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Isabel Busom, Andrea Fernández-Ribas

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Departament d'Economia Aplicada
Edifici B
Campus de Bellaterra
08193 Bellaterra

Telèfon: (93) 581 1680
Fax:(93) 581 2292
E-mail: d.econ.aplicada@uab.es
http://www.ecap.uab.es

Firm Strategies in R&D: Cooperation and Participation in R&D Programs*

Isabel Busom and Andrea Fernández-Ribas
Departament d' Economia Aplicada
Universitat Autònoma de Barcelona

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Abstract

This paper presents empirical evidence on firms' decisions to cooperate in R&D and the extent to which government sponsored R&D programs increase cooperation. Using a sample of firms from the Spanish innovation survey we jointly estimate the determinants of firm participation in R&D programs and of choice of cooperation partners. We find that (i) firms participating in national and European programs have different profiles, suggesting program complementarity; (ii) private-private and public-private cooperation are associated on average with firms with different characteristics, and (iii) national R&D programs seem to have a positive effect on all types of cooperation, but especially on public-private partnerships.

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KEYWORDS: R&D, vertical cooperation, public-private partnerships, innovation policy.

Authors addresses

Isabel Busom
Departament d' Economia Aplicada
Universitat Autònoma de Barcelona
08193 Bellaterra, Spain
Tel: 93 581 1680
Fax: 93 581 22 92
e-mail: Isabel.Busom@uab.es

Andrea Fernández-Ribas
Departament d' Economia Aplicada
Universitat Autònoma de Barcelona
08193 Bellaterra, Spain
Tel: 93 581 1680
Fax: 93 581 22 92
e-mail: Andrea.Fernandez@uab.es

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1. Introduction.

Cooperative agreements to perform R&D activities have been increasing over the last twenty years in OECD countries. Several indicators are revealing: the share of patent co-applications in triad patent families has almost doubled since 1980, and the number of strategic technology alliances has almost tripled on average (OECD 2002). Hagedoorn, Link and Vonortas (2000) also document this trend. The Community Innovation Survey, conducted in EU member countries, provides additional evidence of the importance of R&D partnerships and its variation across firms, industries and countries. According to CIS3,[1] on average 17% of manufacturing firms with innovative activities indicate they had cooperation agreements in 1998-2000; the share is significantly higher for large firms (61%). Partnerships with suppliers or customers are as frequent as partnerships with universities. Cross-country differences are significant. In Finland 22% of SMEs in the manufacturing industries declared being involved in cooperative agreements in 2000, while in Spain or Italy barely 3 % of SMEs did.[2]

At the same time, public support programs to promote R&D cooperation have been implemented since the eighties in the US, Japan and the EU. The European Union's successive European Framework Programs are a significant example. Participation rates into these programs vary widely across EU member countries. In per capita terms, Denmark, Finland and Sweden had the highest participation rates in Framework Program 5, while Spain and Italy were among the lowest.[3]

[1] See European Communities (2004).
[2] See European Commission (2003a).
[3] See European Commission (2003b).

These observations raise a number of issues, such as the measurement of private and social benefits of R&D cooperation, identification of obstacles to cooperation in different countries or industries, determinants of the choice of partners, and evaluation of effects of R&D policies supporting cooperation.

In this paper we investigate empirical patterns of cooperation and the relationship between cooperation and participation in public R&D programs at the firm level in a middle-income country. We address three issues. We first compare the determinants of firms' participation in national and European level R&D programs. To the best of or knowledge the extent of ex post complementarity between programs has not been previously studied. We then study the association between some firm characteristics and choice of cooperation partners. In line with previous work, we test whether some firm characteristics, such as the size of the firm or the range of its market, affect the choice of partners. This may reveal some possible causes of cross-country differences in R&D cooperation rates. Finally, we test whether participation in R&D programs has any effect on firms' choice of partners, taking into account that participation is endogenously determined.

We use both parametric and non-parametric methods and a large sample of Catalan manufacturing firms to study these issues. We find that (i) firms participating in national and European programs have different profiles, suggesting that both types of programs are complementary; (ii) private-private and public-private cooperation are associated with firms with different characteristics, as found in studies for other countries, and (iii) national R&D programs seem to have a positive effect on all types of cooperation, but especially on public-private partnerships.

The paper is structured as follows. In the remainder of this section we provide a brief review of closely related work. We present our data in section 2. In section 3 we describe some hypotheses about firm characteristics and their relationship with participation and cooperation choices. In section 4 we discuss the empirical framework and results, and conclude in section 5.

Theoretical and empirical research has approached R&D cooperation from a variety of perspectives, and the stock of literature is quite extensive. We focus here on a selection of work dealing specifically with the determinants of partner choice and with the role of public R&D programs on those choices. Of particular interest are those studies that use firm level data obtained through the Community Innovation Survey conducted in EU countries.[4]

Belderbos et al. (2003) are the first to use panel data and estimation methods that allow them to test for complementarities between types of partnerships, and to address the simultaneity issue that typically arises between cooperation and R&D effort.[5] The types of partnership considered are horizontal, vertical and private-public cooperation. Two waves of the Dutch CIS survey (1994-1996) and (1996-1998) provide a rich set of variables, including measures of incoming and outgoing spillovers, firm characteristics

[4] We choose to do so because although some questions in the surveys differ, core questions are common in all countries, as well as survey methodology. This makes results more comparable.

and firms' perceptions of main obstacles for R&D activities. The authors find that two factors increase the probability of cooperating with any type of partner: firm size and firms' perceptions on the importance of universities and public research and innovation centers as sources of knowledge. An indicator of the speed of technological change seems to be what distinctively leads firms to cooperate with research centers, while being part of a group and lack of organizational capability affect positively vertical partnerships. The effect of having R&D subsidies is not conclusive, as results vary with the empirical strategy used to control for subsidy endogeneity. Using lagged subsidies, they find a positive effect on the likelihood of vertical and public/private cooperation, but not of horizontal cooperation. However, when restricting the sample to include only firms that are new to cooperation, R&D subsidies are not found to have any effect on vertical or public cooperation, and have a negative effect on horizontal cooperation. As suggested by the authors, the possible endogeneity of R&D subsidies needs further investigation.

Some other studies have looked into the relationship between partner choice and program participation, although not addressing endogeneity issues. Miotti and Sachwald (2003) use data from the French CIS for the 1994-96 period to estimate a sequential model of the determinants of cooperation and the choice of partners. They find differences in the role of some explanatory variables across cooperation types, and in particular that R&D subsidies encourage public/private and horizontal cooperation, but not vertical cooperation. In all cases firm size increases the likelihood of any type of cooperation. Similarly, Mohnen and Hoareau (2003) study the determinants of

[5] Other authors have previously investigated whether different types of partnerships have different determinants, usually with cross-section data. See Kaiser (2002), Fritsch and Lukas (2001), Cassiman and

collaboration between firms and national universities or government labs using a sample of firms from the CIS2 survey, 1994-1996.[6] In that case the most influential factor on the probability that a firm will set up this type of collaboration is receiving R&D subsidies, followed by having applied for patents.

Finally, Bayona, García and Huerta (2003) study the determinants of horizontal and vertical cooperation in Spain. Their results confirm that the drivers of each type of cooperation are not the same. Relatively small firms are found to be more likely to engage in vertical cooperation, while firm size does not affect horizontal cooperation.[7] Participation in international R&D programs increases horizontal cooperation, while it does not affect vertical cooperation.

The common result from these studies is that firm characteristics affect the choice of partners, suggesting that different types of cooperation tend to benefit different types of firms. However, the effects of particular characteristics and, most important from a policy perspective, participation in public R&D programs do not seem to be robust across samples. Table 1 highlights some of the differences and similarities found in those studies. Possible explanations for these differences are the treatment of endogeneity of R&D subsidies, as well as not accounting for possible program heterogeneity. These are the issues we set out to investigate.

[Insert Table 1 about here]

Veugelers (2002), Tether (2002).

[6]The sample includes firms from several European countries: France (about 45% of the sample), Germany (10%), Ireland (4%) and Spain (42%).

[7] They use the Spanish Innovation Survey for 1994-1996. In this and a companion work, Bayona et al (2001) find that the probability of engaging in any type of cooperation increases with firm size and own R&D experience.

2. Data.

The source of our data is the Spanish Innovation Survey (Encuesta sobre Innovación Tecnológica) conducted by the Spanish Statistical Institute (INE) in 1999[8]. We use a sub-sample of 737 Catalan manufacturing firms[9] that report positive expenditures in R&D in 1998.

About 40% of these firms had some type of cooperation in R&D over the period 1996-98,[10] and almost one third (32.4%) declared participation in some publicly supported R&D program. There were three types of programs firms could participate in: European, national and regional level. Most of the firms (74%) participated in only of the programs, mainly at national level.

Table 2 shows the distribution of firms by cooperation and participation status.[11] Cooperation rates are much higher for participants in either type of program than for non-participants. This suggests that public agencies tend to fund R&D projects that involve cooperation. The strong association between participating in EU programs and cooperating is not surprising since cooperation among firms or institutions of several

[8] The questionnaire includes questions on the number of employees (in 1996 and in 1998), sales and export volume in both years, ownership (domestic or foreign subsidiary), R&D expenditures by category (wages, equipment), R&D personnel and innovation expenditures in 1998, and participation in public R&D programs, cooperation in innovation (in R&D), and patent applications within the period 1996-1998.

[9] Catalonia is one of the seventeen Autonomous Communities of Spain. It represents 15% of the Spanish population, about 19% of Spain's GDP, 22% of the Spanish Gross Domestic Expenditure on R&D, and 28% of business innovation expenditures in manufacturing industries.

[10] In the survey the corresponding question specifies that cooperating to innovate means that the firm is actively involved in joint R&D and/or innovation projects with other organizations. Subcontracting is not be considered to be cooperation.

member states is required for obtaining EU R&D funds. The association is not as strong in the case of national programs, since not all lines of funding require cooperation, but the data suggest that national agencies may have a preference for funding R&D partnerships.

[Insert Table 2 about here]

Following previous studies, we will distinguish between three types of partners: customers and/or suppliers (vertical cooperation), Universities or public labs (public-private cooperation) and other firms (horizontal cooperation).[12] About 19% of firms that do R&D collaborate with Universities, 17% cooperate with customers or with suppliers, and about 10% with other firms (non-competitors). Table 3 shows the frequency of cooperation by type of partner and participation status in our sample.[13] Among participants in national programs, the share of collaborations with public labs and Universities is sensibly higher than for non-participants. The pattern is different for participants in EU programs, where collaboration with other firms, customers or suppliers seems to be more prevalent.

Other characteristics of our sample are the following. In terms of firm size distribution, about one third are large firms (200 or more employees), 38% are medium-sized firms (50 to 199 employees), and 30% are small firms (less than 50 employees). About one

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[11]A small number of firms (41) participate in regional level programs, and almost all of them also participate in national level programs. Because of the small number of participants, we will ignore regional programs.

[12] Our initial plan was to include cooperation with competitors as a specific category, but there were too few observations. Firms are asked whether they cooperated with other firms, aside from competitors, customers or suppliers, and as we do have more observations for this case, we use this category.

[13] These categories are not mutually exclusive, and some firms have several types of partners at the same time. In particular, 49 firms cooperate at the same time with customers and suppliers and with universities.

third applied for patents between 1996 and 1998, and only 17% applied for international patents. Foreign owned firms engage in cooperation more frequently than domestic firms (56% versus 38%, respectively).[14] Most large firms declare to allocate resources to R&D on a regular basis, while small firms report occasional R&D activities more frequently.[15]

3. Hypotheses and variables.

3.1. Cooperation.

Several hypotheses have been proposed in the literature to explain the incentives that firms have to cooperate with other firms or with public research institutions.[16] First, to produce an innovation firms might need complementary intangible assets, basically information, tacit knowledge and know-how, which cannot be easily contracted. In that case, monitoring and related problems can be better solved through a partnership. Second, cooperation allows partners to share risks and costs of innovating under growing technological complexity, as well as to exploit economies of scale and scope. Third, when out-coming R&D spillovers are a serious concern, R&D partnerships provide a mechanism to internalize them. Finally R&D cooperation may allow partners to increase market power in the product market. The choice of different types of partnerships will be related to the importance of each of these factors for different firms and to the nature of their R&D projects.

[14] Twenty seven percent of firms in our sample are foreign owned, where foreign owned means having more than a 50% share in ownership.

[15] A discussion of sample representativity and extensive description can be found in Fernández-Ribas (2003).

[16] For a recent survey, see Caloghirou, Ioannides and Vonortas (2003).

One important trait of R&D and innovation projects is the extent of novelty pursued. The OECD's Oslo Manual guidelines, followed by standard innovation surveys, considers a range of innovation degrees. Maximum innovation occurs when it is new to the world, and minimum innovation occurs when a firm implements a new or improved product or process that is already implemented in other firms and industries. Knowing the goal of a project is vey important for understanding partnerships. Unfortunately our data do not provide this type of information, nor on indicators related to motivation for cooperation, such as measures of spillovers, costs or risks associated with R&D projects. We will assume that, on average, R&D partnerships with universities and public research centers tend to involve higher degrees of novelty and risk than private-private partnerships, and discuss how observed firm characteristics are expected to affect costs and benefits of each type of cooperation alliance, and therefore firms' R&D partner choice.

Most previous empirical evidence shows that firm size is a key variable for predicting whether a firm will engage in R&D. However, once a firm does R&D, it is not clear why and how size should be relevant regarding cooperation. On one hand, given a potential R&D project, smaller firms may be more likely to cooperate in order to share associated fixed costs. However, large firms may also find cooperation beneficial when potential R&D projects are very costly. Without information about the nature and scope of R&D projects, it is not possible to make a conclusive prediction on the effects of firm size. If we assume that vertical cooperation involves mostly development and technology transfer projects, while private-public cooperation tends to include a riskier research component, then we would expect SMEs to be more likely to participate in vertical agreements, and large firms more likely to participate in private-public partnerships. We use the number of employees as a measure of firm size, and expect it to have different effects on each type of partnership.[17]

A firm's knowledge capital is an intangible asset that can be expected to be valuable in any kind of R&D cooperation. However, to the extent that some partnerships are established precisely to facilitate technology transfer and product development, partners may be quite different in this respect. We do not have information about partner characteristics for each cooperative agreement, but it is reasonable to expect vertical cooperation agreements to involve some partners with low levels of knowledge capital. In public-private partnerships, in contrast, we would expect firms to have a high level of knowledge capital, as they need to have absorptive capacity to benefit from university research. We define five indicators of the firm's knowledge capital related to experience, knowledge assets and human capital. *Stable RD* is a binary variable taking the value of 1 if the firm allocates at least one time-person to R&D over some years. *PatSp*, binary and equal to 1 if the firm has applied for patents only at the Spanish Patent Office, and *PatInt*, binary and equal to 1 if the firm has applied both in Spain and in some international patent office. The variable *Researchers*, the ratio of R&D researchers to non-R&D employees, approximates human capital intensity. We finally use the (log) average *wage of R&D* employees as an indicator of researcher quality.

Foreign owners have a majority stake in about one fourth of the firms in our sample. We expect subsidiaries to be more likely to engage in vertical partnerships either with the

[17] Table A1 in the Appendix contains the precise definition of each variable.

mother company or with local suppliers or customers. We expect subsidiaries to be less likely, on average, to engage in private-public partnerships, because their links with the mother company allow them to access international technology markets more easily than domestic firms. We define the variable *Foreign*, binary and equal to 1 if foreign share in ownership was at least 50% in 1998.

The relationship between innovating and exporting has been established in the international trade literature, and empirical evidence supports the existence of a causal link from innovation to export performance. Feedback effects from exporting to innovation behavior have been less explored. We think that there are two possible reasons for feedback effects. First, exporters, being exposed to international competition, face higher pressure to innovate through all kinds of R&D strategies than non-exporters. Second, by exporting, firms gain access to a richer network of customers, suppliers or competitors than non-exporters, making international cooperation more likely. We expect exporters to be more likely to cooperate with any partner, and include the share of exports over total sales in our set of explanatory variables.

Cooperation patterns may vary by industry and type of partner. CIS aggregate data show that 25%, chemicals and electrical and optical equipment industries innovated through cooperation in 1997, while in the wood, paper or textile industries the rate was well below 10%. Cooperation with universities and public labs is probably more beneficial in industries where basic and applied research is an increasingly important source of innovations, i.e., the chemical and pharmaceutical industry. To test for industry effects in the choice of partners we define five industry level binary variables: chemical/pharmaceutical industry (*IndCHF*), high-tech industries (*IndHT*), medium-high tech (*IndMHT*), medium-low tech (*IndMLT*) and low tech (*IndLT*).[18]

Finally, participating and receiving public support for R&D activities may increase the likelihood that a firm will set up an R&D partnership. Partnerships involve costs and risks that can deter cooperation. These may be higher when partners have different objectives and incentives, as is the case of firms and universities, where in addition the nature of the project may be relatively open and exploratory.[19] Public funding reduces the cost for firms to experiment with this type of alliance, so we expect it to have a positive effect. In private-private partnerships we expect partnership costs to be smaller on average, with well defined, precise R&D projects. In that case public funding may not have any effect.

3.2. Participation.

The distinctive trait of EU R&D programs is that they explicitly intend to encourage inter-European cooperation, and application rules state that proposed partnerships must involve firms and/or institutions from several member countries. National programs in Spain offer different lines of funding, only a subset requiring cooperation, mostly among firms and public research organizations. We will distinguish, therefore, between EU and national level programs, as they have somewhat different goals, target different types of firms and involve different levels of application costs.

[18] Table A2 shows a detailed industry composition.

What kind of firms benefit from European funding and are able to set up an international partnership? Some evidence has been provided by Hernán, Marín and Siotis (2003), who analyze what determines firm participation in RJVs funded by either the Eureka Program or the EU Framework Program. Using a large database of firms from almost twenty European countries, they find that, among individual firm characteristics, firm size and previous participation experience increase the likelihood of participating. Industry-level characteristics are also significant, especially R&D intensity. One possible explanation for the significance of firm size is that EU programs favor large partnerships, which may be more costly to manage. Our hypothesis is that, in addition to firm size and industry type, firms that have a high level of human capital and compete in international markets will be more likely to participate in international R&D alliances.

National level R&D and innovation programs have several goals, such as increasing both business R&D expenditure and the number researchers employed by firms, promoting cooperative research between firms and universities, public research centers or technological centers, and increasing participation in international programs.[20] Several lines of funding are established accordingly. Firms can decide whether to apply for funding for an individual R&D project or for a joint R&D project with other partners. Application costs are not likely to be a significant barrier in this case. Since all firms in our sample conduct R&D, we assume that most are informed about the existence of these programs and are eligible for public funding.

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[19] See Hall, Link and Scott (2003) for a study on the type of projects involved in public-private partnerships.

Obtention of funding, and hence participation status, will be mostly determined by agencies' preferences and budget. Program information delivered by national public agencies and application forms suggest that in deciding whether to fund an R&D and innovation proposal, agencies weigh its technical and commercial feasibility as well as the benefits generated for other firms and consumers. Firm size, expertise and R&D experience are likely to be associated with technical and commercial feasibility, and hence with participation. However, to the extent that a variety of market failures may affect SMEs in particular, and public agencies wish to offset them, then the relationship between firm size and probability of participation could be negative. Which effect dominates is an empirical question. We also expect national agencies to have a preference for domestic relative to foreign owned firms.[21]

Unobserved variables related both to firm and project characteristics, such as novelty and basicness, are likely to affect both agency's decisions and cooperation partnerships.

4. Empirical models and results.

4.1. Empirical framework.

Whether a firm will set up R&D and innovation agreements with certain partners, and its participation status in publicly supported R&D programs, can be modeled as a recursive system of equations where we allow participation status to affect the choice of cooperation partners, but not vice versa. Participation in EU programs, however, means

[20] See MINER (1998).

[21] We do not have data on rejected applicants, but just on whether a firm obtains or not public funding. Consequently we cannot really test for the agencies' selection criteria, but just test the net effect of firm characteristics on its participation status.

necessarily that firms must cooperate, so participating in those programs and cooperating are not different choices. National-level programs allow firms to apply for different types of R&D subsidies depending on whether or not firms set up a partnership with universities or other public research organizations. Consequently, we first estimate and compare the determinants of participation status in both types of programs, and then estimate the effect that participation in national level programs has on each type of cooperation settlement.[22]

To explain the likelihood of participating in European and national level programs, we estimate the model,

$$P^*_E = Z_E\, b_E + v_E \quad [1]$$

$$P^*_N = Z_N\, b_N + v_N \quad [2]$$

where P^*_E and P^*_N are the unobserved propensity to be a participant in a European and a national level program, respectively. A binary participation status indicator is observed in each case. Z_E and Z_N are vectors of exogenous variables. Firms may participate in both programs at once, but we will not consider interactions between both indicators of participation other than the possibly non-zero correlation between error terms.

To explain a firm's choice of cooperation partners we specify a univariate probit model for each of the three cooperation types, where we include participation status among explanatory variables,

$$Y^*_j = X\, b_{x\,j} + P_N\, d_j + w_j \quad [3]$$

[22] Alternatively, we could include, in each cooperation equation, participation status in each type of program as explanatory variables. But this increases the number of instruments needed to control for endogeneity, and this is not feasible with our data set. In addition, the number of firms participating in EU programs only is too small.

where Y^*_j is the net benefit of establishing one of the three types of collaboration discussed above, X is a vector of individual firm characteristics, P_j is the participation binary indicator, and w_j is a normally distributed random error with zero mean and unit variance. We observe the indicator variable $Y_{Nj} = \mathbf{1}(X\, b_{xj} + P_N\, d_j + w_j > 0)$. Vectors X and Z_N can share some variables, but identification may require exclusion restrictions.

The effect of participating, d_j, on the benefits of cooperation will be overstated if omitted variables contained in w are correlated with P, the participation status. Both firm behavior and public agency selection rules may account for such correlation. Endogeneity tests must be conducted, and, provided that identification conditions are satisfied, structural parameters in [3] can be consistently estimated through instrumental variables. If identification conditions do not hold, a non-parametric estimator of the effects of program participation can still be obtained under certain conditions. This will be discussed below.

4.2. Participation in domestic R&D programs vs. participation in EU and international programs.

We start by estimating two univariate probit models for participation status into national and EU/international programs, as well as a bivariate probit model to test for differences in their determinants. Table 4 reports the results.[23]

[Insert Table 4 about here]

[23] On Table 4 we report marginal effects of univariate models. Results do not change significantly when we use an alternative definition for some explanatory variables. We estimate the bivariate probit model to just to test the equality of coefficients across equations and obtain an estimate of the correlation between error terms. The estimated correlation is significant, negative and close to –1.

We find that what the two types of participation have in common is a negative association with foreign ownership. Otherwise the profile of participants in each program is quite different. When testing for equality of coefficients for each variable in both equations, we clearly reject equality for firm size, having applied for international patents and belonging to low tech industries.

The single most important factor affecting participation in national R&D programs is the firm's research intensity: a one-percent increase in the ratio of R&D personnel to the total number of employees increases the probability of participation by 65%. Having experience in applying for international patents, and belonging to the chemical and pharmaceutical industries also increases the likelihood to participate. Overall, results suggest that the firm's knowledge capital is one of the most important determinants of participation in national programs.[24]

In contrast, the key characteristic of participants in European programs is the extent to which the firm sells in foreign markets, as measured by export intensity. A possible interpretation for this result is that exporting firms develop links with potential international R&D partners, making partnerships easier even if the firm does not have an important own stock of researchers. Industry type, research intensity or patenting experience do not seem to have any significant effect.[25]

[24] These results are similar to those obtained in Blanes and Busom (2003).

[25] Our qualitative results for firm size differ from Hernán, Marín and Siotis (2003). This may be at least partially attributed to differences in sample composition, definition of the dependent variable, which in their case includes two different types of programs (Eureka and Famework Program), as well as differences in the vector of explanatory variables.

These results, together with the significant, high and negative estimate of the correlation between the error terms in both equations can be interpreted as evidence that both types of programs are complementary, as in fact intended by national and European policymakers.

4.3. Participation in national R&D programs and Cooperation: endogeneity tests and reduced form estimates.

To study whether participation in R&D programs affects cooperation and partner choices we consider only national programs and eliminate from the sample those firms that participate in EU programs. We estimate a set of univariate probit models for cooperation as a whole and then separately for each of the three types of cooperation for which we have sufficient observations, including as explanatory variables only those we assume to be exogenous. We then include participation status as an explanatory variable treating it as exogenous. To test for endogeneity, we obtain an estimate of the correlation between participating and each of the cooperation types from a series of bivariate probit models. We finally estimate a set of cooperation models where participation status and participation residuals are included as explanatory variables, as a further test of endogeneity.[26]

Table 5 shows the results of estimating the univariate probit models for cooperation and for each type of cooperation. Columns (1), (3), (5) and (7) show that the net effect of firm characteristics on cooperation varies with the type of cooperation. These can be interpreted as reduced form effects. We find that vertical cooperation is more likely among foreign owned, non-exporting firms, and firms that have intangible assets in the form of international patent applications, as well as high human capital. Firms in the chemical and pharmaceutical industry are less likely to cooperate with suppliers or customers. We interpret these results as suggesting that technology transfer is likely to be an important motivation of this type of cooperation.

We find that, in contrast, cooperation with public research institutions is mostly driven by research intensity: the share of researchers over non-R&D employees increases the likelihood of cooperating by 67%. We interpret this as evidence that having absorptive capacity is of utmost importance for establishing this sort of partnerships, whereas it seems to be much less important for other types. The effect of firm size is positive and significant, but small. Firms in the chemical and pharmaceutical industry are more likely to collaborate with public research institutions. Finally, other types of cooperation are more likely to be chosen by firms with high human capital, do R&D occasionally, and have applied for patents only in Spain.[27]

[Insert Table 5 about here]

When we include participation status in the probit models, and treat it as an additional exogenous variable, we find that all types of cooperation are positively affected. Columns (2), (4), (6) and (8) in Table 5 report the marginal effects. Being a participant becomes one of the most important variables to affect the likelihood of cooperation with public research organizations (it would increase the probability of cooperating by 25%),

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[26] See Wooldridge (2002).

[27] We have estimated a slightly different specification for each equation, using size, size squared, researchers and researchers squared, as explanatory variables. Results are similar. We also estimate a series of bivariate probit models for every pair of cooperation types, and find that correlation estimates are always positive and significant. Equality of coefficients across equations is rejected in all cases.

as well as with firms that are not customers, suppliers or competitors. The impact on vertical cooperation is smaller. Results for other variables remain practically unchanged except for vertical cooperation.

However, the results from the univariate estimations above will be inconsistent if the correlation between the error terms of cooperation and participation is non-zero. To test this we estimate a series of bivariate probit models for participation in national programs and each type of cooperation, where only exogenous explanatory variables are included[28]. We find that the estimated correlation of error terms in both equations is positive and significant in all cases, suggesting that there are indeed common unobserved factors. These estimated correlations, always significant, are 0.30 for vertical cooperation, 0.50 for public-private cooperation, and 0.29 for cooperation with other firms, as reported on Table 6.

An additional test for endogeneity is obtained by estimating each cooperation equation including as explanatory variables both participation status and the residuals obtained in the estimation of participation status. Under the null hypothesis of exogeneity, the coefficients for the residuals should be zero. Our estimates are very imprecise, and turn out to be significant for only one of the equations. The problem we face here is that for identification we need at least one variable that is correlated with participation but not with cooperation. Among the variables made available to us we do not have a good candidate fulfilling this condition, so we cannot use this test in practice, nor obtain

[28] We do not report coefficient estimates to keep the paper short, but they are available on request. We do report error correlation estimates in Table 6 below.

estimates of the structural model for cooperation equations. We next use an alternative method to obtain an estimate of the effect of participation on cooperation.

4.4. The effects of participation on cooperation: a non-parametric approach.

Following the methodological debate in evaluation research, mostly in the field of labor market and social policies, a number of estimators of the effects of program participation on the treated have been proposed in order to deal with the selection bias that typically arises when using non-experimental data.[29] One of these is a matching estimator based on the propensity score. In the spirit of controlled experiments, the idea is to compare the treated with an appropriate control group, using field data and controlling for non-random assignment to treatment. Its advantage in our case is that it does not involve estimating a structural model for cooperation nor relies on identification conditions. This method reduces that part of selection bias caused by correlation between observed characteristics of an individual and its treatment (participation) status. Matching estimators, however, do not deal with a second source of potential selection bias, caused by correlation between cooperation status and unobserved characteristics of cooperating firms.[30]

The first step of the matching method consists in finding in the sample an appropriate control group of non-participants. This amounts to estimating the probability of participating (the *propensity score*), and then choosing, among non-participants, only those that have the same estimated probability of participating as the sample of

[29] See Heckman, Ichimura, Smith and Todd (1998).

[30] As discussed in the previous section, the estimated correlation of unobservables in participation and cooperation status is significant in our case, so we can expect some selection bias to remain. We cannot, however, estimate its magnitude with available data.

participants. We use the specification shown on column (2) of Table 4.[31] Table 7 shows, for five intervals of the estimated probability of participating in national R&D programs, the number of treated (participants) and of available comparable controls. For participants in each block we are able to find comparable non-participants. Thirty-seven observations are discarded for lack of match.[32] Table 8 shows the mean of firm characteristics for treated and for controls. The means of two variables are significantly different: research intensity and having applied for international patents. Inspection of the distribution of research intensity reveals that there are a higher proportion of firms with very low research intensity among non-participants, but otherwise the distributions are quite similar. As for applications for international patents, 31% of non-participants have applied, relative to 50% of participants. We will take this into account below.

The second step consists in calculating the difference in mean cooperation rates for participants and non-participants. This provides an estimate of the average treatment effect on the treated. Table 9 shows the results for each type of partnership, using two matching methods, Kernel and Stratification and three sets of treated and corresponding control groups. The first set uses all 180 treated firms and 444 controls. But as shown on Table 8, treated and controls differ significantly in one of the variables, international patents. Therefore, we estimate treatment effects for the sub-sample of treated and controls that have applied for national and international patents, and then for the sub-sample that have not. We find that the effect of participating is always positive and

[31]This specification provides a slightly better match of treated and controls than specification in col. (1).
[32] The region of common support is in the range (0.087, 0.909), so observations outside this range are discarded.

significant, especially for cooperating with public institutions.[33] Participation seems to increase the likelihood that firms will cooperate with universities or public labs by about 28%, and the magnitude of this effect is similar whether firms have applied for patents or not. However, the effect of participation on the probability of cooperating with customers/suppliers, or with other firms, is higher if firms have applied for patents than if they have not. In both cases the effect of participating on private-private partnerships is smaller than the effect on public-private partnerships. From a policy perspective, this means that subsidizing firms that do not have certain type of intangible assets (international patent applications) will not lead on average to a significant increase in private-private partnerships.

We should keep in mind though, as discussed above, that unobserved characteristics such as the degree of basic/applied science content of an R&D project, would make a firm more likely to cooperate anyway, and that public agencies chose to fund precisely these projects. In that case our ATT estimator would be overestimating the true effect of participating.

5. Conclusions.

In this paper we have analyzed some determinants of firms' decisions to cooperate in R&D and to participate in government sponsored R&D programs. We distinguish between two types of R&D programs, European and national, and three types of R&D collaboration: vertical, public-private partnerships, and with other firms. We extend

[33] These estimates are close to those shown on Table 5 for Vertical and Public Cooperation. They differ in the case of Cooperation with Other firms.

previous work by comparing firm participation in both R&D programs, and assessing the effect of participation in national programs on each type of R&D partnership. We use a sample of innovative Catalan firms from the Spanish innovation survey, and obtain our estimates through parametric and non-parametric methods. Our main findings are summarized as follows.

First, we find that European level and national programs are rather complementary in selecting firms. Participation in national programs is mostly related to the firm's research intensity and previous experience in patenting at both national and international levels. Participation in European level programs is not significantly related to own R&D capacity, but to the export orientation of the firm. Since these are firms that cooperate with other European firms or institutions, these results suggest that Spanish firms join partnerships mostly for technological learning purposes, where other European partners have knowledge assets. Participants in any of the programs tend to be domestic firms, and firm size is positively related to participation, but the magnitude of that effect is rather small, given that these firms do R&D.

Second, we find that the choice of cooperation partners is associated with different firm characteristics, confirming previous results. In our case, vertical cooperation is more likely among firms that sell mostly in the domestic market, are foreign subsidiaries and have applied for international patents. We interpret these results as suggesting that vertical cooperation is used as a mechanism for technology transfer. Cooperation with universities or public labs is substantially more likely when firms have own research capacity and apply for international patents, belong to the chemical and pharmaceutical industry. Firm size affects public-private partnerships, but not vertical cooperation. Finally, cooperation with other firms (not customers, suppliers or competitors) is somewhat related to own research capacity and having applied for international patents, and involves some firms that do R&D occasionally. In summary, our results are in line with similar studies for public-private cooperation, but not for vertical cooperation.

Third, we find that participation in national programs increases the probability that a firm will cooperate with a university or a public research organization by 28%, a substantial effect. Cooperation with other firms, customers or suppliers is also increased as a result of participation if firms have knowledge assets, mostly international patents, but to a smaller extent.

Before we draw policy implications from these results we should make three observations. First, our estimates are based on cross sectional data, limiting our ability to tackle potential endogeneity of remaining explanatory variables. Second, an important proportion of variation in participation and cooperation remains unexplained. Third, matching methods provide unbiased estimates when unobservables affecting cooperation and participation are not correlated. Our evidence suggests that this assumption is unlikely to hold in our case, but with the available data we cannot estimate the magnitude of the bias. Good instruments for participation are needed in order to estimate its effects. Further research can be productive if the design of CIS-type surveys takes into account these data needs.

With these caveats in mind, our results suggest that participation of Catalan firms in European level R&D programs may increase if more firms compete in international markets. Public-private partnerships seem to be determined essentially by the same factors that affect firms in more advanced EU countries. One of the most important is the number of researchers in firms, suggesting that the effectiveness of public funding will be enhanced if complemented with policies that increase the stock of highly qualified human capital at the firm level.

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Table 1 . Firm characteristics and Cooperation.
Summary of Previous Findings

Variable	Study	Horizontal Cooperation	Vertical Cooperation	Public-Private Cooperation
R&D Intensity/Permanent RD	Belderbos et Mohnen et al Bayona et al Miotti et al	Not signif - Not signif Not signif	Positive - Not signif Not signif	Positive Not signif - Positive
Firm size	Belderbos et al Mohnen et al Bayona et al Miotti et al	Positive - Not sig Positive	Positive - Negative Positive	Positive Positive - Positive
R&D Subsidy	Belderbos et al Mohnen et al Bayona et al Miotti et al	Not sig / Neg - Positive Positive	Pos / Not sig - Not sig Not sig	Pos / Not sig Positive - Positive
Foreign ownership	Belderbos et al	Negative	Not sig	Not sig
Patents applied for	Mohnen et al Bayona et al	-	- Negative	Positive -

Table 2. Cooperation and participation in different publicly funded R&D programs.

	National Programs			EU/Intl. Programs		
Cooperate	No	Yes	Total	No	Yes	Total
No	348	71	419	413	6	419
	83.05	16.95	100.00	98.57	1.43	100.00
	66.03	33.81	56.85	**60.47**	11.11	56.85
Yes	179	139	318	270	48	318
	56.29	43.71	100.00	84.91	15.09	100.00
	33.97	**66.19**	43.15	39.53	**88.89**	43.15
Total	527	210	737	683	54	737
	71.51	28.49	100.00	92.67	7.33	100.00
	100.00	100.00	100.00	100.00	100.00	100.00

Table 3. R&D Cooperation by type of Partner and Program Participation.

		National R&D Programs				EU/Int. Programs			
Type of Cooperation		Non-participants		Participants		Non-participants		Participants	
	Total	N	N/198	N	N/110	N	N/260	N	N/48
Vertical: Customers Suppliers	 87 96	91	46%	47	42%	113	43%	25	52%
Public Inst. Labs Universities	 78 138	94	47%	75	68%	154	59%	15	31%
Other firms	73	42	21%	25	23%	49	19%	18	37%
Total	308	198		110		260		48	

Note: Public utilities and a small number of firms with missing information have been eliminated from the sample.

Table 4. Participation in public R&D programs
Single Equation Probit Estimates
Marginal Effects on the Probability of Participating

	National Programs		EU/International Programs	
	(1)	(2)	(3)	(4)
Size (in logs)	**0.05***** (2.80)	-	**0.03***** (3.15)	
Size (level)	-	**0.0002***** (2.41)	-	0.4E-4 (1.51)
Size squared	-	**-0.5E-7*** (1.85)	-	-0.9E-9 (0.29)
Stable RD	0.06 (1.25)	0.06 (1.5)	0.02 (0.92)	0.03 (1.44)
RD wage	0.01 (0.40)	0.02 (0.59)	-0.003 (-0.14)	0.006 (0.30)
Researchers	**0.65***** (2.72)	**1.16***** (2.64)	0.15 (1.34)	0.188 (0.79)
Researchers squared	-	**-0.93*** (-1.74)	**-**	-0.203 (0.52)
PatSp	-0.02 (-0.46)	-0.02 (0.46)	**-0.05**** (-2.09)	**-0.05*** **(**-1.92)
PatInt	**0.17***** (4.06)	**0.17***** (4.19)	0.01 (0.57)	0.11 (0.56)
Foreign	**-0.14***** (-3.39)	**-0.12***** (-2.99)	**-0.06***** (-3.04)	**-0.05**** (-2.47)
Export	0.06 (0.97)	0.07 (1.13)	**0.08***** (2.74)	**0.088***** (2.74)
IndLT	0.09 (1.52)	0.08 (1.45)	-0.04 (-1.56)	-0.04 (1.36)
IndCHF	**0.13**** (2.08)	0.09 (1.61)	-0.02 (-0.85)	-0.03 (-0.94)
IndMHT	0.03 (0.48)	0.02 (0.28)	0.01 (0.32)	0.004 (0.14)
IndHT	0.10 (1.26)	0.05 (0.72)	0.004 (0.12)	-0.006 (0.019)
Log L	-374.72	-374.36	-173.55	-175.05
Pseudo-R2	0.07	0.07	0.11	0.10
N	716	716	716	716
Y=1	180	180	55	55
% correctly predicted	64%		63%	

Notes: z statistics in parentheses. *** denotes significance at the 1 % level; ** a 5 % level.

Table 5. Cooperation

Estimated Marginal Effects on the Probability of observing the dependent variable = 1

	Cooperate All types (1)	Cooperate All types (2)	Vertical Cooperat. (3)	Vertical Cooperat (4)	Public Cooperat. (5)	Public Cooperat. (6)	Other Cooperat. (7)	Other Cooperat. (8)
Size	**0.07***** (3.55)	**0.06***** (2.82)	0.02 (1.57)	0.02 (1.13)	**0.05***** (3.44)	**0.04***** (2.66)	**0.008***** (2.36)	**0.006*** (1.84)
Stable RD	-0.08 (-1.44)	-0.10* (-1.82)	0.01 (0.24)	0.001 (0.02)	0.03 (0.57)	0.007 (0.16)	**-0.02**** (-1.98)	**-0.03**** (-2.12)
RD Wage	0.05 (1.25)	0.05 (1.15)	0.02 (0.74)	0.02 (0.67)	0.02 (0.61)	0.02 (0.47)	0.004 (0.55)	0.003 (0.48)
Researchers	**0.84***** (2.67)	**0.64**** (1.96)	**0.34*** (1.87)	0.25 (1.38)	**0.67***** (3.01)	**0.50***** (2.21)	**0.09**** (2.29)	**0.07*** (1.82)
PatSp	0.01 (0.14)	0.03 (0.47)	0.02 (0.53)	0.03 (0.72)	-0.06 (-1.25)	-0.03 (-0.74)	**0.03*** (1.77)	**0.03*** (1.83)
PatInt	**0.13***** (2.45)	0.07 (1.31)	**0.10***** (2.65)	**0.07**** (1.91)	**0.16***** (3.90)	**0.10***** (2.58)	-0.002 (-0.30)	-0.007 (-0.76)
Foreign	**0.11***** (2.27)	**0.17***** (3.35)	**0.12***** (3.00)	**0.14***** (3.61)	-0.04 (-0.99)	0.004 (0.11)	-0.01 (-1.45)	-0.007 (-0.87)
Export	0.03 (0.45)	0.008 (0.10)	**-0.14***** (-2.48)	**-0.15***** (-2.71)	0.03 (0.49)	0.01 (0.19)	0.002 (0.14)	0.0002 (0.02)
Participation Nat	-	**0.29***** (6.35)	-	**0.13***** (3.67)	-	**0.25***** (6.78)	**-**	**0.26***** (2.83)
IndLT	-0.01 (-0.20)	-0.03 (-0.52)	-0.01 (-0.29)	-0.02 (-0.48)	0.001 (0.03)	-0.02 (-0.41)	0.95*** (3.08)	0.95*** (3.04)
IndCHF	0.07 (1.00)	0.04 (0.54)	**-0.11***** (-2.63)	**-0.12***** (-3.00)	**0.12***** (2.11)	**0.09*** (1.60)	**0.96***** (3.20)	**0.97***** (3.13)
IndMHT	0.03 (0.48)	0.02 (0.33)	0.07 (1.43)	0.06 (1.34)	-0.006 (-0.12)	-0.02 (-0.30)	0.96*** (3.01)	0.96*** (2.97)
IndHT	0.01 (0.15)	-0.01 (-0.18)	-0.03 (-0.68)	-0.04 (-0.82)	-0.05 (-0.73)	-0.07 (1.19)	0.99 (2.98)	0.99*** (2.93)
Log L	-414.74	-394.25	-272.25	-265.56	-297.07	-273.91	-158.75	-154.78
Pseudo-R2	0.06	0.11	0.10	0.12	0.09	0.16	0.09	0.11
N	661	661	661	661	661	661	661	661
Y=1	39 %	39 %	17 %	17 %	20 %	20 %	10%	10%
% correct predict	68 %	68 %	66 %	68 %	63 %	72 %	60 %	61%

Table 6. Testing for endogeneity of Participation

Equation	Estimated rho in a bivariate probit model with all exogenous variables[1] (s.e. in parentheses) [Chi-2 test in brackets]	Estimated coefficient of residuals[2] (s.e. in parentheses)
Cooperation (All types)	0.43*** (0.06) [41.11]	0.87 (2.55)
Vertical Cooperation	0.30*** (0.08) [13.96]	5.49* (3.13)
Public Cooperation	0.50*** (0.06) [46.9]	-1.59 (3.10)
Other	0.29*** (0.10) [0.08]	4.47 (4.72)

[1] Obtained from a bivariate probit estimation of participation and cooperation using all exogenous independent variables.
[2] Obtained regressing cooperation status on participation, the residuals from the estimation of the participation equation and all exogenous variables. Under the null hypothesis of exogeneity, the coefficient of the residuals should not be significant. Identification problems are a matter of concern, however.

Table 7. Number of blocks of Treated and Controls for Participation in National Programs

Block	Inferior of Prob(participating)	Number of Controls Non-participants	Number of Treated Participants	Total
1	0.09	171	31	202
2	0.2	214	95	309
3	0.4	54	38	92
4	0.6	4	14	18
5	0.8	1	2	3
Total		444	180	624

Note: The optimal number of blocks is 5. The balancing property of the propensity score is satisfied: the mean propensity score is not different for treated and controls in each block.

Table 8. Means of Characteristics of Treated and Controls

Variables	Means after matching		Mean Difference
	Treated 179 obs.	Controls 444 obs.	Ho: mean(treated) - mean(control) = 0
Size (level)	249.21 (430.50)	202.77 (354.26)	-46.44 (33.43)
Size sq.	246,399 (1,157,422)	166,334.20 (1,018,253)	-80065 (93850)
Stable RD	0.90 (0.30)	0.82 (0.39)	-0.08* (0.03)
RD wage	10.28 (0.44)	10.25 (0.51)	-0.03 (0.04)
Researchers	0.05 (0.10)	0.03 (0.06)	-0.02*** (0.006)
Researchers sq.	0.01 (0.08)	0.01 (0.05)	-0.007 (0.005)
PatSp	0.18 (0.39)	0.14 (0.34)	-0.05 (0.03)
PatInt	0.50 (0.50)	0.31 (0.46)	-0.18*** (0.04)
Foreign	0.22 (0.41)	0.26 (0.44)	0.04
Export	0.31 (0.27)	0.27 (0.27)	-0.04*
IndLT	0.27 (0.45)	0.29 (0.46)	0.02
IndCHF	0.31 (0.46)	0.27 (0.45)	0.04
IndMHT	0.22 (0.41)	0.22 (0.42)	0.005
IndHT	0.11 (0.32)	0.09 (0.29)	-0.01

Standard deviations in parentheses.

Table 9. Estimates of the effect of Participation on Cooperation
Average Treatment Effect

Sample	Type of matching	Vertical Cooperation	Public Cooperation	Other Cooperation
180 treated, 444 controls	Kernel	0.13 (0.03)[(a)]	0.28 (0.04)	0.14 (0.03)
	Stratification	0.14 (0.03)	0.27 (0.04)	0.15 (0.03)
89 treated, 133 controls[(b)]	Kernel	0.17 (0.06)	0.28 (0.06)	0.17 (0.05)
	Stratification	0.18 (0.05)	0.26 (0.07)	0.17 (0.05)
91 treated, 307 controls[(c)]	Kernel	0.08 (0.04)	0.26 (0.06)	0.12 (0.04)
	Stratification	0.09 (0.05)	0.29 (0.05)	0.11 (0.04)

Notes:
a) Standard errors obtained by bootstraping with 100 replications, are in parentheses.
b) Sub-sample of treated and controls that have applied for interntational patents.
c) Sub-sample of treated and controls that have not applied for international patents.

Appendix.

Table A1. Definition of Variables

Variable	Name in tables	Computed as
Vertical Cooperation	Vertical Cooper.	Binary; =1 if customers or suppliers are partners in firm's R&D or innovation projects
Public Cooperation	Public Cooper.	Binary; =1 if public research organizations are partners in firm's R&D or innovation projects
Other Cooperation	Other Cooper.	Binary; =1 if other organizations are partners in firm's R&D or innovation projects
Firm size	Size	Log employees in 1996
Stable R&D	Stable RD	Binary; =1 if firm does R&D regularly
Average wage of R&D employees	Wage	Log (R&D salaries 1998/number of R&D employees 1998)
Human capital	Researchers	Researchers in 1998/non RD employees, 1998
Patents Spain	PatSp	Binary; =1 if applied for patents only in the Spanish Patent Office during 1996-98
International Patents	PatInt	Binary; = 1 if applied for patents in Spain and international Patent Office during 1996-98
Foreign ownership	Foreign	Binary; =1 if multinational subsidiary in 1998
Export intensity	Export	Exports in 1996/Sales in 1996
Industry dummies	IndLT IndCHF IndMLT IndMHT IndHT	= 1 if Low tech = 1 if Chemical or pharmaceutical = 1 if Medium-low tech = 1 if Medium-high tech = 1 if High tech

Table A2. Classification of Manufacturing Industries

	ISIC codes
IndLT. Low-technology industries	
Food products and beverages and tobacco	15+16
Textiles, textile products, leather and footwear	17+18+19
Wood, pulp, paper, paper products, printing and publishing	20+21+22
Furniture and other manufacturing	36
IndCHF. Chemicals and pharmaceuticals	24
IndMLT. Medium-low-technology industries	
Coke, refined petroleum products and nuclear fuel	23
Rubber and plastic products	25
Other non-metallic mineral products	26
Basic metals	27
Fabricated metal products, except machinery and equipment	28
IndMHT. Medium-high-technology industries	
Machinery and equipment	29
Electrical machinery and apparatus	31
Motor vehicles, trailers and semi-trailers	34
Railroad equipment and transport equipment	35
IndHT. High-technology industries	
Office, accounting and computing machinery	30
Radio, television and communications equipment	32
Medical, precision and optical instruments	33

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