.02	0.34

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively. R&D expenditures are expressed in Euros and personnel in FTE. In addition to the covariates used in the previous estimations (see Table A.1 for the list of variables), treatment in t+1 and treatment in t+2 are included in the estimations of ATT in t+1 and in t+2, respectively.

Table 4. Impact of R&D subsidies by level of government

	National R&D subsidies		Regional R&D subsidies		Only National R&D subsidies		Only Regional R&D subsidies	
Variable	**Difference**	**T-stat**	**Difference**	**T-stat**	**Difference**	**T-stat**	**Difference**	**T-stat**
Total R&D expenditures	118560.98	6.80***	68157.74	4.75***	136504.77	8.30***	59576.36	7.19***
Private R&D expenditures	101017.09	5.20***	39090.18	5.06***	96327.97	6.57***	48639.07	5.27***
Internal R&D expenditures	103383.33	7.14***	53573.53	3.93***	106891.36	8.13***	46685.62	6.58***
Total personnel in R&D	1.40	6.60***	0.55	7.33***	1.71	8.82***	0.62	8.45***
Research personnel	0.54	7.13***	0.26	5.86***	0.62	7.07***	0.24	5.85***
Technicians	0.61	4.55***	0.19	6.18***	0.79	6.65***	0.22	6.71***
Auxiliary staff	0.24	5.05***	0.09	4.28***	0.29	5.38***	0.14	5.60***
PhDs	0.07	3.60***	0.02	1.77*	0.08	3.25***	0.003	0.57
Graduates	0.78	7.10***	0.28	6.88***	0.84	6.85***	0.30	6.88***
Short cycle tertiary	0.26	3.53***	0.11	5.31***	0.37	5.89***	0.14	5.23***
Non-university degree	0.28	4.66***	0.12	3.67***	0.40	6.01***	0.16	4.90***

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively. R&D expenditures are expressed in Euros and personnel in FTE. Dummy variables for subsidies from the European Union (EU) and regional governments are included in the estimation of the impact of national R&D subsidies. Dummy variables for subsidies from EU and national government are included in the estimation of the impact of regional subsidies.

Table A.1. Data description

Variable	Description	Obs.	Mean	Std. Dev.
National subsidies	Dummy=1 if the firm receives national subsidies, 0 otherwise	61404	0.18	0.39
Regional subsidies	Dummy=1 if the firm receives regional subsidies, 0 otherwise	61404	0.19	0.39
European subsidies	Dummy=1 if the firm receives European subsidies, 0 otherwise	61404	0.04	0.20
Total subsidies in t-1	Dummy=1 if the firm receives subsidies from some administration in the previous year, 0 otherwise	61404	0.32	0.46
Internal R&D in t-1	Dummy=1 if the firm performs internal R&D activities in the previous year, 0 otherwise	61404	0.51	0.50
Patents	Dummy=1 if the firm applies for patents, 0 otherwise	61404	0.10	0.30
Training	Dummy=1 if the firm imparts training courses to its workers, 0 otherwise	61404	0.11	0.31
Foreign	Dummy=1 for firms with 50% or more of foreign capital, 0 otherwise	61404	0.13	0.33
Lack of internal funds in t-1	Categorical variable between 1 (not experienced) to 4 (high importance) regarding the firm's assessment of the lack of internal funds as a factor hampering innovation activities	61404	2.35	1.13
Group	Dummy=1 if the firm belongs to a group, 0 otherwise	61404	0.40	0.49
Size non-R&D	Total number of non-R&D employees	61404	302.18	1452.01
R&D cooperation in t-1	Dummy=1 if the firm engages in R&D cooperation, 0 otherwise	61404	0.20	0.40
High technology	Dummy=1 if the firm belongs to high technology manufacturing sector, 0 otherwise	61404	0.05	0.21
Medium-high technology	Dummy=1 if the firm belongs to medium-high technology manufacturing sector, 0 otherwise	61404	0.17	0.38
Medium-low technology	Dummy=1 if the firm belongs to medium-low technology manufacturing sector, 0 otherwise	61404	0.15	0.35
High technology services	Dummy=1 if the firm belongs to high technology services sector, 0 otherwise	61404	0.11	0.31
Researchers in t-1	Number of researchers in FTE	61404	2.62	15.24
Technicians in t-1	Number of R&D technicians in FTE	61404	2.16	12.01
Auxiliary staff in t-1	Number of R&D auxiliary staff in FTE	61404	0.83	4.49
Madrid	Dummy=1 if the firm is located in the Region of Madrid, 0 otherwise	61404	0.18	0.39
Catalonia	Dummy=1 if the firm is located in the Region of Catalonia, 0 otherwise	61404	0.24	0.43
Andalusia	Dummy=1 if the firm is located in the Region of Andalusia, 0 otherwise	61404	0.06	0.25
Export	Dummy=1 if the firm exports, 0 otherwise	61404	0.60	0.49
Age	Age of the firm in years	61404	24.54	19.77

Table A.2. Probit estimations: Predicted probability of receiving an R&D subsidy

	Total subsidies			**National subsidies**			**Regional subsidies**		
	Coef.	Std. Err.	z	Coef.	Std. Err.	z	Coef.	Std. Err.	z
National subsidies							-0.080	0.108	-0.740
Regional subsidies				-0.103	0.086	-1.2			
European subsidies				0.276	0.423	0.65	-0.209	0.430	-0.490
Total subsidies in t-1	0.666	0.041	16.060***	0.409	0.081	5.04***	0.685	0.052	13.180***
Internal R&D in t-1	0.309	0.050	6.150***	0.300	0.079	3.82***	0.292	0.059	4.950***
Researchers in t-1	-0.015	0.032	-0.480	-0.003	0.032	-0.09	-0.031	0.033	-0.930
Technicians in t-1	-0.020	0.037	-0.550	-0.015	0.027	-0.58	-0.003	0.052	-0.050
Auxiliary staff in t-1	0.105	0.063	1.660*	0.012	0.065	0.19	0.180	0.086	2.080**
R&D cooperation in t-1	0.467	0.047	9.970***	0.362	0.073	4.95***	0.378	0.057	6.600***
Lack of internal funds in t-1	-0.017	0.017	-1.020	-0.014	0.030	-0.46	-0.017	0.022	-0.760
High technology	0.222	0.188	1.180	0.232	0.339	0.69	0.441	0.269	1.640
Medium-high technology	0.125	0.054	2.310**	0.158	0.084	1.89*	0.111	0.070	1.600
Medium-low technology	0.109	0.050	2.160**	0.239	0.088	2.71***	0.149	0.065	2.270**
High technology services	0.306	0.077	3.970***	0.222	0.119	1.87*	0.339	0.096	3.540***
Patents	0.291	0.141	2.070**	0.314	0.228	1.38	0.324	0.180	1.800*
Training	0.619	0.129	4.790***	0.444	0.184	2.41***	0.633	0.176	3.590***
Group	0.292	0.054	5.410***	0.268	0.083	3.25***	0.280	0.080	3.490***
International and private	0.175	0.134	1.310	0.076	0.184	0.41	0.395	0.239	1.650*
Madrid	0.180	0.072	2.490***	0.103	0.104	0.99	0.190	0.128	1.480
Catalonia	0.099	0.052	1.900*	0.115	0.081	1.42	0.157	0.081	1.950*
Andalusia	0.488	0.132	3.690***	0.513	0.297	1.73*	0.662	0.174	3.800***
Export	0.167	0.037	4.500***	0.049	0.063	0.78	0.170	0.047	3.600***
Size non-R&D	0.000	0.000	2.360***	0.000	0.000	1.41	0.000	0.000	1.110
Age	0.003	0.002	1.970**	0.006	0.003	2.42***	0.002	0.002	1.150
Constant	108.115	21.580	5.010***	92.841	35.775	2.60***	88.033	27.897	3.160***
	Pseudo R2	LR chi2	p>chi2	Pseudo R2	LR chi2	p>chi2	Pseudo R2	LR chi2	p>chi2
	0.130	1182.940	0.000	0.07	246.92	0.000	0.130	750.420	0.000
	N=7350			N=2622			N= 4731		

Note: Probit estimations carried out after the CEM. ***, **, and * denote significance at the 1%, 5%, and 10% level respectively.

Table A.3. Subsidies from National and Regional administrations. T-test of difference between means. Treated and control groups after matching

	Total subsidies				National subsidies				Regional subsidies			
	Mean			T-test	Mean			T-test	Mean			T-test
Variable	Treated	Control	% bias	t	Treated	Control	% bias	t	Treated	Control	% bias	t
National subsidies									0.06	0.06	4.00	0.87
Regional subsidies					0.28	0.30	-5.50	-0.95				
European subsidies					0.01	0.00	6.90	1.38	0.00	0.00	1.60	0.33
Total subsidies in t-1	0.50	0.50	0.90	0.26	0.52	0.55	-6.20	-1.15	0.56	0.55	2.80	0.65
Internal R&D in t-1	0.53	0.54	-1.90	-0.59	0.56	0.56	1.00	0.18	0.57	0.59	-4.10	-0.98
Researchers in t-1	0.44	0.44	-0.90	-0.25	0.61	0.53	7.60	1.34	0.47	0.48	-1.70	-0.39
Technicians in t-1	0.24	0.23	1.40	0.35	0.44	0.35	4.80	0.88	0.26	0.24	4.60	1.00
Auxiliary staff in t-1	0.13	0.11	7.70	2.29	0.18	0.17	1.30	0.23	0.14	0.13	4.60	0.98
R&D cooperation in t-1	0.26	0.23	8.70	2.45	0.28	0.26	4.60	0.79	0.27	0.24	9.70	2.15
Lack of internal funds in t-1	1.93	1.93	-0.50	-0.17	1.97	1.94	2.40	0.49	1.89	1.87	1.20	0.32
High technology	0.01	0.01	1.90	0.57	0.01	0.01	1.70	0.33	0.01	0.01	-3.00	-0.58
Medium-high technology	0.15	0.15	-1.90	-0.58	0.17	0.18	-3.10	-0.54	0.14	0.15	-1.60	-0.37
Medium-low technology	0.14	0.15	-2.90	-0.93	0.13	0.12	2.30	0.43	0.14	0.14	-0.40	-0.09
High technology services	0.07	0.08	-3.20	-0.91	0.08	0.08	1.30	0.24	0.08	0.08	-3.30	-0.73
Patents	0.02	0.02	1.20	0.33	0.02	0.02	2.70	0.46	0.02	0.02	-1.00	-0.21
Training	0.02	0.02	1.50	0.43	0.03	0.03	2.70	0.46	0.02	0.02	0.00	0.00
Group	0.14	0.15	-2.80	-0.87	0.19	0.19	-1.30	-0.23	0.11	0.11	-2.00	-0.48
Foreign	0.02	0.03	-5.50	-1.54	0.03	0.03	0.00	0.00	0.01	0.01	-2.20	-0.47
Madrid	0.06	0.06	-1.90	-0.60	0.09	0.09	-0.90	-0.18	0.03	0.03	-1.20	-0.29
Catalonia	0.13	0.14	-4.40	-1.39	0.17	0.15	3.30	0.64	0.08	0.10	-6.80	-1.56
Andalusia	0.02	0.02	-4.80	-1.42	0.01	0.01	-2.20	-0.36	0.02	0.02	0.70	0.16
Export	0.59	0.61	-4.60	-1.52	0.60	0.57	5.70	1.11	0.57	0.60	-4.70	-1.20
Size non-R&D	94.51	68.92	2.30	1.30	94.36	101.91	-0.60	-0.44	47.77	51.63	-3.10	-0.81
Age	19.82	19.76	0.50	0.14	20.80	19.66	9.10	1.71	18.58	18.79	-1.90	-0.45
		Pseudo R2	LR chi2	p>chi2		Pseudo R2	LR chi2	p>chi2		Pseudo R2	LR chi2	p>chi2
		0.005	32.29	0.073		0.008	16.86	0.855		0.005	19.23	0.740

Table A.4. Impact of public subsidies on the composition of R&D personnel by occupation and level of education.

	Treated	Control	Difference	Treated group (%)	Control group (%)
Total subsidies					
Research personnel	0.69	0.36	0.33***	47.39	55.94
Technicians	0.51	0.19	0.31***	34.89	30.05
Auxiliary staff	0.26	0.09	0.17***	17.72	14.01
Total	**1.45**	**0.64**	**0.81*** **	**100.00**	**100.00**
PhDs	0.06	0.04	0.03***	4.24	5.49
Graduates	0.71	0.27	0.44***	49.12	42.57
Short cycle tertiary	0.29	0.14	0.15***	19.73	21.23
Non-university degree	0.39	0.20	0.19***	26.92	30.72
Total	**1.45**	**0.64**	**0.81*** **	**100.00**	**100.00**
National subsidies					
Research personnel	0.96	0.41	0.54***	41.72	46.51
Technicians	0.95	0.33	0.62***	41.49	37.25
Auxiliary staff	0.38	0.14	0.24***	16.79	16.24
Total	**2.29**	**0.89**	**1.40*** **	**100.00**	**100.00**
PhDs	0.12	0.04	0.08***	5.09	4.61
Graduates	1.15	0.36	0.79***	50.15	40.91
Short cycle tertiary	0.46	0.19	0.26***	19.88	21.92
Non-university degree	0.57	0.29	0.28***	24.88	32.56
Total	**2.29**	**0.89**	**1.40*** **	**100.00**	**100.00**
Regional subsidies					
Research personnel	0.62	0.36	0.26***	49.64	51.90
Technicians	0.41	0.21	0.20***	32.58	29.93
Auxiliary staff	0.22	0.13	0.10***	17.78	18.17
Total	**1.24**	**0.69**	**0.56*** **	**100.00**	**100.00**
PhDs	0.06	0.03	0.03*	4.44	4.30
Graduates	0.58	0.29	0.29***	46.27	41.88
Short cycle tertiary	0.26	0.14	0.12***	21.05	20.64
Non-university degree	0.35	0.23	0.12***	28.25	33.18
Total	**1.24**	**0.69**	**0.56*** **	**100.00**	**100.00**

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively.

Table A.5. Impact of public subsidies on the composition of R&D personnel by occupation and level of education in the years t+1 and t+2.

Total subsidies (year t+1)

	Treated	Control	Difference	Treated group (%)	Control group (%)
Research personnel	0.49	0.36	0.13**	48.65	47.80
Technicians	0.34	0.27	0.08	34.47	35.72
Auxiliary staff	0.17	0.12	0.04	16.89	16.48
Total	**1.00**	**0.75**	**0.25*****	**100.00**	**100.00**
PhDs	0.05	0.02	0.03***	5.33	3.12
Graduates	0.43	0.31	0.12**	43.43	41.56
Short cycle tertiary	0.20	0.15	0.05	19.97	19.69
Non-university degree	0.31	0.27	0.04	31.27	35.63
Total	**1.00**	**0.75**	**0.25*****	**100.00**	**100.00**

Total subsidies (year t+2)

Research personnel	0.39	0.40	-0.01	45.48	50.47
Technicians	0.31	0.28	0.04	36.97	35.58
Auxiliary staff	0.15	0.11	0.04	17.55	13.95
Total	**0.85**	**0.78**	**0.07**	**100.00**	**100.00**
PhDs	0.07	0.02	0.04**	7.94	3.17
Graduates	0.35	0.35	0.00	41.26	44.85
Short cycle tertiary	0.18	0.18	0.00	20.81	22.44
Non-university degree	0.26	0.23	0.02	30.00	29.54
Total	**0.85**	**0.78**	**0.07**	**100.00**	**100.00**

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively.

Table A.6. Robustness test 1. Impact of R&D subsidies. Subsidies from any public administration

	Total	
Variable	**Difference**	**T-stat**
Total R&D expenditures	69858.65	3.27***
Private R&D expenditures	61581.91	2.52***
Internal R&D expenditures	55345.76	3.37***
Total personnel in R&D	0.70	5.00***
Research personnel	0.35	5.39***
Technicians	0.22	2.94***
Auxiliary staff	0.12	2.87***
PhDs	0.04	3.43***
Graduates	0.36	4.32***
Short cycle tertiary	0.14	3.78***
Non-university degree	0.15	2.80***

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively. R&D expenditures are expressed in Euros and personnel in FTE. The matching procedures, CEM and PSM, are not restricted to firms in the same year and include all the observations from the different years of the sample.

Table A.7. Robustness test 2. Difference in differences estimation

	Total R&D Expenditures	Private R&D Expenditures	Internal R&D Expenditures	Total personnel in R&D	Research personnel	Technicians	Auxiliary staff	PhDs	Graduates	Short cycle	Non-university degree
Treatment	0.288***	0.101***	0.237***	1.064***	0.608***	0.288**	0.168***	0.033**	0.451***	0.222***	0.359***
	(0.022)	(0.026)	(0.021)	(0.134)	(0.054)	(0.098)	(0.037)	(0.012)	(0.090)	(0.038)	(0.046)
N. obs.	15463	12385	14138	42464	42464	42464	42464	42464	42464	42464	42464

Note: Standard errors in parenthesis. ***, **, and * denote significance at the 1%, 5%, and 10% level respectively. The sample includes only observations for which R&D subsidies in t-1=0. Estimates were obtained using the Fixed Effects method. R&D expenditure variables are in logarithms. In addition to the treatment, the following variables are used as controls: R&D cooperation (t-1), lack of internal funds (t-1), patents, training, number of non-R&D employees (in logs), age (in logs) and year.

Table A.8. Robustness test 3 (Placebo test): Impact of R&D subsidies on non-R&D employment. Subsidies from any public administration

Variable	**Sample**	**Treated**	**Controls**	**Difference**	**S.E.**	**T-stat**
Size non-R&D	Unmatched	151.94	131.58	20.35	40.02	0.51
	ATT	151.94	170.73	-18.79	59.15	-0.32