ASSESSING THE RELATIONSHIP BETWEEN R&D SUBSIDY, R&D COOPERATION AND ABSORPTIVE CAPACITY. AN INVESTIGATION ON THE MANUFACTURING SPANISH CASE

Abstract

Private companies want to eliminate outgoing spillovers while policymakers seek to maximize them. With subsidized R&D cooperation agreements both agents partially achieve their objectives. For this reason, in Europe, policymakers grant subsidies for R&D activities with the condition of establishing R&D cooperation agreements. This study explores the relationship of complementarity between R&D subsidy, R&D cooperation and absorptive capacity in the context of its contribution to labor productivity of enterprises. The data used comes from the Technological Innovation Panel (PITEC), managed by the Spanish National Statistics Institute. We selected manufacturing companies in the period 2008-2013. We evaluate the existence of complementarity through the systems approach and the interaction approach. The econometric technique that we used to estimate the coefficients of our empirical model was maximum-likelihood random effects. As a consequence of the low absorptive capacity of Spanish manufacturing firms we find that R&D subsidies and R&D cooperation agreements are not complementary variables, i.e., receiving public subsidies as a result of establishing R&D cooperation agreements has a lower impact on productivity than the sum of the individual impacts of R&D cooperation and R&D subsidies. In consequence, this result calls into question the convenience of using subsidized R&D cooperation agreements as a tool for promoting innovation in EU countries as there are notable differences between the companies in these countries in terms of absorption capacity.

Keywords: R&D cooperation, R&D subsidy, Absorptive capacity, Complementarity approach

1 Introduction

In general, the economic literature assumes that highly innovative firms perform better than less innovative ones (Wolfe, 1994). Hence, it would be expected that companies invest heavily in R&D. This is, however, not always the case, since R&D investments generate outgoing spillovers, allowing a large number of competitors to take advantage of the efforts in R&D of other companies at virtually no cost. Thus, companies that benefit from outgoing spillovers can potentially reduce the market share of companies that invest in R&D, causing a decrease in their expected returns. These spillovers erode incentives to undertake private R&D investments and reduce the socially optimal level of such investments. Therefore, it could happen that some R&D projects with high social returns are never carried out by private companies. In this regard, most of the literature on innovation agrees that the outgoing spillovers lead to underinvestment in R&D from the social point of view. This underinvestment justifies policymakers in granting direct subsidies to private companies to undertake R&D investments (Aerts and Czarnitzki, 2006), or encouraging this kind of investment in politically desirable fields (Broekel et al., 2011). Policymakers try to maximize the amount of private R&D investments and to promote the rapid dissemination of R&D knowledge derived from these investments (Grossman and Helpman, 1991; Romer, 1990), as this increases the number of efficient and competitive domestic firms. But, in many cases, policymakers fail to increase the amount of R&D investments to the desired level, as many private companies decide not to apply for R&D subsidies and make the corresponding investments, because they do not want to strengthen the competitive position of rival companies.

Thus, it appears that private companies and public authorities pursue conflicting goals: private companies want to minimize the outgoing spillovers, while policymakers seek to maximize them. However, there is a scenario in which both agents can reach an agreement, if both renounce their maximalist positions: R&D cooperation agreements (Katz and Ordover, 1990).

These agreements do not enable companies to eliminate outgoing spillovers, but rather to facilitate their control. With this kind of cooperation, the partners involved are able to maximize the incoming spillovers derived from partners and non-partners, while minimizing the outgoing spillovers to non-partners[1] (Cassiman and Veugelers, 2002; Martin, 2002).

As such, R&D subsidies granted by governments have the condition that cooperative agreements are established between the recipient firms (Broekel and Graf, 2012; Czarnitzki et al., 2007; Fornahl et al., 2011). Often, the odds of obtaining R&D subsidies from the European Union (EU) increase when firms cooperate in R&D (Scherngell and Barber, 2011). Thus, governments encourage the creation of R&D knowledge and its dissemination.

[1] A large number of R&D cooperation agreements are taking place between companies that have a high potential to take advantage of spillovers generated by other companies. Thus, the partners mutually internalize their outgoing spillovers. In general, it is assumed that non-partner companies do not have such high potential, so they will not be in a position to benefit from spillovers generated by the partners.

By fostering and promoting R&D cooperation agreements through R&D subsidies, companies and governments do not fully achieve their particular objectives, but there is no doubt that these objectives are partially fulfilled. By attracting public funds to support innovation, companies get an easier return on their R&D investments, while governments, through such subsidies, facilitate many R&D investments that otherwise would not take place and encourage the spread of new knowledge, benefiting many other national or European companies. For example, through the Eureka Programme, the EU aims to promote cooperation agreements between European companies to develop advanced technology projects with a market orientation (Bayona-Sáez and Garcia-Marco, 2010; Marin and Siotis, 2008; Kuhlman and Edler, 2003).

Overall, however, the results achieved at European level are not fully satisfactory (Benfratello and Sembenelli, 2002), which is a clear indication of the need to undertake a thorough analysis of the use of subsidized R&D cooperation agreements as a key instrument in promoting innovation policy (European Commission, 2011a; Edler, 2010).

As the innovation literature has paid little attention to this issue (Broekel, 2015), the present paper is set in this research stream. We ask ourselves whether the use of subsidized R&D cooperation agreements as a tool for promoting innovation is an innovation policy that must be applied homogeneously throughout the territory of the EU. Under the assumption that the answer is that a homogeneous policy should not be applied, then we also ask ourselves what the angular variable that determines the corresponding selection criteria should be, and what should be the policy of promoting innovation in these cases. In this regard, we must bear in mind that companies do not have the same absorptive capacity, and that absorptive capacity is key to learning about knowledge produced by other innovative firms (Cohen and Levinthal, 1989). It could be that many companies subscribe to cooperation agreements that report more disadvantages than advantages, in order to obtain R&D subsidies. This happens because they do not have the absorptive capacity to make good use of the knowledge flows that other companies produce.

Our analysis focuses on the Spanish manufacturing sector, which is positioned in an intermediate position with respect to European technological development. Because of this position, Spain is, in our opinion, an ideal setting for analyzing the widespread use of subsidized R&D cooperation agreements as a tool for promoting innovation.

The results of our empirical research indicate that the relationship between R&D cooperation and R&D subsidies in companies with low absorptive capacity is substitutive; there is no relationship between the two variables in high absorptive capacity companies. Therefore, the implementation of a policy of subsidized R&D cooperation agreements identical for all countries in the EU does not seem advisable. Also, the results indicate that the relationship between absorptive capacity and R&D cooperation is substitutive. This is an indication that the average absorptive capacity of Spanish manufacturing firms is low. Finally, we have also found no relationship between the variables R&D subsidies and absorptive capacity. This is a clear indication that absorptive capacity is not taken into account when promoting subsidized R&D cooperation agreements.

In the next section, we present the theoretical background and formulate our hypotheses. Section 3 describes the data set and the econometric methodologies used to estimate the coefficients and to test complementarities. We also define the variables used. In Section 4, the results are presented, and in section 5 we discuss them. Finally, conclusions are presented in Section 6.

2 Theoretical background and hypotheses

The ability to innovate depends not only on internal R&D, but also on an organization's capacity to absorb knowledge generated outside their borders (Schwartz et al., 2012). In this sense, R&D cooperation agreements are the most common way for companies to learn about knowledge produced by other innovative companies (Belderbos et al, 2004a; Franco and Gussoni, 2014). For this reason, many countries from the EU have designed innovation policies aimed at promoting R&D cooperation agreements between different kinds of companies and between them and other public institutions (Muldur et al., 2006). Among these policies, one of the most common is the subsidized R&D cooperation agreement (Broekel, 2015), where the development of new knowledge is stimulated and more rapidly diffused (Hottenrott and Lopes-Bento, 2014). A clear example of such policies are the Framework Programmes from the EU, whereby various European companies receive strong public support for R&D under the condition of establishing cooperation agreements between them (Scherngell and Barber, 2011).

There is an extensive literature on the relationship between collaborative research and innovation performance; however, little attention has been placed on the impact that subsidized R&D cooperation agreements may have on business productivity.

However, while many companies request and receive R&D subsidies, it is not clear that the outcome of such public support is beneficial for companies. Although it is true that most of the literature on innovation states that, in general, cooperation improves innovative performance and productivity (Laursen and Salter, 2006; Van Beers and Zand 2014) , there is no empirical evidence to prove irrefutably that subsidized R&D cooperation agreements improve the productivity of the companies involved (Broekel et al., 2011).

In this sense, one would expect that many companies establish R&D cooperation agreements simply in order to get subsidies (Broekel et al., 2011). However, companies often have a notable lack of internal capability to leverage the expertise that partners bring; hence, the costs associated with the cooperation may be higher than the additional revenue reported. Consequently, in these situations, cooperation has a negative impact on the productivity of these companies.

Nevertheless, very few studies have been performed to analyze whether subsidized R&D cooperation agreements are more effective in raising private R&D investments than sustaining R&D subsidies without the conditionality of cooperating in R&D (e.g. Hinloopen, 2001). In this study, therefore, we intend to go a step further. Our intention is to test whether the relationship between the variables of cooperation and R&D subsidies is complementary, substitutive or independent.

If policymakers dictate that the establishment of cooperation agreements is a prerequisite for the granting of R&D subsidies it is because they believe that the relationship between the two variables is complementary, i.e. the impact on the productivity of the joint implementation of these variables is greater than the sum of their respective impacts separately. But if organizations are the ones who decide to apply for R&D subsidies and cooperation agreements, these companies should determine whether that complementarity exists. It could be that this relationship is substitutive, and therefore the joint implementation of both variables decreases business productivity. If this happens, companies would not be interested in participating in R&D subsidy programmes under this condition of cooperation. It is possible that many companies end up as mice, who in the search for the coveted cheese (public subsidies) end up getting caught in the mousetrap (cooperation).

In addition to analyzing whether the subsidized R&D cooperation agreements impact positively or negatively on productivity, this study is also interested in testing under what conditions the relationship between these two variables is complementary or substitutive. In this sense, we must bear in mind that the capacity to absorb relevant knowledge from partners depends on the organization’s absorptive capacity (Cohen and Levinthal, 1989), and that the absorptive capacity differs from company to company (Graevenitz, 2004). Accordingly, it is possible that many companies do not reach the minimum level of absorptive capacity beyond which cooperation is beneficial for companies. If the minimum level of absorptive capacity is not reached, establishing cooperation agreements may be detrimental to businesses, even taking into account the additional funds received from R&D subsidy programmes. Consequently, the relationship between cooperation and public subsidies should not be analyzed in isolation. Instead it should only be analyzed by taking into account the absorptive capacity of the companies, to the extent that this variable is listed as one of the main features of firms that cooperate (Belderbos et al., 2004b). In order to test this relation, we use the complementarity approach (Topkis 1978; Milgrom and Roberts 1990).

We analyse the relationships between the variables R&D cooperation, R&D subsidy and absorptive capacity in terms of complementarity/substitutability/independence. Following the complementarity approach, the relationship between variables is tested pairwise. As we explore the relationship between two variables in the context of three variables, the number of non-trivial inequality constraints implied by the definition of supermodularity is two (Mohnen and Roller, 2005) whether we enter the third variable or not. If the two inequalities give complementary/substitutable/independent results, it can be argued that there is unconditional complementarity/substitutability/independence. If only one of the inequalities is complementary/substitutable/independent, it can be argued that there is conditional complementarity/substitutability/independence.

According to the literature review conducted, it appears that the relationship between cooperation and public subsidies should be complementary as long as the companies involved have enough absorptive capacity. However, our analysis focuses on the Spanish manufacturing sector, characterized by low technological intensity[2]. Given that the companies with low absorption capacity are majority in Spain, we suspect that the relationship between cooperation and public subsidies does not meet the objectives pursued by public support programmes for R&D. In this case, the interaction of both variables would not increase the productivity of enterprises. Accordingly, we propose the following hypothesis:

[2] In 2009, Spanish R&D intensity was 1.38%, while in Finland, Germany, Austria and France it was 3.93%, 2.82%, 2.79% and 2.21% respectively (European Commission, 2011b). In this study we use R&D intensity as a proxy for absorptive capacity. Many previous studies have used the same proxy variable (e.g. Belderbos et al, 2004a; Cassiman and Veugelers, 2002; Cohen and Levinthal, 1990).

Hypothesis 1: In the Spanish manufacturing sector, which has a predominance of companies with low absorptive capacity, the relationship between R&D cooperation and R&D subsidies is unconditionally[3] substitutive in relation to the labor productivity of firms.

The relationship between knowledge spillovers and R&D cooperation is one of the most popular topics in the literature on innovation (e.g. D'Aspremont and Jacquemin, 1988). Most of this literature claims that firms cooperate with R&D because it allows them to internalize the R&D spillover arising from R&D activities carried out by other companies (D'Aspremont and Jacquemin, 1988). However, to identify, assimilate and develop primary knowledge generated by others, companies need to have an adequate absorptive capacity. Yet companies differ from each other in their absorptive capacities (Escribano et al., 2009). In general, two companies are unable to get the same benefits even assuming that they participate in the same cooperative agreement with a third company (Giuliani and Bell, 2005). The level of profits or losses that the cooperation agreements provide depends on the absorptive capacity that companies have.

Indeed, the existence of different levels of absorptive capacity is one of the main reasons why many companies do not establish cooperative agreements or the results of these agreements are not satisfactory for the parties concerned. In short, having a high absorptive capacity is crucial to reap the benefits that cooperation agreements offer (Badillo and Moreno, 2014). Thus, many companies make considerable efforts to obtain a broad and strong absorptive capacity. In this sense, Cohen and Levinthal (1989) indicate that the absorptive capacity can be built up by investing in in-house R&D, showing why many studies have found a close relationship between R&D spending and R&D cooperation (e.g. Veugeleurs, 1997).

Hence, according to the above-mentioned literature, we presume that the impact on the productivity of the joint implementation of cooperation and absorptive capacity is greater than the sum of their respective impacts separately, as long as the absorptive capacity reaches the minimum level required. But in our view, this is not the case for Spanish companies, which have a lower level of R&D activities than companies from more advanced European countries

[3] We test the relationship between R&D cooperation and R&D subsidy variables in two different subsamples. One is formed by companies that have low absorptive capacity; the other is formed by companies that have a high capacity for absorption (of course, the concepts "high" and "low" refer to the Spanish reality). Clearly, our hypothesis is unconditional as we assume that the relationship between the variables analysed in both subsamples is that of substitution. Therefore, this substitution relationship is not conditioned by the existence of companies with high or low absorptive capacity.

and a traditionally low absorptive capacity (Segarra-Blasco, 2011). It is also necessary to highlight two additional facts:

(1) In Spain, the average number of employees per company is 4.9, less than half the number in Germany and one of the smallest sizes in the main EU countries (Círculo de Empresarios Documents, 2013).

(2) The literature on innovation indicates that smaller companies have, in general, a lower absorptive capacity (Lee and Sung, 2005).

We therefore believe that, on average, cooperation within the Spanish manufacturing sector does not yield positive results in terms of productivity, because companies are probably not able to extract sufficient profits from cooperation to offset the corresponding increase in costs that cooperation entails. Therefore, we propose the following hypothesis:

Hypothesis 2: In the Spanish manufacturing sector, which has a predominance of companies with low absorptive capacity, the relationship between R&D cooperation and absorptive capacity is unconditionally[4] substitutive in relation to the labor productivity of firms.

Public support programmes to jointly promote R&D activities and cooperation agreements are a tool for innovation policy, and their use is becoming more common (Busom and Fernández-Ribas, 2004). Such programmes aim to encourage and accelerate the creation of new knowledge and its dissemination (Busom, 2000). However, subsidized R&D cooperation agreements only reach their objectives in companies with an adequate absorptive capacity, as otherwise the companies involved could not absorb and develop shared knowledge, and public resources encouraging this kind of agreement would be allocated inefficiently. As such, it seems reasonable to closely analyze the absorptive capacity of the companies involved before granting R&D subsidies under the condition of establishing cooperation agreements. If policymakers act in this way, the simultaneous action of R&D subsidies and absorptive capacity variables should have a positive impact on productivity; that is, both variables must be complementary. If the variables are substitutive, it would indicate that the simultaneous

[4] That is, we assume that the test that analyses the relationship between R&D cooperation and absorptive capacity in the two subsamples constructed from the third variable (companies receiving subsidies and companies not receiving subsidies) is substitutive. Therefore, a priori, in this second hypothesis we assume that the relation analysed is not conditioned by the value of the R&D subsidy variable. Our hypothesis is that the relationship is also unconditionally substitutive.

impact of both variables on productivity is less than the sum of the respective individual impacts. That is, the benefits that companies extract from cooperation would not outweigh the costs that this cooperation entails. Probably, in this case, an insufficient absorptive capacity would limit any potential benefits offered by cooperation agreements.

We have no preconceived idea as to whether the authorities have considered absorptive capacity as a key variable in the decision whether to use subsidized R&D cooperation agreements. In our view, they should, but we do not know if they have done so. Therefore, we do not establish any hypothesis on this matter.

3 Data, variables and methodology

The data used in this study comes from the Technological Innovation Panel (PITEC), managed by the Spanish National Statistics Institute (INE). PITEC is a firm-level panel database on the innovative activities of Spanish firms based on Community Innovation Survey (CIS) data.

We based the construction of the panel database on the PITEC databases for the following years (with the number of companies surveyed in brackets): 2008 (12,813), 2009 (12,817), 2010 (12,821), 2011 (12,828), 2012 (12,838) and 2013 (12,839). We selected manufacturing companies. After removing observations with missing values and those that had some sort of impact on the variables of interest, we obtained a database with 4,379 observations for each of the years under analysis, and 21,895 observations for the whole database. Our panel data are strongly balanced; that is, all the individual units are observed in all the time periods[5].

All independent variables of the econometric model used have a one-year delay in relation to the dependent variable (labor productivity). Thus, we have into account the impact on productivity of certain policies arising from a specific time lag (Belderbos et al., 2004b). Furthermore, in order to overcome the traditional problems of unobserved heterogeneity, we used panel data.

To perform the test of complementarity it is necessary to define a function of firm performance. In this study, we used as the dependent variable the logarithm of labor productivity, a broad measure of performance that reflects the influences of many different

[5] Originally, our panel data contained 4,536 manufacturing companies. However, as our goal is to work with a strongly balanced sample, we eliminated all the incorporations in the PITEC database that took place after 2008 (10 firms) and those companies that disappeared from PITEC between 2009 and 2013 (147 firms). Thus, our panel data set is made up of 4,379 firms.

sources that generate productivity, and has been used in a large number of studies analyzing the relationship between R&D and productivity (e.g. Hall et al., 2010).

To perform the test of complementarity, it is necessary to define R&D cooperation, R&D subsidies and absorptive capacity in (0,1) mode. In this sense, PITEC asked companies if during the period of analysis they conducted R&D cooperation agreements (0 no, 1 yes). Then they asked companies if they received R&D subsidies from regional authorities, state administration, the EU or the sixth and seventh Framework Programme of the EU. If at least one of the corresponding answers is yes, the variable R&D subsidies takes the value 1; if all answers are negative it takes value 0. Finally, like many other studies have done, we use R&D intensity as a proxy for absorptive capacity (e.g. Cohen and Levinthal, 1990, Tsai, 2001). For companies whose R&D intensity is lower than the average value, the variable absorptive capacity will take the value 0 (low absorptive capacity); by contrast, those with equal or higher value than the corresponding average value will take the value 1 (high absorptive capacity).

When estimating the coefficients of the regression model, these three variables were enlarged to eight possible combinations, of which each combination represented exclusively the interaction of the three analysed variables (R&D cooperation, R&D subsidies, absorptive capacity). For example, (1, 1, 0) represented a company which has implemented R&D cooperation, has received some kind of R&D subsidy and has a low absorptive capacity.

Besides the eight exclusive combinations, we introduced into the model different independent variables such as income spillovers, outgoing spillovers and different obstacles to innovation. The variables are similar to those used in other studies exploring the influence of R&D intensity and R&D cooperation on some measure of performance. In addition, we included industry dummies at the two-digit industry classification level and year dummies in order to take into account the influence of the singularity of each sector and the secular variation in labor productivity respectively. A precise definition of how the variables were constructed and their basic descriptive statistics can be found in Table 1.

Table 1. Variable definitions and descriptive statistics

Variable name	Variable construction	Sample mean / Standar dev.	Range (Min/Max)
Labor productivity (dependent variable)	Log of sales per employee	5.20/.36	2.14/7.15
R&D cooperation	The firm cooperates in R&D with other enterprises or institutions (0,1)	.28/.45	0/1

R&D subsidies	1, if the company gets R&D subsidies from one or more of the following programs: Regional, State, EU, FP6 and FP7. 0, if it fails to finance any program.	.31/.46	0/1
Absorptive capacity	Relationship between internal and external R&D expenditures and total sales of the firm (To apply in interaction approach). If the above relationship is less than the average, absorptive capacity takes value 0. Otherwise, value 1 (To apply in system approach).	.18/.39	0/1
Income spillovers	Sum of importance (number between 0 (not used) and 3 (high)) of conferences, fairs and exhibitions; journals; and professional associations as sources of innovation. Rescaled between 0 (no spillovers) and 1 (maximum spillovers).	.27/.28	0/1
Outgoing spillovers	Sum of the scores (number between 0 (not used) and 1 (used)) of formal protection methods for innovations (patents, registration of design, trademarks and copyright). Rescaled between 0 (not used) and 1 (highly important).	.10/.19	0/1
Cost obstacles	It is a measure of the importance of the costs as an obstacle to innovation process (number between 0 (not relevant) and 3 (high)). Rescaled between 0 (not relevant) and 1 (high).	.62/.35	0/1
Financial obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): lack of funds within the company or group and lack of external funding. Rescaled between 0 (not relevant) and 1 (high).	.60/.34	0/1
Knowledge obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): lack of qualified personnel; lack of information on technology; lack of information on market, and the difficulty of finding cooperation partners. Rescaled between 0 (not relevant) and 1 (high).	.40/.26	0/1
Market obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): market dominated by established enterprises, and uncertain demand for innovative goods or services. Rescaled between 0 (not relevant) and 1 (high).	.53/.31	0/1
Export intensity	Export share in total firm sales	.29/.32	0/1

Size	Log of number of employees	1.74/.61	0/4.01
Industry dummies	Dummies for: food, beverages, and snuff, textiles, clothing, leather and footwear, wood and cork, cardboard and paper, printing, chemicals, pharmaceuticals, rubber and plastics, minerals, metallurgy, metal manufacturing, electronic and optical computer products, electrical equipment, other machinery, motor vehicles, ship building, aircraft construction, other transportation equipment, furniture, other manufacturing activities, and repair of machinery (0,1)		0/1

We use the complementarity approach as empirical methodology (Topkis 1978; Milgrom and Roberts 1990). This approach allows us to test the relationship between two variables (complementarity, substitutability and no relation), conditioned on the presence or absence of other variables or company policies. Moreover, it makes it possible to establish whether receiving public support for innovation in the establishment of R&D cooperation has benefits for companies (when the relationship is complementary) or entails losses (when the relationship is substitutive). The output provided by this approach is appropriate for the objectives we pursue. The use of causality as a research methodology does not allow simultaneous exploration of the three relationships and the use of correlation coefficients can lead to biased results as a positive/negative correlation is neither necessary nor sufficient for complementarity/substitutability (Athey and Stern, 1998).

Regarding the methodology it should be noted that, formally, a pair of variables is complementary if the sum of the benefits of doing just one or the other is no greater than the benefit of doing both together.

Essentially, two investigative approaches are used to evaluate the existence of complementarity between variables or company policies (Ennen and Richter, 2010): the systems approach and the interaction approach.

The systems approach for enterprise policy analysis was first developed by Milgrom and Roberts (1990). To implement this approach, an objective function needs to be established.Suppose there are two activities X_i and X_j, and Z is a vector of exogenous variables in an objective function $F(X_i,X_j,Z)$. Assume that X_i and X_j are dichotomous choices that take the value 1 if they are adopted by the firm and the value 0 if they are not. The complementarity approach regresses an objective on exclusive combinations of innovation activities:

$$F(X_i, X_j, Z) = \beta_{00}(1-X_i)(1-X_j)+\beta_{10}X_i(1-X_j)+\beta_{01}(1-X_i)X_j+\beta_{11}X_iX_j+\beta_z Z + e$$

where β_{11} measures the cross-partial returns of choosing X_i and X_j jointly; β_{10} for choosing only of X_i; β_{01} for choosing only of X_j; β_{00} for choosing none of them.

Then, the objective function $F(X_i,X_j,Z)$ is supermodular and X_i and X_j are complementary if:

$$\beta_{11}+\beta_{00}-\beta_{10}-\beta_{01}>0$$

Obviously, the objective function $F(X_i,X_j,Z)$ is submodular and X_i and X_j are substitutes if:

$$\beta_{11}+\beta_{00}-\beta_{10}-\beta_{01}<0$$

According to Topkis (1978), if there are k variables, the number of non-trivial inequalities to be tested will be $2^{k-2}\sum_{i=1}^{k-1} i$. In our particular case, since there are three variables to consider, the number of restrictions to be tested will be six. For example, if we want to test for the complementarity between R&D cooperation and R&D subsidies, we have to test the two following non-trivial inequalities:

$\beta_{110}+\beta_{000}-\beta_{100}-\beta_{010}>0$ (between companies with low absorptive capacity)

$\beta_{111}+\beta_{001}-\beta 101-\beta_{011}>0$ (between companies with high absorptive capacity)

In the interaction approach, the variables for which complementarity is evaluated do not have to be transformed into exclusive binary combinations, keeping their original characteristic (e.g. their continuous nature, if they have it). In this approach, the existence of complementarity is evaluated through the sign and the significance of the coefficients of the interactive variables. The formal representation of the interaction approach is as follows:

$$F(X_i, X_j, Z) = \beta_0+\beta_1X_i+\beta_2X_j+\beta_3(XiXj)+\beta_z Z + e$$

If the coefficient β_3 is positive and statistically significant, there is complementarity between the variables X_i and X_j. In contrast, if it is negative and significant, the variables are substitutes.

These two approaches have their advantages and disadvantages. Without trying to be exhaustive, we cite below some of these advantages and disadvantages:

1) The systems approach uses exclusive combinations of binary variables, which forces the transformation of continuous variables into binary variables. This transformation may cause loss of information and consequently reduce the sensitivity of the analysis of complementarity. Therefore, there are authors who prefer to use the interaction approach (Lee, 2008).

2) In the interaction approach, the reading of complementarity tests is quick and simple as the output of the regression directly facilitates identification of the sign and the significance of the coefficients of interest. However, in the systems approach the output of the regression employed does not directly provide a test of complementarity. In this case, the regression only facilitates identification of the coefficients of the corresponding exclusive variables. The complementarity test is then implemented based on these coefficients.

3) In the systems approach, it is necessary to estimate all the coefficients of the exclusive variables to be able to perform the complementarity test. However, when dealing with exclusive variables, multicollinearity problems arise. This forces us to suppress the constant of the model when we make the estimation. This reduces the number of models that can be used as it is not possible to suppress the constant in the estimation of certain models (for example, with panel data and linear models it is not possible to suppress the constant in random-effects, between-effects and fixed-effects GLS models). Therefore, with these kinds of estimators it is not possible to use the systems approach.

4) There are also estimators that while allowing suppression of the constant do not provide all the coefficients of the exclusive variables (for example, the Arellano–Bond linear dynamic data-estimator (GMM)). Nor is it possible to use the systems approach in these cases.

However, in spite of the restrictions and complexity that the use of the systems approach entails, it is the approach most used by researchers (Ennen and Richter, 2010). The reason is that when more than two variables are involved, the systems approach provides more information than the interaction approach.

When it comes to assessing complementarity between two unique variables, both approaches provide the same information: complementarity, substitution, or no relation. However, when it comes to analysing the relationship between three or more variables, there are differentiating nuances in the information that the two approaches provide. Thus, the interaction approach reveals, without greater nuances, whether or not two variables are complementary. However, the systems approach tells us whether the relationship between the two variables is not complementary or is unconditional or exhibits conditional complementarity. That is, it allows us to determine the extent to which the relationship between two variables is conditioned by the presence or absence of other variables. When it comes to assessing the impact that is derived from the application of certain business policies, this information is invaluable.

In addition, it is possible that the interaction approach may indicate that two variables are not complementary, while the systems approach can point out that between these two variables there is conditional complementarity in a particular policy being implemented. That is, for the systems approach complementarity simultaneously exists and does not exist. However, in the interaction approach there is only one state: complementarity or non-complementarity. The interaction approach only provides one reading: the relationship that has the most weight. The systems approach provides much richer information.

To verify how the two approaches work, in our empirical analysis we use both, although for reasons of space we only comment on the results provided by the systems approach. Clearly, for the results to be comparable, it is necessary to use the same econometric estimation technique in both approaches.

The econometric technique that we used to estimate the coefficients is maximum-likelihood random effects[6]. This econometric technique had the advantage of providing estimations of all the coefficients, even in the event that there were time-invariant regressors[7].

[6] For panel data and linear models, Stata provides five different model estimators. Three of these estimators do not allow suppression of the constant of the model, so they cannot be used in the systems approach. The complementarity tests in the systems approach and the interaction approach of the two other estimators (the ML random-effects and population-average estimators) provide the same results. We expose the corresponding data to the ML random-effects estimator.

[7]The population under analysis is made up of manufacturing companies with very different characteristics. It is therefore necessary to control this diversity (Cassiman and Veugelers, 2006). To this end, we include industry dummies at the two-digit industry classification level. These dummy variables are time invariant. However, invariant regressors are dropped in some models (for example, in GMM for the dynamic panel model and the fixed-effects model) because they are eliminated after first-differencing. Therefore, some models cannot be used to perform the complementarity tests as they do not allow suppression of the constant and/or do not allow the correct specification of our empirical model (that is to say, they cannot incorporate invariant regressors).

4 Results

Tables 2 and 3 reflect the relationship, in terms of frequencies, between the three variables that constitute the focus of this study.

Table2. Relationship between R&D subsidy and Absorptive capacity and R&D cooperation (Number of firms)

		Absorptive capacity			R&D cooperation		
		Low	High	Total	No	Yes	Total
R&D subsidy	No	13508	1514	15022	12717	2305	15022
	Yes	4389	2484	6873	3012	3861	6873
	Total	17897	3998	21895	15729	6166	21895

Table3. Relationship between R&D cooperation and Absorptive capacity (Number of firms)

		Absorptive capacity		
		Low	High	Total
R&D cooperation	No	13692	2037	15729
	Yes	4205	1961	6166
	Total	17897	3998	21895

Table 2 shows that of the 6,873 firms that obtain R&D subsidies, 4,389 firms have low absorptive capacity and 2,484 firms have high absorptive capacity. These figures constitute a clear indication that there are no problems of self-selection among Spanish manufacturing firms as those with low absorptive capacity are the ones that receive a higher proportion of R&D subsidies. Table 2 also shows the greater likelihood of cooperation among firms receiving R&D subsidies as of the 6,166 firms that have cooperation agreements, 3,861 receive R&D subsidies and 2,305 do not. However, Table 3 shows that of the 6,166 firms that cooperate, only 1,961 companies have high absorptive capacity.

In short, Tables 2 and 3 show evidence that firms that receive R&D subsidies are more likely to establish cooperation agreements, even though such firms show a propensity to have lower absorptive capacity. Under these conditions, we can intuit that the granting of R&D subsidies under the condition of cooperation with other firms should not produce significant increases in business productivity. However, the analysis of complementarity/substitutability should confirm or reject this intuition that we extract from the descriptive analysis.

Table 4 contains the results of the maximum-likelihood random effects estimation for labor productivity. The estimation of the coefficients of the eight exclusive variables is needed in order to perform hypothesis tests of the Systems approach in the post-estimation phase. Therefore, as the estimation of these coefficients is not an objective of this paper, but an instrument, we make no comment on its significance.

Table 4. Productivity Regressions

Variables	Model for systems approach		Model for interaction approach	
	Coef.	S.E.	Coef.	S.E.
R&D cooperation	-	-	.02***	.004
R&D subsidy	-	-	.006*	.004
Absorptive capacity	-	-	-.03	.02
R&D cooperation x R&D subsidy	-	-	-.01*	.006
R&D cooperation x Absorptive capacity	-	-	-.03***	.007
R&D subsidy x Absorptive capacity	-	-	0.02	0.0228419
Income spillovers	.03***	.006	0.03***	0.006
Outgoing spillovers	-.004	.008	-0.004	0.008
Cost obstacles	-.007	.005	-0.008	0.005
Financial obstacles	-.02***	.006	-0.02***	0.006
Knowledge obstacles	.006	.007	0.006	0.007
Market obstacles	.002	.005	0.002	0.005
Export intensity	.04***	.006	0.04***	0.006
Size	.09***	.006	0.09***	0.006
(0, 0, 0)	5.14***	.02	-	-
(1, 0, 0)	5.16***	.02	-	-
(0, 1, 0)	5.14***	.02	-	-
(0, 0, 1)	5.13***	.02	-	-
(1, 1, 0)	5.15***	.02	-	-
(1, 0, 1)	5.12***	.02	-	-
(0, 1, 1)	5.14***	.02	-	-
(1, 1, 1)	5.13***	.02	-	-
Constant	-	-	5.14***	0.02
Year dummies	Included		Included	
Industry dummies	Included		Included	
Model	Wald chi2(42)= 1.37e+06 p-value= 0.0000		L.R. chi2(40)= 1409.98 p-value= 0.0000	

Statistical significance of the coefficients: at 1% ***, 5%** and 10% *. Total sample size is 21895
Dependent variable is "Labor productivity"
Examples: (0,0,0)= (No R&D cooperation, No R&D subsidy, Low absorptive capacity)
(1,1,1)= (Yes R&D cooperation, Yes R&D subsidy, High absorptive capacity)

Table 5 shows the results of the tests of complementarity/substitutability that we have carried out for the systems approach. For each pair of variables we checked whether the relation is significant or not. If the relationship is not significant, then we can say that there is no relationship between the two variables. Conversely, if the test indicates that the relationship is significant, then we have to perform a second test in order to confirm whether this relationship is complementary or substitutive.

Table 5. Complementarity tests for systems approach

		Chi2	P-value
R&D Cooperation – RD Subsidy	Absorptive Capacity = 0		
	T1: $\beta_{110} + \beta_{000} - \beta_{010} - \beta_{100} = 0$	2.92	0.09
	T2: $\beta_{110} + \beta_{000} - \beta_{010} - \beta_{100} \leq 0$		0.96
	Complements/Substitutes/No relation	**Substitute**	
	Absorptive Capacity = 1		
	T1: $\beta_{111} + \beta_{001} - \beta_{011} - \beta_{101} = 0$	0.08	0.77
	T2: $\beta_{111} + \beta_{001} - \beta_{011} - \beta_{101} \leq 0$		
	Complements/Substitutes/No relation	**No relation**	
R&D Cooperation – Absorptive Capacity	RD Subsidy = 0		
	T1: $\beta_{101} + \beta_{000} - \beta_{100} - \beta_{001} = 0$	10.77	0.001
	T2: $\beta_{101} + \beta_{000} - \beta_{100} - \beta_{001} \leq 0$		0.99
	Complements/Substitutes/No relation	**Substitute**	
	RD Subsidy = 1		
	T1: $\beta_{111} + \beta_{010} - \beta_{110} - \beta_{011} = 0$	5.16	0.02
	T2: $\beta_{111} + \beta_{010} - \beta_{110} - \beta_{011} \leq 0$		0.99
	Complements/Substitutes/No relation	**Substitute**	
RD Subsidy – Absorptive Capacity	Cooperation = 0		
	T1: $\beta_{011} + \beta_{000} - \beta_{010} - \beta_{001} = 0$	0.53	0.47
	T2: $\beta_{011} + \beta_{000} - \beta_{010} - \beta_{001} \leq 0$		
	Complements/Substitutes/No relation	**No relation**	

	Cooperation = 1		
	T1: $\beta_{111} + \beta_{100} - \beta_{110} - \beta_{101} = 0$	0.69	0.41
	T2: $\beta_{111} + \beta_{100} - \beta_{110} - \beta_{101} \leq 0$		
	Complements/Substitutes/No relation	**No relation**	

The complementarity test conducted among companies that have low absorptive capacity indicates that the relationship between R&D cooperation and R&D subsidies is substitutive. Therefore, it appears that in the Spanish manufacturing sector many companies embark on cooperation agreements that diminish their productivity levels. These companies show a low absorptive capacity and, therefore, a manifest inability to extract all the potential benefits offered by cooperation agreements. The additional funds that many of these companies receive for participating in R&D public programmes are insufficient to offset the costs incurred by their participation in the respective R&D cooperation agreements.

Moreover, the test conducted with companies that exhibit a high absorptive capacity indicates that there is no relationship between R&D cooperation and R&D subsidies. That is, even among companies that have a high absorptive capacity, the benefits that these companies extract from R&D cooperation agreements – counting among these benefits the additional funds from programmes of public support for innovation – do not exceed the costs associated with the cooperation agreements.

Finally, we point out that Table 4 gives us directly the results of the complementarity test derived from the interaction approach. These tests fully coincide with those provided by the systems approach as the coefficients of the interactions between R&D cooperation and R&D subsidy and between R&D cooperation and absorptive capacity are negative and significant, i.e. in the interaction approach both pairs of variables are also substitutive. Likewise, the coefficient of the interaction between R&D subsidy and absorptive capacity is not significant, from which it can be deduced that there is no relationship between the two variables. However, as we have seen, the explanatory richness of the results of the systems approach is much greater.

5. Discussion

The promotion of R&D cooperation agreements by granting subsidies for innovation does not impact positively on the productivity of Spanish manufacturing firms; in the best case scenario, their influence is zero. However, in relation to other countries, there is empirical evidence to suggest that the interaction between R&D cooperation and R&D subsidies have a positive influence on the firm's innovative performance and in the development of companies (e.g. Czarnitzki et al., 2007; Broekel et al., 2011; Sakakibara; 2001). Therefore, public policies to promote the innovation and competitiveness of Spanish manufacturing firms do not seem to be meeting their objectives. In the field of policymakers, three possible reflections can be inferred from these results.

Firstly, the substitutability between R&D cooperation and R&D subsidies in companies that exhibit a low absorptive capacity was expected from the perspective of the theoretical foundations, as these kinds of companies are not able to take advantage from knowledge spillovers generated by R&D cooperation agreements. What is not so logical is that the government allocates funds to promote R&D investments with the condition that such companies have to cooperate. It seems that many of these companies are embarking on the establishment of R&D cooperation agreements for the sole purpose of capturing public subsidies in the short term, even if this means that in the medium term this obtaining of public funds causes a reduction in productivity. But this kind of promotion also ends up hurting the government, since it means an inefficient allocation of resources, to the extent that it does not increase the stock of advanced capabilities of the companies involved, nor achieves the dissemination of advanced knowledge, nor improves the competitiveness of their respective companies. In short, none of the purposes that justify direct intervention by public authorities on the market economy are met. The logical thing would be to support R&D activities that are close to the borders of knowledge of these companies, but not force them to cooperate[8]. Only when the R&D effort reaches a certain critical level, does R&D cooperation seem advisable.

Secondly, the simultaneity of R&D subsidies and R&D cooperation does not have a positive impact on the productivity of those Spanish manufacturing companies that have a high absorptive capacity. This result is a clear indication that the Spanish manufacturing companies that we have listed as high-absorptive capacity companies have a mediocre average absorptive capacity. As previously noted, R&D expenditures of Spanish companies are, on average, much lower than those made by companies in other advanced European countries. Accordingly, these kinds of Spanish companies are not able to benefit fully from R&D cooperation agreements. It is true that their productivity is better than that of low-absorptive capacity

[8] From a different perspective, but with similar consequences, Hinloopen (2001) notes that in the case of optimally subsidizing cooperative or non-cooperative R&D, 'sustaining R&D collaboratives is a redundant industrial policy, all else equal'.

companies; however, it is clearly insufficient. Therefore, in these kinds of companies it does not seem advisable to require the condition of cooperating as one of the determining factors to achieve public subsidies for innovation. In Spain, this condition should only be required for companies that have similar levels of absorptive capacity to the most advanced European companies.

Thirdly, the European Commission has proposed reducing the innovation gap that exists between Europe and the United States and Japan. One of the policies in support of this reduction is to support R&D with subsidies, but by establishing a condition of cooperation, since the adaption of knowledge from external sources can be achieved by firms' engagement in inter-organizational cooperation (Broekel, 2015; Czarnitzki et al., 2007; European Commission, 2011b). Thereby, it is intended to encourage the creation and dissemination of new knowledge within the EU. But the EU is a mosaic of countries with different resources and capacities for innovation and the principle of 'one politics fits all' can yield to suboptimal (Broekel et al., 2011) or even counterproductive results. Innovation policies in the EU must consider and adapt themselves to the structural realities from each country. The results obtained in this study indicate that in Spain, the subsidized R&D cooperation agreements policy does not achieve the desired objectives. In technologically advanced countries this policy may be correct. But in Spain there are clear indications that it may be a failed policy. Initially, in Spain it seems more advisable to conduct a policy aimed at increasing the technological intensity and the average size of companies[9], because investments in R&D not only expand the knowledge base of companies, but also help reduce the cognitive distance between firms (Franco et al., 2012). Obviously, in our view, such aid should not be linked to the obligation of cooperation. This requirement should be required only to companies that have a level of technological intensity similar to that in more technologically advanced countries.

Therefore, Hypothesis 1 was partially accepted. It should be noted that the simultaneity of R&D cooperation agreements and R&D subsidies does not increase, on average, the productivity of Spanish companies, whatever their absorptive capacity.

[9] In the field of innovation literature there is a general perception that large companies are better positioned to capture the benefits of R&D cooperation. Larger firms have a greater and better capacity to internalize knowledge-intensive activities (Rammer et al., 2009). Many empirical studies have highlighted that large firms have a higher propensity to cooperate because they have a high absorptive capacity (e.g. Faems et al, 2010; López, 2008). However, it should be noted that this greater absorptive capacity comes mainly from their greater R&D (e.g. Ebersberger and Herstad, 2013).

Regarding the relationship between R&D cooperation and absorptive capacity, we find that our second hypothesis is fully accepted. In the two subsamples – companies which do not receive R&D subsidies and companies which do – this relationship is substitutive. According to the theoretical foundations based on the ability of companies to absorb and create new knowledge, it is normal that this relationship is complementary, i.e. as the absorptive capacity of firms increases, the likelihood that companies will cooperate in R&D should also increase, since thereby the productivity of companies increases. However, in Spain this is not true. As the average absorptive capacity of Spanish companies is very low, more organizational cooperation decreases the average productivity of the companies, because cooperation costs outweigh the benefits that such cooperation generates. Again we conclude that public efforts should be directed towards increasing the absorptive capacity of Spanish companies. In our view, this should be the cornerstone of a public policy to promote innovation.

Finally, the tests that explore the relationship between R&D subsidies and absorptive capacity indicate that there is no relationship between these two variables, whether companies cooperate or not. Among the companies that cooperate, this lack of relationship between the two explored variables is a clear indication that the granting of state aid for R&D does not take into account the absorptive capacity of firms, a key variable that strongly influences the costs and benefits of R&D cooperation (Edler, 2008), and therefore the productivity of companies (Belderbos et al, 2004b).

6 Conclusions

Czarnitzki et al. (2007) have emphasized that 'over the last decades, direct subsidies for collaborative research have become a favored incentive scheme in European countries'. However, the economic literature has paid little attention to this form of public resource allocation (Schwartz et al., 2012). In this study we addressed this issue with an econometric methodology that has never been used in these kinds of studies before. Our aim was to see whether the achievement of R&D subsidies and the simultaneous establishment of R&D cooperation agreements have complementary effects on business productivity, i.e. whether receiving public subsidies as a result of establishing R&D cooperation agreements has a higher impact on productivity than the sum of the individual impacts of R&D cooperation and R&D subsidies. It notes that if there is complementarity, the policy of subsidized R&D cooperation agreements seems appropriate because the pursued objectives are achieved. If there is no relationship between the variables analyzed (R&D cooperation and R&D subsidies), then the policy of promoting and supporting R&D cooperation agreements with public aid becomes redundant, as the alternative to grant direct aid to the R&D (without the condition of establishing R&D cooperation agreements) enables organizations to achieve the same objectives. Finally, if the relationship between the variables is substitutive, the policy of subsidized R&D cooperation agreements does not seem advisable, because, on average, companies will see their corresponding productivity diminished.

Moreover, it should be emphasized that the data of our empirical analysis is from the Spanish manufacturing sector. The Spanish economy is characterized by a medium level of development when compared other countries of the EU. In our view, Spain is an ideal setting to test, using a single contrast, the effectiveness of European policy to promote R&D cooperation agreements through subsidies.

The results of empirical analysis indicate that the relationship between R&D cooperation and R&D subsidies in companies with low absorptive capacity is substitutive; and there is no relationship between the two variables in high absorptive capacity companies. In short, we can say that there is no complementarity between R&D cooperation and R&D subsidies. Therefore, the implementation of a policy of subsidized R&D cooperation agreements identical for all countries of the EU does not seem advisable. In the more advanced EU countries, whose companies have a high average absorptive capacity, the policy may be appropriate; but it does not seem advisable in countries whose companies have a low average level of absorptive capacity. In these cases, it seems more appropriate to encourage companies to make direct investments in R&D, because this kind of investment not only improves technological capabilities, but also helps to increase their absorptive capacity (Cohen and Levinthal, 1990), a variable that is key to maximize the benefits from R&D cooperation agreements. Only if companies in all the EU countries have reached a good average level of absorptive capacity, does the consistent implementation of a policy of subsidized R&D cooperation agreements make sense. The results indicate that it is not advisable to apply the same recipe to different national realities in terms of R&D.

Therefore, it appears that many Spanish manufacturers get trapped in subsidized R&D cooperation: chasing the public aid, they end up accepting cooperation agreements that diminish their productivity basis. In the end, both companies and society lose out.

We have also tested the relationship between absorptive capacity and R&D cooperation. It was expected that R&D cooperation and absorptive capacity were complementary variables. However, in this study both variables are substitutive. This is a further indication that the average absorptive capacity of Spanish manufacturing firms is low, so the costs of coordinating

R&D are higher than the benefits of R&D cooperation. In general, almost all the models that analyze the influence of spillovers on R&D cooperation agreements do not consider these costs (Czarnitzki et al., 2007). However, our study does take them into account, at least indirectly, to the extent that both revenue and cost impact on productivity.

Finally, we have also found no relationship between the variables R&D subsidies and absorptive capacity, nor between companies which cooperate and those which do not. This is a clear indication that absorptive capacity is not taken into account when promoting subsidized R&D cooperation agreements. However, the theoretical foundations of R&D cooperation agreements indicate that this variable must play a central role in these kinds of agreements.

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